QUALITY ISSUES FOR SYSTEM OPERATORS WITH SPECIAL REFERENCE TO EUROPEAN REGULATORS

1. INTRODUCTION

This note summarizes recent information[1] on quality issues for system operators, focusing on requirements which have already been issued or announced by some of the European Regulators. An important source of information is the report from the CEER/WGQES (Council of European Energy Regulators / Working Group on Quality of Electricity Supply), which was issued in April 2001 and presented, among others, at the last CIRED conference [1].

For the CEER/WGQES, the quality of electricity supply has three main dimensions :
• *commercial quality :* concerning the quality of relationships between a supplier and a user,
• *continuity of supply :* characterized by the number and duration of interruptions,
• *voltage quality :* main parameters being frequency, magnitude, waveform and symmetry.

One could argue that there is some confusion between the electricity supplier (concerned with the first aspect only) and the system operator (concerned with the three aspects). Also, speaking about the quality at the interface between the network and the users may seem more correct than speaking about the quality of electricity supply, because quality issues may be of importance for producers as well as for consumers. However, in the rest of this report, the wording used by the CEER/WGQES will be mostly used, leaving a thorough discussion on vocabulary issues aside here.

Many countries have implemented standards for the first two aspects but not widely for the third one.

The concepts of guaranteed standards of performance (which relate to individual service delivery and carry a penalty payment) and overall standards (which govern overall target performance for a service item, frequently including quality incentives) are widely used.

For the CEER/WGQES, quality of supply regulation should focus on those dimensions of service quality which are:
• important to consumers,
• controllable by companies, and
• measurable by regulators.

Modern quality regulation strategies tend to focus on outputs (effects on customers) rather than input or expenditure. Performance can be measured at the local or national level; regulated companies normally perform measurements, while the regulatory body sets measurement rules and checks measurement procedures.

2. COMMERCIAL QUALITY REGULATION

Consumer information is a central aspect of commercial quality.

Two types of standards:

• *Guaranteed Standard*s. The definition of guaranteed standards includes the following attributes:
1) Service covered (e.g. estimating charges).
2) Required performance level – usually with a response time (e.g. 5 working days).
3) Penalty payment to be paid to a customer who fails to receive this level of service (e.g. 20 euros).

[1] Mainly information received at the last CIRED conference (Amsterdam, 19-21 June 2001).

• *Overall Standard*s, defined as follows:
1) Service covered (e.g. connecting new customers' premises to electricity distribution system).
2) Minimum performance level (e.g. 90% of cases should be connected within 20 working days, over a one year period).

In the case of reacting to failure of a supplier's fuse, the most demanding standard is in the Netherlands (2 hours) and the least demanding standard is in Portugal (4 hours).

There are different approaches to the payment of penalties. For Italy, Spain and some standards in the UK, the payment is automatic. For other standards in UK and for all the commercial guaranteed standards in Portugal, customers must claim for the compensation payment if a standard is not met. In the Netherlands, penalty payments are not yet defined.

3. CONTINUITY OF SUPPLY REGULATION

3.1 Benchmarking of actual continuity levels

The main features of continuity of supply are as follows :
• The type of interruption: planned or unplanned.
• The duration of each interruption: short or long. The European technical standard EN 50160 defines interruptions that last more than 3 minutes as "long interruptions", and others as "short interruptions".
• The voltage levels of faults and other causes of interruptions: low/medium/high voltage.
• The type of continuity indicators: number or duration of outages. For the CEER/WGQES, the cumulative yearly duration of interruptions per customer, referred to as Customer Minutes Lost (CML) or System Average Interruption Duration Index (SAIDI), indicates how long in a year energy is not supplied (average per customer)[2]. The number of outages per customer in a year, termed customer interruptions (CI) or SAIFI, System Average Interruption Frequency Index, indicates how many times in a year energy is not supplied.

Remark. For the CEER/WGQES, very short interruptions, due to automatic reclosure systems that operate in less than a few seconds may be referred to as "transient interruptions". Short and transient interruptions can produce equipment damage. Voltage dips or sags can also cause damage but these are not referred to as interruptions, rather as voltage quality.
This is in contradiction with the UNIPEDE recommendation [13], for which interruptions lasting less than 3 min are considered as a "voltage quality" (not "voltage continuity") problem, in the category of "voltage dips and short interruptions".
This question should be addressed by WG CIGRE/CIRED 36.07.

[2] For transmission systems it is more customary to use the Average Interruption Time (AIT) concept, which is the ratio between the total Energy Not Supplied (ENS) and the average power demand. The AIT may be considered as a good approximation of the contribution from the transmission system to the overall CML or SAIDI.

