ORGANISATIONAL AND TECHNOLOGICAL ASPECTS THAT IMPACT ON SUPPLY QUALITY

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SUMMARY

This article presents a method for evaluating the costs of Supply Quality in the context of a new regulatory framework, to enable compliance with Strategic Plans for Investment - Costs and the priority classification of actions related to Supply Quality.

Consideration is given to technological (automation, technological innovation, etc.), as well as organisational aspects (co-ordination and optimisation discharges, integrated operation management, contractor management, etc.) and estimates made of the cost/benefit associated with each aspect.

OBJECT

The purpose of this paper is to establish a method for evaluating the costs of Supply Quality, in order to establish strategic plans and enable priority classification of actions to achieve the target values for the Quality indices while at the same time minimising their economic impact.

A regulatory framework that penalises non-compliance with established levels will shortly be coming into force in Spain and this is sufficient reason to attempt to evaluate the economic impact of this regulation and to determine the most suitable strategic options to successfully meet this challenge.

On the other hand, the process of integration of Spanish Distribution companies of the Endesa Group (10 million customers), involves a confluence of standards, procedures and information systems. This entails fixing global objectives for the Group aimed at obtaining optimum application of resources, and the need to go beyond the current limited outlook of a company to a unified vision of Group as a whole.

The varied initial situations of the companies, with differences of culture, technology, climatic and geographical environments (some companies are insular), needs and priorities, presents inconveniences as well as advantages. Among the advantages we can include the great wealth and diversity of experience of 7 companies that have acted during many years under independent management.

METHOD

This paper describes a factorial analysis of the aspects that influence Supply Quality. However, some specific peculiarities of the problem, the time factor for instance, prevent us from making a classic analysis. As is well known, Supply Quality has a large degree of inertia that affects each component in different ways, so that the efficiency of different actions may take more or less time to become apparent in the Quality indices.

The procedure is based on identifying the aspects that influence Supply Quality, determine which indices they act on and to what degree, determine the time taken for them to become effective and quantify the cost of the associated actions.

Before making any comparison of the cost/benefit ratios of each factor, we must first establish a unit of measurement that puts them on an equal footing. As Spanish Quality indices refer to installed power, the efficiency ratios for each of them have been valued on the basis of millions of pesetas per unit variation of the index (for example, minute of equivalent interruption time) on 1 GVA of installed power.

The cost/benefit ratios of each component can also present wide variations from one geographical environment to another and they are not constant in time. These ratios are a function of the current levels of Quality (the higher the Quality attained, the more expensive is any further improvement) and of the improvement strategies that may have been applied in the past (that is to say, of the relative importance historically given to each aspect).

Therefore, an interesting approach to be taken whenever developing strategic plans is to attempt to aggregate all the information available in the Group for each factor. They can then be classified in descending order of the effectiveness associated with each one. This will provide us with two key pieces of information:

a) the marginal cost of unit improvement of the factor.
b) the volume of the investment required to obtain a certain degree of improvement.

Superposing different factors will enable comparisons to be made of the situations that result in an equal effectiveness of the improvement. Using this criterion enables globalisation of the effects of various factors while minimising their associated cost.

Although this approach should be sufficient for the development and evaluation of Strategic Plans, before assigning priority indexes to actions a detailed study of the zone of the action should be made, since it is always possible that there are peculiarities not considered in the general model.

In the initial situation there is a group of companies, with different histories and problems, which have been applying diverse strategies in regard to Supply Quality.

REGULATORY FRAMEWORK

Although the text for the Regulatory Framework for the development of Electricity Distribution in Spain is not yet final, everything indicates that it will include economic indices associated with Availability of Supply (Zone Quality and Individual Quality) and also with Product Quality (Wave Quality).

This means that, Non-quality will have a cost in addition to that of the Energy not supplied and the corrective maintenance required.

The current draft of the Distribution Regulation defines Zone Quality as that measured by companies within a region according to four different types of zone:

- Urban zones: Consisting of local organisations or townships with more than 50,000 inhabitants, including provincial capitals.

- Semiurban zones: Consisting of local organisations or townships with a population between 5,000 and 50,000 inhabitants.

- Concentrated rural zones: Consisting of organisations or townships with a population between 500 and 5,000 inhabitants.

- Disperse rural zones: Consisting of local organisations or townships with a population of less than 500 inhabitants.

The following indices will be evaluated for these Zones of each province/company:

- TIEPI. Equivalent Interruption time of the Power Installed in the Medium Tension network.

- Percentile 80 of the TIEPI, or value of the TIEPI that is surpassed by 20 % of the Transformer Stations with the highest TIEPI.

- NIEPI. Number of Equivalent Interruptions of the Power Installed in the Medium Tension network.

