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Quality of Supply in Liberalized Electricity Markets

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Abstract **-** There are many attempts to standardize and regulate quality of supply in electricity markets. The paper is focused on two electricity markets: in Australia and Europe. The market in Australia was created in 1994 by the introduction of the Victorian electricity market. The European electricity market is under construction due to the Directive 96/92 and requires not only development of new quality regulations, but also the synchronization of various standards and approaches which have been historically developed in membership countries. Quality of supply issues become more important every year as in 2004 a group of ten countries are to join the European Union.

Index Terms **-** Quality of supply, standards, regulation, electricity markets.

I. INTRODUCTION

Open electricity markets have changed relations between electricity distributors and customers. This leads to more customer-oriented approach in electricity supply. Competitive markets are governed by Codes and Rules or Laws, which are legal documents to be obeyed by all market participants. The countries introducing electricity markets have usually established some institutions, such as regulatory bodies or electricity industry ombudsmen, in order to regulate quality of supply standards and facilitate the communication between energy distributors and customers.

In the state of Victoria, the quality of electricity supply is regulated by the Distribution Code. After the first experience, the Distribution Code has been changed in a long consultation process and a new issue seems to be one of the most comprehensive documents to regulate quality of supply in distribution networks. A complex approach to regulate power quality applied in the Distribution Code is accompanying by the energy and network services price control with the introduction of parameters allowing for tariff adjustment in accordance with the improvement of supply quality.

In Europe, the new directive on electricity will create a more international and liberal electricity market. This will influence national legislation in all EU-member countries. In these countries the question will be raised how customers can be protected against specific (eventually) negative aspects of the liberalization.

The implementation of the electricity market in the European Union has changed the legal environment for the electricity supply industry. Power supply companies, transmission and distribution network service providers become subjects to new regulations.

There are several initiatives in the European countries to analyze the new regulation and to set standards allowing for better quality of supply. Unipede/Eurelectric has undertaken two surveys dealing with the regulation of distribution tariffs and protection of energy consumers in liberalized electricity markets [1], [2]. The Council of European Energy Regulators has established the Working Group on Quality of Electricity Supply to analyze how quality of supply is regulated in the EU countries [3].

II. SUPPLY QUALITY IN ELECTRICITY MARKETS

A. Australian Electricity Market

The National Electricity Market in Australia was established in 1997. Currently, this market operates in three geographical areas. The largest segment embraces three states: New South Wales, Victoria and South Australia. Transmission systems of in this area are connected. The Queensland electrical system is not connected with the three-state market and acts as a separate component. Similarly, the Tasmanian electricity market operates as a separate island system [4].

The National Electricity Market in Australia is regulated by the Electricity Market Code under the National Electricity Code Administrator. Market competitiveness is verified by the Australian Competition and Consumer Committee. The state retail markets and distribution businesses operating in the state geographical areas act under the regulation set by the state regulatory bodies. In Victoria, the retail market and distribution tariffs are regulated by the Office of the Regulator-General.

The electricity market in Victoria was initially governed by several Codes. The hierarchy of the Codes was the following: System Code, the Wholesale Metering Code, the Distribution Code, the Supply and Sale Code, and the Retail Tariff Metering Code. That is, the extent that a Code is inconsistent with the provision of another Code below it in the above list, the first mentioned Code in the above hierarchy generally prevails. The introduction of the National Electricity Market shifted transmission system regulations to the National Electricity Code leaving distribution business' regulation to the state regulatory. The Distribution Code still plays the same role regulating distribution companies geographically located in a particular state.

The Distribution Code in Victoria is designed to regulate in a safe, efficient and reliable manner: the supply of electricity from a distribution company's Distribution System; and the way in which a customer's electrical installations affect the D distribution system from which a supply of electricity is received [5].

The distribution licenses require each Distribution Company to comply with the Distribution Code. As a result of requirements imposed on: each distribution company under its distribution and retail licenses and independent Retailers, under their retail licenses. Each supply and sales contract involving either a franchise or non-franchise customer requires the relevant customer to comply with those provisions of the Distribution Code. By applying this approach it is possible to regulate the way in which customers' electrical installations affect distribution systems [6].