Table 1 : Main continuity of supply factors in distribution networks

COUNTRY	PLANNED VS UNPLANNED INTERRUPTIONS	LONG VS SHORT INTERRUPTIONS	VOLTAGE LEVELS	NUMBER VS DURATION INDICATORS
BELGIUM	Recording: only unplanned	Recording: only long (>1')	Recording: only above 1 kV	Currently available: both
ITALY	Recording: both; regulation: only unplanned	Recording: both; Regulation: only long	Recording: all voltage levels; regulation: only for MV/LV users; (in future also for HV users)	Currently available: both; regulation: only duration (CML); number likely in future.
NETHERLANDS	Recording: only unplanned	Recording: only long	Recording: all voltage levels	Currently available: only duration (CML)
NORWAY	Recording and regulation: both	Recording and regulation: only long	Recording and regulation: only above 1 kV	Currently available: only duration (CML)
PORTUGAL	Recording and regulation: both	Recording: only long (>1'); regulation: only long (>3')	Recording: only above 1 kV; regulation: for all users (HV/MV/LV)	Currently available: only duration (>1') (TIEPI); regulation: TIEPI and from 2002 also CML and CI
SPAIN	Recording: both; regulation: only unplanned	Recording and regulation: only long	Recording: only above 1 kV; regulation: for all users (HV/MV/LV)	Currently available: only duration (TIEPI); proposed regulation: both indicators (CML and CI)
UNITED KINGDOM	Recording and regulation:both	Recording and regulation: only long(>1'); short (>1") outages to be recorded in future	Recording: all voltage levels; regulation: for all users (HV/MV/LV)	Currently available: both number (CI) and duration (CML)

Notes:
CI: Customer interruption per year (equivalent to SAIFI, System Average Interruption Frequency Index).
CML: Customer minutes lost per year (equivalent to SAIDI, System Average Interruption Duration Index).
TIEPI: hours lost per year, weighted by the installed transformer capacity for MV users and – only for Spain – on the contracted power for MV users.

Benchmarking of actual continuity levels can be attempted if some assumptions are made before comparing data:

• The scope of benchmarking must be narrowed to long unplanned interruptions, generally defined as outages longer than 3'.
• In some countries available data are for interruptions at all voltage levels, while in other countries (Belgium, Norway, Spain and Portugal) only interruptions originating in networks above 1kV are monitored.
• Most important difference is between continuity indicators weighted by the number of customers (used in Belgium, the United Kingdom, Italy, Norway and the Netherlands) and continuity indicators weighted by the power affected (used in Spain and Portugal).

Table 2 : cumulative yearly duration of interruptions:
countries using customer-weighted indicators

COUNTRY	AVERAGE CUSTOMER MINUTES LOST PER YEAR			
	1996	1997	1998	1999
ITALY (1)	272	209	196	191
BELGIUM (2)	37	43	42	47
NETHERLANDS (2)	26	18	21	25
NORWAY (2)	170	205	130	180
UK	72	75	70	63
SWEDEN	-	79	66	152
FRANCE (3)	74	56	46	57

(1) Only Enel (93% of LV users); data for 1999 subject to verification.
(2) Only interruptions above 1kV
(3) Storms excluded in 1999 (455 min. lost storms included)

Table 3 : cumulative yearly duration of interruptions
countries using power-weighted indicators

COUNTRY	AVERAGE HOURS LOST PER YEAR			
	1996	1997	1998	1999
SPAIN (1)	2.66	2.79	2.11	2.61
PORTUGAL (2)	6.30	9.40	8.33	6.08

(1) Only interruptions above 1kV
(2) Only interruptions above 1 kV; planned outages included; data for 1996, 1997 and 1998 correspond to one region of Portugal (Lisbon and Tagus Valley); data for 1999 refer to the whole mainland of Portugal

Table 4 : yearly number of interruptions per LV customer:
countries using customer-weighted indicators

COUNTRY	AVERAGE CUSTOMER INTERRUPTIONS PER YEAR			
	1996	1997	1998	1999
ITALY (1)	4.8	4.6	4.1	3.8
NETHERLANDS	0.14	0.10	0.11	0.14
UK (2)	0.82	0.82	0.73	0.77
BELGIUM (2)	0.90	0.91	0.83	0.94
SWEDEN	-	4.3	0.7	1.2
FRANCE	1.60	1.31	1.22	1.26

(1) Only Enel (93% of LV users); data for 1999 subject to verification
(2) Includes outages longer than 1’

However, benchmarking should take account of the influence of external factors, for example the influence of load density [4, 6]. The charts below show a comparison of continuity performance[3] for the distribution networks of individual companies in a selection of OECD countries (Australia, Japan, Spain, United Kingdom, United States) as a function of load density (GWh per km²) and of circuit utilization (MWh per MV km). Whilst there is more data available (i.e. published) for the load density comparison, the circuit utilization comparison may be considered to provide a closer reflection of the effect of MV circuit lengths and hence topography of the networks. Both comparisons show however that there is a general consistency between reliability and load density.