In product quality, a possible variation of the supply voltage is fixed at ± 10% of the rated value. This band is reduced to 80% for supplies to distributors in HT and MT.

The legislation makes it obligatory to implement corrective actions for product quality within a maximum term of 6 months.

Historically the availability indices (duration and frequency of interruptions) in Spain have been based on the power installed in MT/LT Transformer Stations, this means that the zone indices for Supply Quality do not include incidents in low-tension networks.

Exceeding any of the threshold values established for the indices in any Zone would automatically involve the obligation of the Distributor company to present Improvement Plans. These plans will be subject to approval by the competent Authorities, and will have to be implemented by the Distributor within certain fixed periods.

The following table shows the threshold values for these indices according to the current draft of the Regulation.

ZONE	TIEPI	P80-TIEPI	NIEPI
Urban	3 h	4 h	4 cuts
Semiurban	6 h	8 h	8 cuts
Concentrated Rural	12 h	16 h	12 cuts
Disperse Rural	24 h	32 h	16 cuts

Each customer that has incident registering equipment will be assigned an Individual Quality requirement that establishes a discount in the billing proportional to the excess in the number of no-supply hours, or the number of interruptions, that exceed the regulatory thresholds. This discount is valued at 5 times the average price per kWh of the annual billing, up to a maximum of 10% of such annual billing.

The following table shows the limits fixed for Individual Quality for each natural year.

	MT Customers		BT Customers	
ZONE	Time	Number	Time	Number
Urban	4 h	8 cuts	6 h	10 cuts
Semiurban	8 h	20 cuts	10 h	26 cuts
Conc. Rural	15 h	30 cuts	20 h	39 cuts
Disp. Rural	20 h	40 cuts	20 h	39 cuts

Planned outages and interruptions due to the actions of third parties are excluded from this calculation, as well as those in which force majeure can be demonstrated before the competent authorities.

FACTORS THAT INFLUENCE SUPPLY QUALITY

Supply Quality is the result of a series of organisational and technological aspects, that influence it to different degrees, but which are all equally necessary to attain it.

The following aspects have been considered:

1. **Control Centres**
    1) Integrated Operational Management
    2) Standards of Network Conductivity
    3) Remote control systems for
        - Commanding Substations
        - Commanding Distribution Centres
        - Commanding points on the network.

2. **Automatisms in Substations**
    1) Automatic voltage control
    2) Re-connection devices
    3) Automatic switching of reactive energy equalisers
    4) Balancing of charges in voltage zeroes.

3. **Capability for manual adjustment in MT/LT transformers**.

4. **Automatisms in the MT and LT networks.**

5. **Co-ordination of protection systems**

6. **Standardisation and Quality Control of materials**

7. **Construction Quality Standards**

8. **Control of the Quality of Workmanship**

9. **Planning criteria**
    - Line lengths
    - Saturation of installations
    - Voltage levels and drops
    - Short-circuit powers
    - Safety criteria (n-1)
    - Capacity for load transfer.

10. **Maintenance strategies**

11. **Prevention of damages caused by third parties**

12. **Working live, Generator groups, mobile Transformation Centres and Substations**

13. **Technological adequation**

14. **Co-ordination and Optimisation of Planned Outages**

15. **Information systems (Management support)**
    - Cartography System
    - Material database
    - System for Planned Outage Management
    - System for Supply Quality

INITIAL SITUATION

Even though in an ideal situation, if these 15 factors are applied with optimum efficiency, they should enable the ENDESA GROUP to obtain much lower values for the Availability indices. In the current situation the value for TIEPI is close to 3 hours and that of the NIEPI about 4 interruptions per annum.

The percentile classification of these indices by their origin is:

Interruptions	TIEPI	NIEPI
Generation + Transportation	10.2%	23.3%
Distribution related	56.5%	58.4%
Third party actions	9.9%	9.2%
Programmed	23.4%	9.1%

The ENDESA GROUP is unique in the national context as it includes companies supplying insular areas, which are heavily penalised by incidents related to Generation.

The historical evolution of the TIEPI over the last 5 years indicates a progressive improvement of this index at a general level. This improvement is also noted at an individual level of the groups of companies, but it tends to stabilise itself at values close to the current ones. This means that, according to the curve for Maintenance Costs + Investment/Supply Quality, it is located very close to the balance point.

ACTIONS DESIGNED TO IMPROVE PRODUCT QUALITY (WAVE).

The elements that contribute to the improvement of the Wave Quality are:

- Voltage controllers in HT/MT transformer and reactive energy equalisers in Substations
- Control of MT/MT transforming in the network.
- Vacuum control over MT/LT transformation
- High short-circuit power
- Electromagnetic compatibility.