The quality regulation is also included in a system of price control. The first electricity price and network services regulation period embraced years from 1994 to 2000. It has provided the experience in regulation of distribution businesses allowing for the development of new rules for the next regulatory period 2001 – 2005. When setting up new distribution tariffs, the following issues have been taken into account [5], [6]:

- In the first regulatory period positive economic trends allowed distribution businesses to obtain larger than predicted income despite the drop in electricity tariffs. This indicated a need for a large value of the X parameter in the first year of a new regulatory period.
- Verification of distribution tariffs embraces both the electricity and the network prices as well as the balance between tariff components.
- Financial incentive incorporated in tariff structures to improve supply quality by tie up of tariff increase with quality targets and quality actual performance.
- Reduction of regulatory risk by setting verification rules and their parameters such as X, Y and S for the entire regulatory period covering years 2001 – 2005.

B. European Electricity Market

In January 2000, the Council of European Energy Regulators (CEER) formed a Working Group on Quality of Electricity Supply that aimed at comparing quality levels, standards, and regulation strategies for electricity supply in European countries [7]. The main objectives to be achieved by the Working Group were defined as:

- Comparing strategies and experiences in implementing quality of service regulation in each country represented in the Working Group.
- Identifying of the quality of service indicators/standards used in each country; description of the way information is collected and standards are computed; selection of possible standards that could be used for comparison of utilities from different EU countries.
- Performing a first benchmarking study on quality of service.
- Identifying of possible recommendations to be made to international bodies concerning quality of service benchmarking studies.

The Working Group has published the first report providing a comprehensive overview of the quality standards and practices in the European countries. The report can be also used to set up a common benchmark for supply quality [7].

C. Italian Electricity Market

Of the many European countries Italy seems to be one of the most advanced in quality regulation. In this country, the Regulatory Authority for Electricity and Gas (AAEG) is responsible for the regulation and control of quality. The Law requires AAEG to pay close attention to quality of supply and protection of electricity consumers' rights. In Italy, the quality of supply standards have been introduced and the systems of incentives and penalties for distribution companies as a function of supply quality has been implemented [8].

The next step after imposing quality standards should be the implementation of a monitoring system allowing for the verification how distribution businesses comply with the standards. Since 2000 Italy has been experiencing a new system for measurement and regulation of continuity of electricity supply. The system has been designed, after wide consultation, by the Italian regulatory authority (AAEG) that is also in charge of the standard implementation and audits. The Measurement Code devotes special attention to responsibility for interruptions and continuity of supply. Audits on continuity records are conducted to assure that the data provided are reliable; in some cases, a fine can be put on the utilities that do not record quality as required. The measurement, regulation and audit aim at the identification of responsibilities of distribution utilities for quality of supply and encouragement to reduce a number of interruptions [8].

III. WHAT IS QUALITY OF ELECTRICITY SUPPLY?

The answer to this simple question in not obvious. In different countries and industry sectors the quality has different meanings. The discussion below is based on the report [7] for the Council of European Regulators. This report indicates three main categories of supply quality, called quality dimensions. These main directions comprise:

- Commercial quality which relates to the quality of relationships between a supplier and a user
- Continuity of supply which is characterized by the number and duration of interruptions
- Voltage quality characterized by several parameters of the voltage supplied

A. Commercial Quality

Commercial quality becomes more important in electricity markets when an energy user considers to change an energy supplier. Despite the change an energy supplier, a legible customer, called sometimes a customer with TPA rights, is still physically connected to the same network of a local distribution company. Before selecting a new supplier, a customer asks for information or makes a request to be connected to the network. In such a case, commercial quality covers many aspects of the relationship. However, only some of these relations can be measured and regulated through standards or other legal instruments.