[3] Customer minutes of interruption is sometimes referred to as the System Average Interruption Duration Index (SAIDI) in Anglophone countries. In Spain the parameter used is TIEPI (*Tiempo de interrupción equivalente de la potencia instalada).*

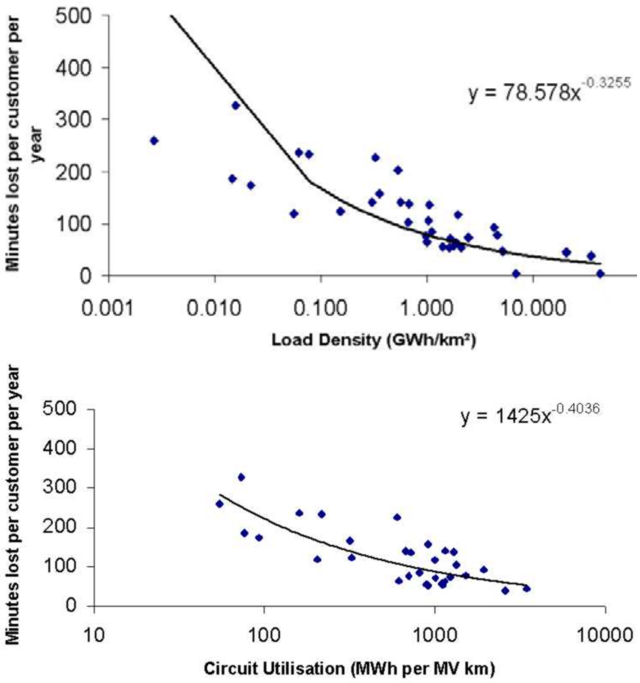

Fig. 1 : Customer minutes of interruption in OECD countries

3.2 Strategies to guarantee and promote continuity of supply

There are two main approaches:
• The "quality of supply" approach focuses on the individual level of continuity for each user. This approach requires that continuity be recorded at the customer level. It can be used more easily for high and medium voltage level customers rather than for those supplied at low voltage level.
• The "quality of system" approach focuses on overall continuity through the measurement of average performance.
Regulators generally combine the two approaches.

In making their decisions about continuity of supply regulation, regulators must address some common preliminary problems before setting standards:
• Measurement of interruptions*:* different kinds of continuity indicators can be adopted.
• Responsibility for interruptions: some interruptions do not result from the activities of the distributor.
• Severe weather and "acts of God".[4]
• Differences in geographical characteristics and network structure (concerning this last point, only the influence of load density has been assessed in a quantitative manner, see Fig.1).

[4] Several definitions exist for "acts of God" (force majeure). E.g. in Italy, for the verification of yearly improvement standards, the interruptions caused by following are not included:
• force majeure:
- acts of public authorities
- natural disasters
- severe weather conditions only if design requirements are exceeded
• external causes:
- damages by third parties
- interruptions caused by users
- loss of supply from national transmission grid
- loss of supply from other distributors.

3.3 Continuity of supply standards

There are four main areas covered by continuity of supply standards already enforced or envisaged in six countries:

- Individual customer standards.
- Average standards: this kind of continuity of supply standard is used to improve quality in a given area.
- Yearly rate of improvement standards.
- Worst-served customer standards. Another way to set continuity of supply standards is to define the maximum percentage of users subject to a maximum number of interruptions (or minutes lost) in one year.

Individual and worst-served customer standards often take the form of guaranteed standards, but they require individual measurement of interruptions which can be difficult and costly.

Table 5 : main types of standards for continuity of supply[5]

COUNTRY	INDIVIDUAL CUSTOMER STANDARDS	ZONAL AVERAGE STANDARDS	YEARLY RATE OF IMPROVEMENT STANDARDS	WORST-SERVED CUSTOMER STANDARDS
ITALY	Max. duration of interruption for HV and MV customers	Avg. customer minutes lost *	Minimum yearly improvement differentiated according to the starting level	Overall standard
NETHERLANDS	Max. duration of interruption for each customer	Avg. customer minutes lost	None	None
NORWAY	None	None	Company's revenue cap depends on difference between actual and expected interruption costs [2]	None
PORTUGAL	Max. number and max. duration of interruption for each customer**	Std. of duration (TIEPI, *from 2001;* SAIDI, *from 2002*), and std. of number (SAIFI) **	None	None
SPAIN	Max. number and max. duration of interruption for each customer**	Max. customer minutes lost and max. average number of interruption **	None	None
UNITED KINGDOM	Max. duration of interruption for each customer	None	Minimum yearly improvement differentiated according to the starting level and past performance improvement	Overall standard

Notes:
* Standards differentiated according to geographical classification.
** Standards differentiated according to voltage level and geographical classification.

Table 6 : effects of continuity of supply regulation

COUNTRY	PENALTY PAYMENTS TO COSTUMERS	LINK BETWEEN TARIFF AND CONTINUITY	COMPARATIVE PUBLISHING
ITALY	yes	yes	Regulator
NETHERLANDS	yes		Companies
NORWAY		yes	Regulator
PORTUGAL	yes		Regulator
SPAIN	yes		Companies, Ministry in future
UNITED KINGDOM	yes	yes	Regulator

[5] See Annex 1 : Continuity of supply standards.

4. VOLTAGE QUALITY REGULATION

Actual data on voltage quality for benchmarking purposes is either unavailable or limited in scope.

Standards for voltage quality can be issued by standardization bodies through a consensus process or by regulators after a consultation process.

The following definition of voltage quality was adopted by the CEER/WGQES from European Standard 50160: “The characteristics of the supply voltage concerning: frequency, magnitude, waveform and symmetry of the phases”.

