TECHNICAL REPORT

Economics of Power Quality

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Chapter 1

Power Quality

1.1 Introduction

The term Power Quality includes, in general, a set of boundary conditions which allow electrical systems connected to the grid to function in their intended manner, without significant loss of performance or life. Therefore, the operation of the power system outside these boundaries directly impacts on the economical performance of the whole system.

In the broadest sense, the term Power Quality should be interpreted as a service quality encompassing the three aspects—reliability of supply, quality of power offered, and provision of information, tranposed to the Spanish regulation by the Real Decreto 1955/2000. In the strict sense Power Quality is refered to the degradation of some of the wave parameters in the measurement point. These parameters are frequency, width, shape and symmetry.

The disturbances responsable for this degradation are classified by the IEC as conducted low-frequency phenomena, radiated low-frequency phenomena, conducted high-frequency phenomena, radiated high frequency phenomena, electrostatic discharge phenomena und nuclear electromagnetic phenomena. From all these phenomena this work focuses on conducted low-frequency phenomena and more specifically on voltage dips and short interruptions.

This chapter provides the definition of voltage dips and short interruptions considered throughout the work and investigates the effects on the equipment of those perturbations as well as a revision of the application of the so-called electromagnetic compatilibity, which tries to minimize those effects.

1.2 Short-duration variations

In the IEC terminology, the category short-duration variations is used to refer to voltage dips and short interruptions.

Short-duration variations are usually caused by fault conditions, the energization of large loads which require high startng currents, or intermittent loose connections in power wiring. Depending on the fault location and the system conditions, the fault can cause temporary voltage rises, voltage dips or interruptions.

To caracterize voltage dips and interruptions, there are different definitions specially regarding to their duration. On this work the definition considered is the one proposed by IEEE standard [5], see as follows. Dips are defined as a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for duration of 0.5 cycle to 1 min. Interruption is defined as complete loss of voltage (<0.1 pu) on one or more phase conductors.

1.2.1 Voltage dips

Voltage dips are defined as a decrease to between 0.1 and 0.9 pu on rms voltage and classified by duration in three different subcategories:

Instantaneous from 0.5 to 30 cycles.

Momentary from 0.5 to 3 s.

Temporary from 3 s to 1 min.

Voltage dips are usually associated with system faults but they can also be caused by switching heavy loads or starting large motors. In more detail, the causes of voltage sag can be divided into two categories, depending on the location of the source in relationship to the power meter. In other words, faults can happen on the utility side of the meter which includes switching operations, power system faults, regulator dysfunction and lightning. While on the end user side of the meter, the faults include nonlinear loads, poor grounding, electromagnetic interference and static electricity [7].

Voltage dips are frequent and widespread and can be considered the first power quality phenomenon affecting industry.

1.2.2 Interruptions

Interruptions are defined as a complete loss of voltage (<0.1 pu) on one or more phase conductors and classified by duration in two different subcategories:

Momentary from 0.5 to 3 s.

Temporary from 3 s to 1 min.

Interruptions can be the result of power system faults, equipment failures, and control malfunctions. The duration of an interruption due to a fault on the utility system is determined by utility protective devices and the particular event that is causing the fault. The duration of an interruption due to equipment malfunctions or loose connections can be irregular.

1.3 Effects on equipment

The most prevalent problem associated with short-duration rms variations is equipment shutdown. In many industries wiht critical process loads, even istantaneous short-duration phenomena can cause process shutdowns requiring hours to restart. In many facilities, if the equipment trips, the effect on the process is the same for a short-duration variation as for a long-duration phenomena.

1.3.1 Voltage dips

Short-duration dips cause numeours process disruptions. Often, the dip is sensed be electronic process controllers equipped with fault-detection circuitry that initiates shitdown of other, less-sensitive loads. Additionally, many control power systems and emergency stop circuits use hard-wired relay logic and contactors that can be highly sensitive to dips. A common solution to this problem is to serve the electronic controller with a constant-voltage transformer, or other mitigating device, to provide adequate voltage to the controller or contactors/relays during a sag (dip). The application challenge is to maintain the electronic controller during sags that will not damage process equipment protected by the fault circuitry or compromise safety systems, while simultaneously reducing nuisance shutdowns.