When standards are used for the regulation, they can relate to the overall provision of services (often called Overall standards) or to the delivery of services to individual customers (often called Guaranteed standards). Guaranteed standards are usually associated with some kind of reimbursement to the user in the event of non-compliance. Standards can be defined, for example, in terms of the maximum time to provide supply, metering, reading and billing, information supply, telephone enquiry responses, appointments, customers' complaints, emergency services [7].

B. Continuity of Supply

Continuity of supply is understand by some as reliability of supply. However, the report [7] indicates broader meaning of supply reliability pointing that reliability also depends on "adequacy", i.e. "the ability of the electric system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account the scheduled

and unscheduled outages of system facilities", as defined by the U.S. National Association of Regulatory Utility Commissioners (NARUC).

The continuity of supply in transmission and distribution networks can be evaluated by several indicators or parameters. Regulation can aim at compensation to customers for very long supply interruptions, keeping restoration times under control, and at creating the incentives to reduce the total number and duration of interruptions (and disincentives to increase them). Different methods and accuracies of measuring interruptions and in assigning liability for each of them create problems in regulating continuity of supply [9], [5].

C. *Voltage Quality*

Voltage quality covers the area called quality of supply. Speaking more precisely, voltage quality does not relate only to supply voltage, but also to the quality of supply currents that should stay within the defined ranges of quality parameters. Voltage quality becomes more important for distribution business and customers. The concern results from the sensitivity of end-user equipment and the increasing concern of equipment degradation caused by poor supply quality. Industrial equipment becomes more vulnerable to voltage distortion. Electronic devices of residential customers are also sensitive to parameters of supply voltages and currents [7]. Main parameters of voltage quality are determined in various of standards, recommended practices or electricity market legal regulations [1], [3].

IV QUALITY REGULATION MECHANISM

A. *Approaches to Regulation*

The challenge for regulatory bodies in the countries introducing liberalization in the electricity supply industry is the selection and implementation of an adequate mechanism to regulate supply quality. Commonly used approaches include [7], [10]:

- comparative publication on quality performance between companies, or yardstick competition to stimulate competitive behavior. Yardstick competition requires clear and detailed rules for measurement methods and data;
- overall and guaranteed standards of performance;
- economic penalties if standards are not met. Penalties have to be high enough to create an incentive to maintain standards, and can be paid to affected customers or into a fund for quality promotion programs;
- other sanctions like written warnings, license modification or license withdrawal;
- tariff reduction or other economic penalties which affect companies' revenues or profits. Performance indicators used for Performance-Based Regulation can be introduced in the price-cap formula by using a specific Q factor and may include different quality factors, consumer satisfaction indices or employees' health and safety indicators
- incentives to promote step changes in quality levels.

B. *Aspects for Consideration*

Deciding on a quality regulation mechanism the following aspects should be taken into consideration:

- What is relation of the documents imposing the quality regulation mechanism to other legal documents relating to power supply industry?
- Who issues such quality regulating documents and who will verify if actual practices are in accordance with the quality regulation?
- What should the system of incentives or penalties be to improve supply quality or keep supply parameters within prescribed ranges?
- How to balance the cost of investment to improve of supply quality with the cost of energy and network services?
- How to develop a cost effective quality monitoring system?

C. *Details of Regulation*

The specific character of power supply causes difficulties in quality supply regulation. Quality of supply is affected by customers' equipment and the structure and parameters of supply network. To obtain an adequate level of supply quality both the customers and the distribution companies should take the best endeavor to ensure adequate supply quality.

In legal regulation it is stated that a customer must use the best endeavor to ensure that the distribution system, and the reliability and quality of supply to other customers are not adversely affected by the customer's actions or equipment. Also a distribution business must use the best endeavor to assess and record the nature, location, condition and performance of its distribution system assets, develop and implement plans for the acquisition, creation, maintenance, operation, refurbishment, repair and disposal of its distribution system assets and plans for the establishment and then the augmentation of transmission connections [4].

However the term "use the best endeavor" has broad meaning and it can be interpreted in various ways, in particular, when a dispute arises on supply quality and responsibility to improve quality of supply. The regulatory body should indicate independent institutions and give them authorization to judge disputes between customers and distribution companies.