Although EN 50160 gives (indicative) values for many of the phenomena, it is only applicable at voltage levels up to 35 kV. For higher levels no standards exist ; in the Netherlands, Italy and Portugal some criteria from EN 50160 are extended to voltage levels of 50 kV and higher.

Table 7 : voltage quality: comparison of present regulation[6]

	ITALY	**NETHERLANDS**	**NORWAY**	**PORTUGAL**	**SPAIN**	**UNITED KINGDOM**
Is voltage quality part of the regulation?	yes	yes	yes	yes	yes	yes
Is voltage quality regulated on system level?	yes	yes	no	yes	no	yes
Is voltage quality regulated on individual level?	yes	yes	no	yes	yes	yes
Is there a penalty when the standards are not met?	no	no	no	no	no	yes
Does the voltage quality regulation apply uniformly in your country?	yes	yes	yes	yes	yes	yes
Is voltage quality (also) regulated per region or zone?	no	no	no	no	no	yes
Is the European standard EN 50160 imposed by regulation?	no	yes	yes	yes	yes	no
If yes, please indicate the voltage levels:		All levels	22 kV	≤ 45 kV	≤ 36 kV	
Is voltage quality also regulated for voltage levels > 35 kV?	yes	yes	no	yes	yes	yes

At the system level the voltage quality may be regulated by introducing a “Q-factor” in price-cap regulation. At the local level voltage quality may be better regulated by other means, for example through connection agreements.

[6] See Annex 2 : Voltage quality standards.

5. CONCLUSIONS

The following types of standards are widely applied in most countries reviewed :

- Guaranteed standards – which set targets to be achieved for service delivery in the case of individual customers – are a common tool ; for instance in the UK the Guaranteed standard for maximum duration of interruption is 18 hours for all users, while in the Netherlands, the regulator proposes to set a 4 hour standard. In Italy different levels will be set at different voltage levels. Guaranteed standards are always linked to penalty payments, which can be either automatic or subject to customers' claim.
- Overall standards – which set standards to be achieved on a company-wide level – are considered by the CEER/WGQES a useful tool in promoting quality improvement (or aiming at reaching the socio-economic optimal quality).

A link between quality (particularly continuity of supply) and tariff is likely to be introduced in three countries in the near future. Italy introduced such a link in 2000, Norway will do it in 2001 and the UK is likely to do so in 2002. Although the detailed regulatory mechanisms differ, they share the principle that a part of the companies' revenue will be at risk depending on performance against quality standards. In the UK this will be limited to 2%; in Italy the exposure could be greater than this and in Norway no limit is envisaged.

On commercial quality standards, benchmarking shows that for some standards there is a significant difference in performance targets. For example, in areas like responding to queries on charges and payments, and executing simple works, ratios of 4:1 exist in the response times for the countries examined. On the other hand, some other response times, for example responding to failure of a supplier fuse or scheduling appointments, have much lower performance ratios, typically 1.5-2:1.

On technical quality standards, there is a wide variability of definition and reporting standards. But crude comparisons of performance levels can be made particularly with regard to amount of customer minutes lost and number of customer interruptions. A wide spread of performance is evident between countries. Some of the factors which influence this are population density, geography, network configuration, and the use of overhead lines or underground cables.

The CEER/WGQES considers that the following factors will be important in improving future benchmarking studies :

- Increased transparency of reporting.
- Increased exchange of information between regulators.
- The adoption of at least one continuity of supply indicator for customer minutes lost (cumulative duration per LV customer), and one indicator for the average yearly number of interruptions per LV customer.
- On voltage quality, better coordination between national regulatory bodies and international technical standards bodies to facilitate the development of appropriate international standards in future.
- Evaluate and compare factors which can affect benchmarking studies including identification of company responsibility, force majeure, severe weather effects and geographical impact.

The main aim in regulating both technical and commercial quality is to give utilities incentives to provide an optimal level of service. Optimal levels are obtained as the result of minimizing the cost of investment and operational costs related to quality improvement[7] and the costs suffered by customers as a result of quality degradation.

It is not easy to determine customers' valuations of quality directly. The most usual way is to evaluate the economic losses resulting from long interruptions.[8] It is however important to bear in mind that interruption costs are not equal to value of quality but are instead a proxy for it.[9]

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[7] See Annex 3 : Improving supply quality by improving system design and operation.

[8] See Annex 4 : Cost of supply interruptions.

[9] Each downgrading of power quality has a cost but it is generally not perceived (reduction in equipment life expectancy, additional losses…). For example, the flow of harmonic currents due to the presence of electronic converters in customers installations causes additional system losses of 1 TWh/year in Germany, i.e. the yearly production of 500 wind turbines of 1 MW [12].