ACTIONS DESIGNED TO IMPROVE THE AVAILABILITY OF SUPPLY.

This section analyses the cost of Quality associated with different actions. These actions can be classified according to their objective:

Actions on

- Accidental interruptions
  - Prevention of interruptions
    - Design of installations (technological aspect)
    - Standardisation and approval of materials
    - Quality of Workmanship
    - Preventive maintenance
    - Renovation of facilities and technological suitability
    - Actions to prevent damages caused by third parties
  - Reduce the affected area
    - Design of the network structure
    - Automation of the network
    - Use of generators
    - Use of mobile substations and Transformation Centres
- Planned outages
  - Prevent interruptions
    - Work live
    - Generators
    - Mobile Substations and Transformation Centres
    - Design of the network structure
  - Reduce the affected area
    - Co-ordination of discharges
    - Optimisation of work procedures

As there is no need to be exhaustive and within the limits of this article, only the effect of three of the factors with greatest impact on Supply Quality will be analysed: Planning of the Network, Maintenance and Automation.

Design of the network structure

Adequate design of the geometry of the network and its facilities can improve the availability of supply as it reduces the impact of unforeseen interruptions and reduces or prevents planned outages while at the same time bringing about:

- Optimisation of investment costs.
- Improved Supply Quality.
- Easier development and optimisation of development costs.
- Reduction of network losses.

The experience with networks in urban zones or with a high load density, where there is a higher level of Supply Quality, confirms that this is due to the fact that in these zones the network is made up of short, interconnected underground lines. It is true that this has partly come about by compliance with certain regulatory, environmental and administrative requirements.

In view of this experience, and in a more general way, the factors in the design of the network structure that improve supply availability are:

- Length of the lines.
- Degree of interconnection.
- Degree of reservation.
- Degree of underground installation.

Supply availability defines certain regulatory minima that the network must comply with and, as they are an economic component, they are included, together with other econometric concepts, in the total cost to be minimised.

The Endesa Group has defined the structure of its network using "Network Planning Criteria", that are taken into consideration for each type of network:

- Voltage level
- Type of zone according to Quality regulations
- Industrial character of the zone
- Type of network (aerial/underground/mixed)
- Environmental conditions (isokeraunic levels, salinity, pollution, etc.)

Having defined the standards, the supply availability will be considered in the analysis and selection of investments as another criterion to be fulfilled by the planned network and also be used, together with other technical requirements associated with Product Quality, to define the most appropriate network structure.

When comparing alternatives for improving the availability of the supply, modification of the structure of the network will be considered in conjunction with other alternatives such as automation or renovation, using the same parameter of comparative pesetas per minute of improved TIEPI and installed GVA.

Facilities maintenance

The objectives of this maintenance are:

- Comply with regulatory aspects, especially those related to safety of persons and protection of the environment.
- Comply with the Regulations for the Control of Distribution and Marketing as developed by Law 54/97 of the Electrical Sector for the Planning of the National Electricity Distribution System.
- Adapt overall maintenance costs to the General Standard of Quality.
- Extend the useful life of the installations.

And it includes the following tasks:
TO INSPECT.- Maintenance designed to verify that the condition of the installations offers the necessary guarantees for supply availability under safe conditions and without having a negative effect on the environment.
TO ADEQUATE.- Maintenance designed to recover or improve the operation of installations which have deteriorated because of obsolescence or the action of external elements, or the inclusion of technical modifications.
TO REPAIR.- Maintenance originated by malfunctions in installations whenever these malfunctions affect the service or leave the installations in conditions preventing their use. Its objective is replacement of the damaged component to restore the installation to acceptable operational condition.

The objectives of maintenance can be the mere Replacement of damaged parts, the Maintenance of the Quality levels, and Improvement of Quality levels.

Replacement maintenance is the minimum service required. It is reactive maintenance, with a very low cost initially in a company whose installations are in good condition, but if it is the only system used, it tends to worsen Supply Quality, bringing about an exponential increase in its maintenance costs. Abuse of this maintenance system can have serious consequences for any electricity supply company.

Maintenance of Quality levels requires constant checking and adaptation to maintain installations in acceptable conditions, within a pre-determined standard of quality, as well as to optimise assets. This cost is significant and is directly related to the volume of the installations to be maintained, their working life, and their location within a more or less aggressive zone.

Maintenance designed to improve the Quality involves verification and adaptation as well as renovation. It is designed to include the selective replacement of all components of the network that have a high probability of failure. This is referred to as proactive maintenance to improve Supply Quality. The Cost of this type of maintenance is very high because of the technological diversity of the elements installed, and the state of the art at the time of their installation.