V. QUALITY OF SUPPLY IN THE DISTRIBUTION CODE IN VICTORIA

A. *Splitting Responsibility for Supply Quality*

An example of quality regulation in the part relating to voltage and current quality is the Distribution Code in Victoria. The Code introduces several attempts to split responsibility between distribution businesses and distribution customers. It was assumed that a distribution company is mainly responsible for parameters of supply voltages provided to a customer, who is responsible for current parameters, keeping the parameters within the prescribed ranges.

The authors of this paper, who a few years ago proposed such a solution for the Office of the Regulator-General which was introduced in the Distribution Code, are aware that the solution is not prefect, but it tries to keep responsibility

balance between a distribution company and customers. There can be circumstances when poor quality of supply results from specific conditions, for example resonance between customers' equipment and a distribution network, and the direct application of the Code is difficult. However, in such a case, the Regulator can authorize an independent expert to analyze the case and indicate measures that should be undertaken to improve supply quality

The following sections describe shortly regulation in the Distribution Code in Victoria [4].

B. Supply Frequency

The Electricity Distribution Code states that National Electricity Market Management Company (NEMMCO) is responsible for the frequency of each distributor's distribution system, having an obligation under the National Electricity Code to use reasonable endeavour to maintain system frequency at 50 Hz, subject to the allowable variations set out in that Code, so a distributor has no obligation in respect to the frequency of its distribution system.

C. Voltage Deviations

It has been decided that subject to the variation determined in Table 1, a distributor must maintain a nominal voltage level at the point of supply to the customer's electrical installation in accordance with the Electricity Safety (Network Assets) Regulations 1997 or, if these regulations do not apply to the distributor, at one of the following standard nominal voltages: (a) 240 V; (b) 415 V; (c) 480 V; (d) 6.6 kV; (e) 11 kV; (f) 22 kV; or (g) 66 kV. The variations from the relevant standard nominal voltage listed in clause 3.2.1 may occur in accordance with Table 1. A distributor must use its best endeavours to minimise the frequency of voltage variations as allowed (Table 1) for periods of less than 1 minute.

TABLE 1

THE ALLOWED VOLTAGE VARIATIONS

Voltage Level in kV	Voltage Range for Time Periods			Impulse Voltage
	Steady State	Less than 1min	Less than 10sec	
< 1.0	±6%	±10%	Phase to Earth+50%-100% Phase to Earth-20%-100%	10kV
1.66	±6% (±10% Rural Area)	±10%	Phase to Earth+80%-100% Phase to Earth-20%-100%	60kV
11				95kV
22				150kV
66	±10%	±15%	Phase to Earth+50%-100% Phase to Earth-20%-100%	325kV

The Distribution Code allows for the use of distribution lines to sent ripple control and other communication signal stating that a distributor may send, in accordance with IEC 1000-2-2, signals for the following: (a) ripple control systems; or (b) medium-frequency power-line carrier systems; or (c) radio-frequency power-line carrier systems.

D. Harmonics

Harmonic levels in distribution networks are the function of mutual interaction of customers' equipment and a supply network. Some harmonics generated by equipment with non-linear characteristics are boosted by a network resonance, so a critical point becomes who is responsible for harmonic distortion. The Distribution Code splits responsibility between a distributor and a customer imposing the obligation on voltage harmonics on a distributor, while a customer is responsible for current distortion. Despite that the solution is not perfect, it keeps the responsibility balance between a distributor and a customer. When a dispute arises, the Office of the Regulator-General can employ experts to judge the case.

The Distribution Code states that a distributor must ensure that harmonic levels in the voltage at point of common coupling nearest to a customer's point of supply comply with the levels specified in Table 2. The current harmonics allowed are determined using IEEE Standard.

TABLE 2

THE ALLOWED VOLTAGE HARMONICS

Voltage at a point of common coupling	Total harmonic distortion	Individual voltage harmonics	
		Odd	Even
<1kV	5%	4%	2%
>1kV and ≤66kV	3%	2%	1%

The Distribution Code imposes the obligation on a customer who must keep harmonic currents below the limits specified in Table 3, and otherwise comply at its nearest point of common coupling with the IEEE Standard 519-1992 'Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.