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ANNEX 1

CONTINUITY OF SUPPLY STANDARDS

Table A1.1 : duration of interruption per customer per single outage

COUNTRY	STANDARD	USERS INVOLVED	TYPE OF STANDARD AND EFFECTS	EXCLUSIONS
UK	• Restoring within 18 hours • Minimum percentage: within 3 hours, 85-95% depending on company; within 18 hours, 99%	• All users • All users	• Guaranteed; Penalty payment automatic • Overall standard	• Companies can claim exclusions for Exceptional Circumstances (not defined).
ITALY	Maximum time to be defined	All users	Guaranteed; Penalty payment to be defined, automatic	Excluded Acts of God (strictly defined)
NETHERLANDS	Restoring within 4 hours	All users	Guaranteed; Penalty payment automatic; - residential: 35 € / interruption - industrial: 0.35 €/kWh, with max = 90 000 €	
PORTUGAL	Restoring: 80% within 4 hour	MV and LV users	Overall standard	Acts of God, planned interruptions

Table A1.2 : number of interruptions per customer per year

COUNTRY	STANDARD	USERS INVOLVED	TYPE OF STANDARD AND EFFECTS	EXCLUSIONS
UK	• Max N/year: to be defined • Percentage customers suffering more than N/year: to be defined	• All users • All users	• Guaranteed; penalty to be defined • Overall standard	To be defined
SPAIN	• Max N/year: 12 (urban); 15(semiurban); 18 (rural concentrated); 24 (rural sparse) • Max N/year: 8 (urban); 12 (semiurban); 16 (rural concentrated); 20 (rural sparse) • Max NIEPI (interruptions per installed kW): 4 (urban); 6 (semiurban); 10 (rural concentrated); 15 (rural sparse)	• LV users • MV users • LV and MV users	• Guaranteed; penalty related to number of interruptions in excess of the standard; • Idem • Overall standard	Only long (t>3min) Exclusions: acts of God and third party actions
PORTUGAL	• Max N/year: 12 (zones A); 26 (zones B); 46 (zones C) • Max N/year: 8 (zones A); 20 (zones B); 40 (zones C) • Max N/year: 8 • Max N/year: 3	• LV users • MV users • HV users • EHV users	Guaranteed; penalty related to number of interruptions in excess of the standard, by claim. In addition, some overall standards without penalty (SAIFI - MV & LV)	Only long (t>3min) Exclusions for exceptional circumstances (well defined)

Table A1.3 : cumulative yearly duration of interruption

COUNTRY	STANDARD	USERS INVOLVED	TYPE OF STANDARD AND EFFECTS	EXCLUSIONS
NETHERLANDS	Customer minutes lost: 20 minutes	All users	Overall standard, only indicative	
ITALY	Customer minutes lost: 30 minutes (urban), 45 minutes (semiurban), 60 minutes (rural)	MV and LV users	Overall standard, only indicative	Excluded acts of God and third party action
SPAIN	• Max. hours of interruption per customer per year: LV:6, MV:4 (urban); LV:10, MV: 8 (semiurban); LV:15, MV:12 (rural concentrated); LV:20, MV:16 (rural sparse)	• LV and MV users	• Guaranteed; penalty related to outage hours in excess of standard, by claim	Excluded acts of God and third party action
	• Average TIEPI (hours lost per kW installed): 2 (urban); 4 (semiurban); 8 (rural concentr.); 12 (rural sparse)	• LV and MV users	• Overall standard	
	• 80 percentile TIEPI (value that is not overcome by 80% of municipalities): 3 (urban); 6 (semiurban); 12 (rural concentrated); 18 (rural sparse)	• LV and MV users	• Overall worst-served standard	
PORTUGAL	• Max. hours of interruption per customer per year: LV:6, MV:4 (zones A); LV:10, MV:8 (zones B); LV:25, MV:20 (zones C)	• MV and LV users	• Guaranteed; penalty related to outage hours in excess of standard, by claim: - 15 € (BT, <21 kVA) - 25 € (BT, >21 kVA)	Only long (t>3min) Exclusions for exceptional circumstances (well defined)
	• Max. hours of interruption per HV customer per year: EHV: 1; HV: 4	• EHV and HV users	- 75 € (MT, HT)	
	• Average TIEPI (hours lost per kW installed): 3 (zones A); 6 (zones B); 24 (zones C)	• LV and MV users	• Overall standard (In addition, other overall standards without penalty: SAIDI - MV & LV)	

Table A1.4 : improvement standards

COUNTRY	STANDARD	USERS INVOLVED	TYPE OF STANDARD AND EFFECTS	EXCLUSIONS
ITALY	Min rate improv. in customer minutes lost: ranging 0 to 16% yearly according to starting level and territorial density	MV and LV users	Overall standard with economic effect (link to tariff)	Excluded acts of God and third party action
UK	Min rate improv. in customer minutes lost and customer interruptions: ranging 5 to 10% over 5 years	All users	Target figures for end of price control in 2005	None but subject to statistical analysis to exclude exceptional conditions
NORWAY	Company's revenue cap (R) depends on difference between actual and expected interruption costs (IC)	All users	Overall standard, $\Delta R = E(IC) - IC$ (1) (2)	Only long interruptions (t>3min) and incidents >1kV

(1) Aim = socio-economic optimum, i.e. min sum of company's costs and interruption costs;
filters are used to eliminate stochastic variations;
agreements for individual compensation remain possible with large customers (> 400 MWh/year)

(2) Average specific interruption costs in €/kWh ENS (Energy Not Supplied) :