Improvement of the Supply Quality by maintenance must carry out through selective campaigns based on replacement of material whose malfunction mainly affects the Availability of Supply.

Improvement maintenance requires having an inventory of all the elements installed in a data base which includes their type, model and make, as well as their location in the network, and the influence of the malfunction of each of the elements installed on the indices for Supply Quality.

So far the only studies carried out have been based on the selective replacement of certain types of rigid insulators, circuit-breakers, underground cables and terminals using obsolete technology, and evaluating its relative effectiveness on the improvement of Quality.

This type of action mainly influences the NIEPI (frequency) and its corresponding repercussion on the TIEPI (interruption time).

The cost ratios associated with an improvement of 1 minute in the TIEPI for an installed power of 1 GVA and the improvements obtainable in this index for each technological replacement are:

Technological Replacement	Cost/benefit MESP/minTIEPI.GVA	Improvement obtainable
Rigid insulators	42.60	6 min.
Circuit-breakers	130.67	9 min.
Underground cable	147.60	5.4 min.
Terminals	7.19	7.2 min

Automation and remote control

Improvements brought about by automation of the network are based on the incorporation of automatic or remote controlled switching and signalling devices in order to simplify the location of malfunctions, reduction of interruption times and limiting their effects.

The effects of these actions are easy to quantify and priority ratings can be assigned on the basis of the rankings of the worst lines and their contribution to availability indices. The cost of a remote control device is a standard value and this means that it is possible to establish a cost ratio of MESP/min x GVA. The value of this ratio will be clearly marked by the contribution of the worst lines to the TIEPI, since this is where a remote control device will have greatest effect.

However the benefits of the installation of automatisms are short term and must be complemented by other measures. Automation in itself will not improve the quality of the installations and so will not bring about any reduction in the number of malfunctions (NIEPI). On the contrary, the inclusion of addition vulnerable components to the installations may even bring about an increase in the number of malfunctions and associated maintenance costs.

An alternative approach to the analysis of improvement by automation is through a theoretical model applied to real data, or simulation studies using computers to process the data.

The theoretical model considers typical power lines with an evenly distributed installed power and switching points located at equal distances.

In this simplified model, the reinstatement time t_r is composed of two elements: the time t_1, that elapses from activation of the line protection until execution of the first manual switching operation, and the time t_2, between completion of this action and resumption of the service.

$$t_r = t_1 + t_2$$

The incorporation of remote controlled switching devices at interconnections and intermediate points of the network reduces these times according to:

$$t_r = \frac{t_1}{N + 0{,}5} + C_x * t_2$$

Where N is the number of remote control points for the line and C_x is a non-linear reduction factor (<1), that must be determined empirically. According to the available data, the value of C_x can be approximated by the following equation:

$$C_x = 1 - 0{,}115 * N + 0{,}009 * N^2$$

Given that under non-automatic conditions the time t_1 is 20% of the total reinstatement time t_r, the reduction of TIEPI brought about by the introduction of N points would be:

Number of remote control points	Reduction of TIEPI (in %)
0	0
1.5	**22.0**
2.5	31.7
3.5	38.2
4.5	42.4

As was to be expected, there is a progressive reduction of the improvement with the increase in the number of points. This clearly indicates that the most basic actions have the most beneficial influence on the ratio of MESP/ minute reduction of TIEPI.

The classification of the lines by individual TIEPI measured over several years gives the priority ranking for Individual Quality, the classification of the lines according to their contribution to the overall TIEPI gives the ranking for Zone Quality. In both cases it is possible to make an estimate of the expected reduction in the TIEPI, and the line with the highest action priority rating will always be where the reduction of one or the other TIEPI results in a greater marginal ratio, provided minimum Individual Quality criteria are maintained.

By estimating the unit cost of automation of a point of the network at MESP 2.8, the studies by simulation give ratios between 1.38 and 23.34 MESP/min. x GVA. This clearly shows the need to act selectively.

CONCLUSIONS

This article has presented a method to evaluate actions and assign them priority ratings in order to:

- Eliminate the costs derived from Non-quality based on the application of a given Management Model. Technical aspects are not the only factors influencing network Quality, operation and management also play an important role.
- Respond to the economic indices of a regulatory framework.
- Create an economic index associated with Supply Quality otherwise there will not be enough incentive to maintain this quality. The costs of Quality, however, should be adequately compensated by the billing system.
- Planning of the installations must be conditioned to respond to demand and quality, as well as by a third variable which is constituted by environmental aspects: wildlife, forestry environment, industrial pollution, visual impact, etc., that not only increase the cost of investments, but even make certain planning alternatives impossible without being adequately reflected in the billing system.