TABLE 3

THE ALLOWED CURRENT HARMONICS

Maximum Harmonic Current Distortion in Percent of I_L						
I_{sc}/I_L	Individual Harmonic Order "h" (Odd Harmonics)					Total Harmonic Distortion
	<11	11≤17	17≤23	23≤35	35≤h	
<20	4.0%	2.0%	1.5%	0.6%	0.3%	5.0%
20<50	7.0%	3.5%	2.5%	1.0%	0.5%	8.0%
50<100	10.0%	4.5%	4.0%	1.5%	0.7%	12.0%
100<1000	12.0%	5.5%	5.0%	2.0%	1.0%	15.0%
>1000	15.0%	7.0%	6.0%	2.5%	1.4%	20.0%

E. Negative Sequence Voltage and Load Balance

The level of negative sequence components in distribution networks depends on the balance of customers' load and symmetry of supply lines. The main parameter used on unbalance analysis is the level of negative sequence. Such a parameter is difficult to understand for most customers, and in particular, they are not familiar with measures that should be taken to keep this parameter under the prescribed values. The Distribution Code splits responsibility imposing the obligation on the distributor to keep negative sequence voltages at the allowed level, while the customer should keep his load balanced.

The Distribution Code states that a distributor must maintain negative sequence voltage at the point of common coupling to a customer's three phase electrical installation at a level equal to or less than 1 %. However, the negative sequence voltage may vary above 1% of the applicable voltage level, but not beyond 2% for a total of 5 minutes in every 30 minute period.

The Distribution Code prescribes that a customer must ensure that the current in each phase of a three phase electrical installation does not deviate from the average of the three phase currents: (a) by more than 5% for a standard nominal voltage up to 1 kV; and (b) by more than 2% for a standard nominal voltage above 1 kV. However, the deviations are permissible for periods of less than 2 minutes: (a) up to10% for a standard nominal voltage up to 1 kV; and (b) up to 4% for a standard nominal voltage above 1 kV.

VI. RELIABILITY OF SUPPLY IN VICTORIA

Reliability of supply, which is meant as continuity of supply, is regulated by the Distribution Code and benchmarking set by the Office of the Regulator-General [5]. Before 31st December each year, a distributor must publish on its website, and in a newspaper circulating in the area in which its distribution system is located, its targets for reliability of supply for the following year. As a minimum, these targets must include for customers supplied from CBD feeders, urban feeders, short rural feeders and long rural feeders:

- average minutes off supply per customer (SAIDI) due to planned interruptions;
- . average minutes off supply per customer (SAIDI) due to unplanned interruptions;
- average number of unplanned interruptions per customer (SAIFI), excluding momentary interruptions;
- average number of momentary interruptions per customer (MAIFI)
- average duration of unplanned interruptions (CAIDI); and
- estimates of the number of customers the distributor expects will be entitled to payments.

A range of incentives may be provided to distributors to meet their performance obligations, notably reliability targets and benchmarks. The Office of the Regulator-General, in considering the issue of performance-related incentives, has formed the following views:

- comparative performance reporting by the Office is seen as an effective incentive to maintain and improve performance, and should be continued and enhanced while maintaining a focus on a limited number of key indicators;
- the enforcement of license conditions by the Office, using its powers under the Office of the Regulator-General Act 1994, is seen as an effective incentive, but in practice will be rarely required given that compliance will normally be achieved without restoring those powers;
- there are potential advantages and disadvantages in adjusting distribution prices in proportion to the difference between actual and benchmark reliability, and it should be left to distributors, in consultation with their customers, to consider whether to propose such adjustments in their price review submissions.