Category	Notified interrupt.	Non-notified interrupt.
Residential & agricultural	0.38	0.50
Industrial & commercial	4.38	6.25

E(IC) = average level of quality today (not the optimal level)

ANNEX 2

VOLTAGE QUALITY STANDARDS

Table A2.1 : voltage quality standards

VOLTAGE QUALITY	ITALY	NETHERLANDS	NORWAY	PORTUGAL	SPAIN	UNITED KINGDOM
Frequency	EN 50160	EN 50160 with fc=±1% (99,5 % of the year)		EN 50160	EN 50160	fc=±1%fn
Magnitude	EN 50160	EN 50160 with minor adjustments	22 kV; other levels not regulated	≤45 kV EN 50160; > 45 kV: Uc=±5%Un	LV & MV: Uc=±7%Un > MV: n.a.	LV (230V): Uc=+10% / -6%Un > LV: Uc=±10%Un
Fluctuations of magnitude	EN 50160	EN 50160 with levels for 99,5% of the week		Uc=±5%		
Voltage dips		EN 50160		≤45 kV: EN 50160		
Temporary or transient overvoltages		EN 50160				
Unbalance	EN 50160	EN 50160 with levels for 99,5% of the week		≤45 kV: EN 50160; > 45 kV, indicative values: U- ≤2% (95% of the week, 10 min RMS)		
Harmonics	EN 50160 with levels for 99,5% of the week	EN 50160		≤45 kV: EN 50160; > 45 kV: indicative values		THD < 5% at 275 and 400 kV, no explicit levels for lower voltages
Interharmonics						
Mains signalling	EN 50160	EN 50160				
DC components						

Table A2.2 : Summary of technical standard EN 50160 (1999)
"Voltage characteristics of electricity supplied by public distribution systems"

TOPIC	LOW VOLTAGE	MEDIUM VOLTAGE
Frequency	49.5-50.5 Hz (99,5% of the year) or 47-52 Hz (all year)	49.5-50.5Hz (99,5% of the year) or 47-52 Hz (all year)
Magnitude	Un ±10% (95% of the week, 10 min RMS) Un +10/-15% (100% of the week, 10 min RMS)	Uc±10% (95% of the week, 10 min RMS)
Fluctuations of voltage magnitude	+5% up to +10% some times per day Flicker: Plt ≤1 (95% of the week)	+4% up to +6% some times per day Flicker: Plt ≤1 (95% of the week)
Voltage Unbalance	U- ≤2%(95% of the week, 10 min RMS); 3% in some areas	U- ≤2%(95% of the week, 10 min RMS); 3% in some areas
Harmonic voltage	U3 ≤5%, U5 ≤6%, U7 ≤5%, U11 ≤3.5%, U13 ≤3% and THD ≤8% (95% of the week, 10 min RMS)	U3 ≤5%, U5 ≤6%, U7 ≤5%, U11 ≤3.5%, U13 ≤3% and THD ≤8% (95% of the week, 10 min RMS)
Voltage dips	Indicative: up to a few tens to up to one thousand	indicative: up to a few tens to up to one thousand
Short interruptions	Indicative: up to a few tens to up to a few hundred	indicative: up to a few tens to up to a few hundred
Long interruptions	Indicative: (interrupt.>3 min) annual frequency 10 up to 50, depending on area	indicative: (interrupt.>3 min) annual frequency 10 up to 50, depending on area

ANNEX 3

IMPROVING SUPPLY QUALITY BY IMPROVING SYSTEM DESIGN AND OPERATION

Linking T&D tariffs to power quality (continuity of supply and voltage quality) makes sense only if the quality may be controlled by the system operators. This may be categorized as follows :

A Controlling disturbances near sensitive installations :
- a in the power system (concept of Custom Power),
- b in the customer's installation (concept of energy services).

B Controlling disturbances at the source :
- a disturbing installations : controlling emission levels,
- b incidents.

The last point (B-b) is the most difficult one. Limiting the number of incidents and limiting the impact of each of them means optimizing the power system an all its aspects (design, operation, asset management, maintenance, control of ancillaries, fault analysis, etc.). Linking those efforts with the resulting level of power quality is not obvious. This annex aims at giving a few comments about that.

Distribution systems

Within the UK, about 60% of supply interruptions are caused by faults on the MV network. There is therefore an emphasis on improving the MV network [7].

Currently the key network performance criteria which are likely to be used to govern the regulated income of the UK distribution companies are:
Security – Average number of interruptions > 3 minutes per year per 100 customers.[10]
Availability – Average number of minutes lost per customer per year due to interruptions > 3 minutes.[11]
Overall Standard (1a) – Percentage of customer supply interruptions restored within 3 hours.

The more substantial improvement in *Availability* is attributable to several main causes:
a) Faster fault identification and location
b) Faster switching
c) Alternative supplies

The targets set by OFGEM (the UK Regulator) for the 5 years 2000-5 require improvements in both Security and Availability.

The principal techniques for improving the performance of the MV network may be roughly classified as follows:

• Reduce the number of faults:
- refurbishment or the complete rebuilding of lines to higher standards
- higher levels of maintenance
- tree lopping
- surge protection
- training 3 rd parties to limit damage.