Electronic devices with battery backup should be unaffected by short-duration reductions in voltage. Power electronic-based power supplies often misoperate prior to tripping as the stored energy is depleted from dc-bus capacitors. Equipment such as transformers, cable, bus, switchgear, CTs, and PTs should not incur damage or malfunction due to short-duration sags. A slight speed change of induction machinery and a slight reduction in output from a capacitor bank can occur during a sag. The visible light output of some lighting devices may be reduced briefly during a sag. Note that a power quality monitor might record a sag, but the load equipment might see an interruption. For example, consider a system with a contactor connected between the power source and an induction motor. If the supply sags, the motor will experience not only the sag, but perhaps a momentary or sustained interruption if the contactor bounces or opens during the sag.

1.3.2 Interruptions

Even instantaneous interruptions may addect electronic and lighting equipment and cause misoperation or shutdown. Electronic equipment includes power and electronic controllers, computers and the electronic controls for rotating machinery. Momentary and temporary interuptions will almost always cause equipment to stop operating and may cause drop-out of induction motor contactors. In some cases, interruptions may damage electronic equipment, especially during the abrupt recovery of the voltage.

1.4 Electromagnetic compatibility

In order to avoide the effects of voltage sags, both users and manufacturers are obligated to comply with different standards in order to assure power compatibility between equipment and power grid.

The main standarts dealing with this power compatilibity between equipment and power grid are IEEE, IEC, CBEMA and SEMI.

1.4.1 IEEE standard 1346-1998

IEEE standard 1346-1998 is also known as “Recommended Practice for Evaluating Electric Power System Compatibility With Electronic Process Equipment” [2].

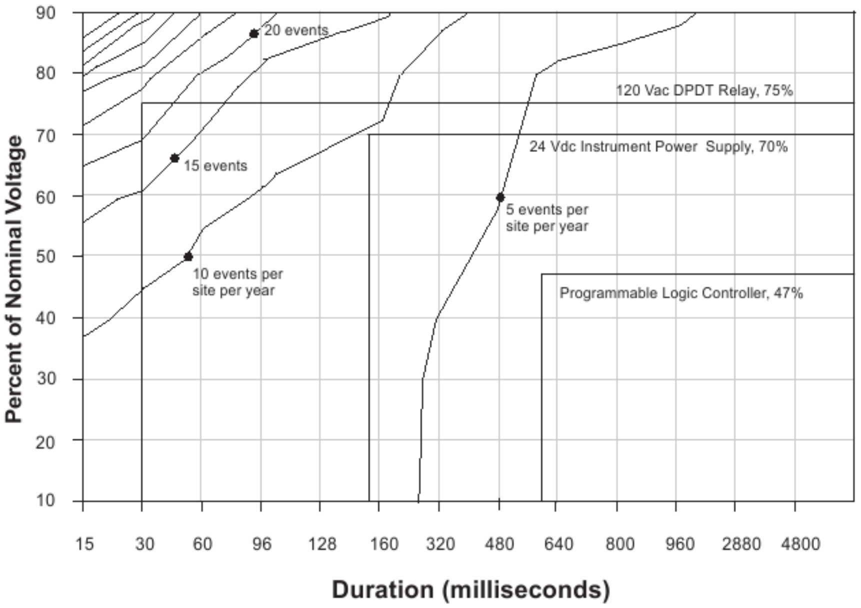


Figure 1.1: Sample overlay of sag environment and equipment susceptibilities

The purpose of the IEEE std. 1346-1998 is to recommend a standard methodology for the technical and financial analysis of compatibility of process equipment with an electric power system. This recommended practice does not intend to set performance limits for utility systems, power distribution systems, or electronic process equipment. Rather, it shows how the performance data for each of these enti- ties can be analyzed to evaluate their compatibility as a system in financial terms.