The Office of the Regulator-General has identified the following issues relating to reliability of supply and incentives to improve supply reliability [6]:

- unless the price adjustments vary amongst customers to reflect the levels of reliability they actually received, and the value placed by different customer segments on reliability, a distributor faces a distorted incentive: that is, to make local reliability improvements where they are cheapest rather than where the greatest net benefit to customers will be achieved. This may encourage 'gaming' behavior by distributors, rather than responsiveness to customers' needs;
- rewarding distributors for over-performance, as well as penalizing them for under-performance, creates a symmetrical incentive, but may be seen by customers as requiring them to pay twice (for the incentive as well as the cost of achieving the enhanced performance). Surveys generally show that customers generally place less value on improvements in reliability than in reductions, so a symmetrical incentive would not reflect those preferences;
- incentives should exceed the reduction (or increase) in the distributor's costs arising from the reduced (enhanced) performance, but should be less than the value placed by customers on the reduction (increase) in reliability. However, there is no agreed method of measuring customers' valuations of reliability, and the surveys conducted to date suggest a large range: residential customers place a far lower value on reliability than industrial, commercial and agricultural customers; and
- reliability levels vary significantly from year to year, so that annual adjustments may be made in response to variations beyond a distributor's control. This could be avoided in part by only making adjustments following significant variations in reliability from benchmark levels.
- there are similar advantages and disadvantages in making guaranteed payments to customers who receive reliability below a worst-case benchmark; again, it should be left to distributors, in consultation with their customers, to consider whether to propose such payments in their price review submissions; and
- distributors also face incentives arising from any obligations imposed by the Energy Industry Ombudsman of Victoria or the courts to compensate customers for the consequences of sub-standard reliability or voltage quality.

VII. RELIABILITY OF SUPPLY IN ITALY

Italy seems to be one of the most advanced countries in the introduction of quality regulation, monitoring systems and incentives or penalties to improve supply quality. In March 1998, the AAEG issued a consultation paper setting out the guidelines for regulation of quality in the electricity supply. Continuity of supply is the most important factor for both domestic and business users of the electricity supply. As a first step a detailed method for the measurement of continuity indicators has been proposed by a second consultation paper (November 1998). With a third consultation paper (November 1999), a new regulation for continuity of supply has been devised, which has been enacted from January 1st, 2000, introducing a link between the continuity of supply and the tariff [3], [8].

The main criteria followed by the AEEG in defining the new regulations on the quality of the electricity supply are the followings [9]:

- Universality: it is essential to set the same quality standards for users in the same circumstances.
- Gradual implementation: implementing control systems and improving quality takes time (more for technical aspects than for relationships with users).
- Responsibility: responsibility for quality, including continuity of supply
- Value of quality: modern quality regulation strategies.
- Audit and control: quality can only be measured by companies. The regulatory body determines the measurement rules and checks measurement procedures by means of sample inspections.

Each year, by the end of March, utilities must submit their figures on the continuity indicators to the AAEG. After its sample controls, the AAEG calculates the 2-year rolling average and compares the actual levels with district-wide standards. If the utilities have improved continuity more than required, they gain an extra incentive related to the extra-improvement. If they have improved continuity less than required, they must pay a penalty related to the less-than-required improvement [9].

In Italy, the incentive system is funded by the penalties paid by utilities for districts in which the basic improvement rates are not met, and for the net difference between incentives and penalties, through a Q-parameter in the price-cap formula:

$$P = RPI - X + Q \qquad (1)$$

Where RPI – Retail Price Index, X – coefficient of regulation, Q – quality parameter.

The Q factor is calculated ex-post, and may assume a negative or positive sign. In the case when Q>0, it means that as a whole the system has improved more than required, and all users are called to contribute. On the contrary, when Q <0, it means that the whole system has improved less than required, and all users benefit from the reduction in a tariff [9].

VIII. CONCLUSIONS

Open electricity markets have changed relations between electricity distributors and customers. There is a need to establish the commonly accepted regulation for supply quality in various aspects of this quality. The experience from countries where electricity markets were introduced several years ago or from countries leading in the implementation of supply quality should be carefully analyzed. This should allow for the development of the commonly accepted standard of supply quality and incentive systems to improve quality of supply. Such standards and incentive system will be beneficial for both distribution businesses and energy users.

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