• Reduce the number of customers affected by a fault:
- additional protection devices
- additional isolation switches
- provision of extra circuits.

• Restore supply more quickly:

[10] The classical definition of the security of a power system is its ability to remain stable in case of dynamic disturbances. It is interesting to note the meaning of "security" for the authors of [7].
[11] It is more usual to call this "unavailability". It is interesting to note the meaning of "availability" for the authors of [7].

- faster fault location
- speeding up of response times
- alternative supply points
- use of faster or automated switching
- better preparation for coping with major storms
- use of mobile generators and live line working.

The asset management team usually deals with the task of selecting where improvements are required and determining whether, for example, circuits should be refurbished or further devices added to improve the customer performance.

Transmission systems

Norwegian statistics demonstrated the importance of the reliability of protection and control (P&C) equipment in HV systems [8]. As shown in Fig. A3.1, P&C equipment is subject to more faults than any of the primary components, even compared to overhead lines.

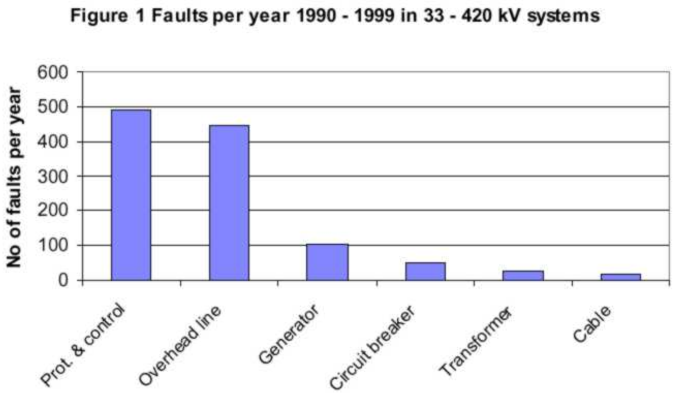

Fig. A3.1 : Faults per year 1990-1999 in 33-420 kV Norwegian systems

Furthermore, as shown in Fig. A3.2, P&C is the second largest contributor to ENS (energy not supplied), after overhead lines.

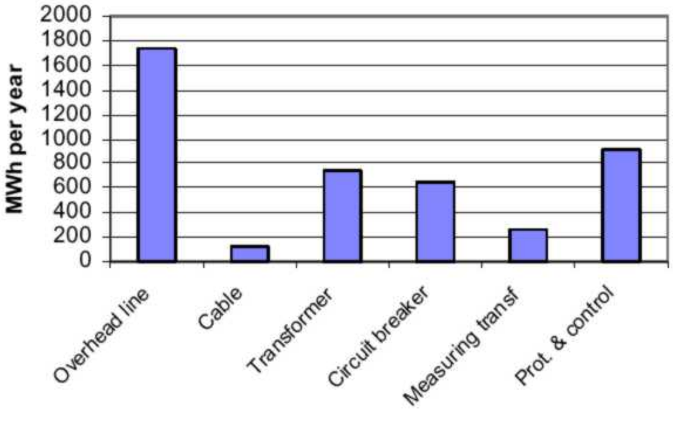

Fig. A3.2 : ENS per year 1995-1999 in 33-420 kV Norwegian systems

The reliability of P&C is of high importance for the quality of supply and for the amount of ENS. The reliability measures the ability of the protection to operate when it is supposed to and the ability of the protection not to perform unwanted operations. The first aspect is called dependability and the last aspect defines the security.[12]

Socio-economic optimum

Obviously, all efforts to improve the quality have a cost and should not go beyond the socio-economic optimum which can be illustrated by Fig. A3.3.

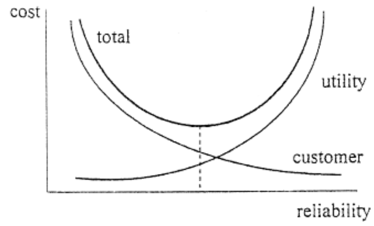

Fig. A3.3 : Total quality costs.

An example attempt to reach the optimum is given in Norway (see Table A1.4), where the revenue caps for Transmission and Distribution (T&D) are quality dependent [2]. The arrangement takes into account all incidents in networks with voltage levels above 1 kV that results in interruptions of duration above 3 minutes. Based on estimates of energy not supplies (ENS) and average specific interruption costs for each customer category, interruption costs (IC) are calculated for each company annually. The expected level of ENS is calculated for each company and hence the expected level of IC. At the end of the year the regulator calculates the difference between expected and actual IC. If the difference is positive, i.e. the quality of supply has been better than expected, the difference will be added to the company's revenue cap. The difference will be subtracted from the revenue caps if the quality has been worse than expected.

With this arrangement, a rise in quality of supply always gives higher revenue and tariffs, but a regulated company will not increase the quality if it costs more than the customers will gain from it. In theory, whatever the initial level of quality, all system operators will shift their quality towards the socio-economic optimum.

12 The classical definition of the security of a power system is its ability to remain stable in case of dynamic disturbances. It is interesting to note the meaning of "security of P&C" for the authors of [8].

ANNEX 4

COST OF SUPPLY INTERRUPTIONS

In Belgium, an estimation of some 3.1 € per kWh not supplied is frequently referred to. This is based on the ratio between gross national product (± 250 G€/year) and electricity consumption (± 80 TWh/year). Two remarks about that :

1. For a consumer, the financial cost of an interruption is sometimes hardly dependent on the duration – or of the energy not supplied (ENS). For example, in case of voltage dip, interruption duration and ENS are practically equal to zero, but the industrial process may be stopped for several hours.

2. International data may be found in the report presented by R. Billinton at the CIGRE Study Committee 38 at its Paris meeting in September 2000 [9] :
   - Australia : 4.0 €/kWh now, but it was decided to upgrade to 16 €/kWh from April 2002.
   - UK : 3.0 €/kWh, but it was estimated that the costs agreed by NGC to improve security were in line with 30 €/kWh.
   - Norway : 0.50 €/kWh for domestic consumers and 6.3 €/kWh for industrial consumers.
   - France : 0.75 €/kW and 9.0 €/kWh (from the 1st remark, it seems logical to consider the power in addition to the energy not supplied).

Comments on the influence of the interruption duration may also be found in two recent papers :

1. Fig. A4.1 gives an example of the costs variations with interruption duration, for various types of industrial consumers [10].

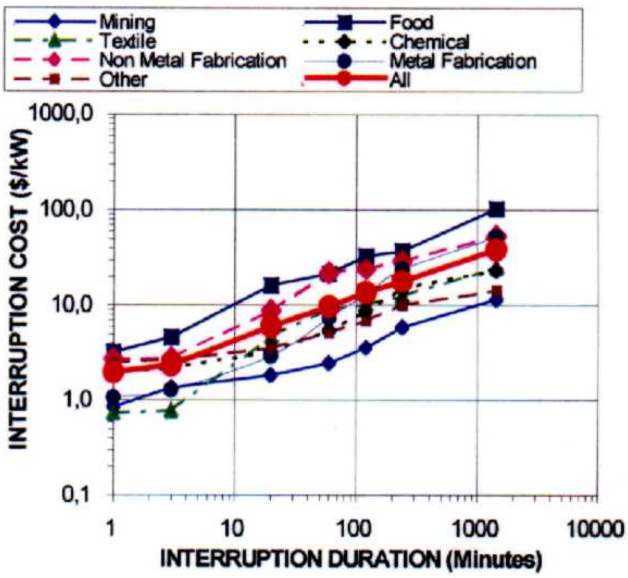

Fig. A4.1 : Industrial consumers damage function

2. EPRI [11] gives some general figures for three kinds of industries (see Tables A4.1 and A4.2) :
   - Digital Economy,
   - Continuous Process Manufacturing (CPM),
   - Fabrication & Essential Services (F&ES).

Table A4.1 : Average cost per outage by duration ($)

Duration	Average cost
1 s	1 477
3 min	2 107
1 h	7 795

Table A4.2 : Average cost per outage by annual kWh and duration ($)

Annual kWh	1 s	3 min	1 h
< 50 MWh	-	-	3 304
50 – 500 MWh	-	-	6 783
0.5 – 5.0 GWh	1 739	1 913	12 870
> 5 GWh	31 478	44 522	58 435

A comparison between Greeks and American sets of data for the duration dependence (assuming that the costs per kW are the same for a 3-min duration) is given in Fig. A4.2.

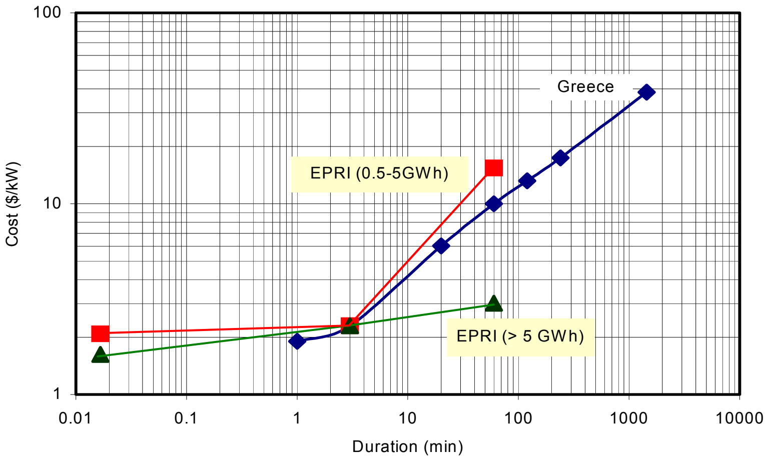

Fig. A4.2 : Outage costs in function of outage duration

The three sets of data seem to indicate a very slow cost increase in function of the duration in the range 1 s – 3 min (range of "short interruptions"). The increase seems to be stronger for long interruptions (but this is not true for the US heavy industry). In this range, however, the Greeks data correspond to cost = k · duration $^{0.45}$: the average cost of an interruption is thus not proportional to its duration but rather to the square root of it. This means that the cost per kWh not supplied is decreasing with the duration.