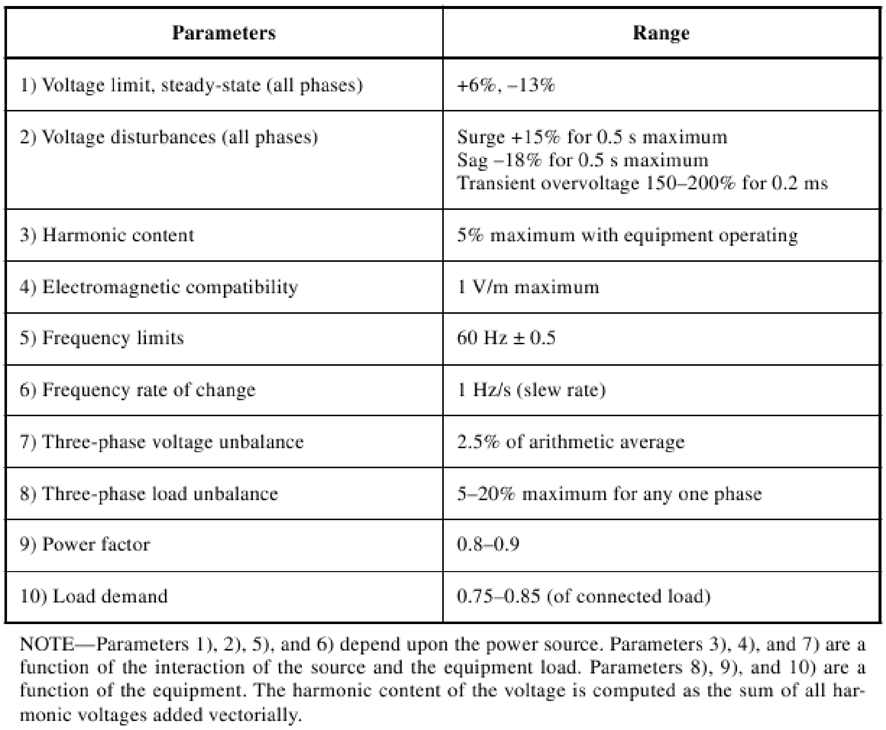
This recommended practice is intended to be applied at the planning or design stage of a system where power supply and equipment choices are still flexible and incompatibilities can be resolved. Consequently, this document does not discuss troubleshooting or correcting existing power quality problems.

This standard provides a compatibility evaluation for three different type of equipments: 120 Vac DPDT Relay, 24 Vdc instrument power supply and programmable logic controller. It also provides a voltage sag chart, with data of the number of events per year in a facility-example, see figure 1.1.

1.4.2 IEEE standard 446-1995

IEEE standard 446-1995 is also known as "IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications" [1].

This standard presents recommended engineering principles, practices, and guidelines for the selection, design, installation, application, operation, and maintenance of emergency and standby power systems. This information is



Parameters	Range
1) Voltage limit, steady-state (all phases)	+6%, −13%
2) Voltage disturbances (all phases)	Surge +15% for 0.5 s maximum Sag −18% for 0.5 s maximum Transient overvoltage 150–200% for 0.2 ms
3) Harmonic content	5% maximum with equipment operating
4) Electromagnetic compatibility	1 V/m maximum
5) Frequency limits	60 Hz ± 0.5
6) Frequency rate of change	1 Hz/s (slew rate)
7) Three-phase voltage unbalance	2.5% of arithmetic average
8) Three-phase load unbalance	5–20% maximum for any one phase
9) Power factor	0.8–0.9
10) Load demand	0.75–0.85 (of connected load)

NOTE—Parameters 1), 2), 5), and 6) depend upon the power source. Parameters 3), 4), and 7) are a function of the interaction of the source and the equipment load. Parameters 8), 9), and 10) are a function of the equipment. The harmonic content of the voltage is computed as the sum of all harmonic voltages added vectorially.

Figure 1.2: Typical range of input power quality and load parameters of a major computer manufacturer

primarily presented from a user's viewpoint; however, managing the effects of power system disturbances requires close cooperation between users, electric utilities, and equipment manufacturers.

This standard provides typical power quality input range that it is allowable for computer manufacturers, see figure 1.2. Similar to the ITI (CBEMA) Curve, see on next subsection.

1.4.3 ITI (CBEMA) Curve

The ITI (CBEMA) Curve [21] was published by Technical Committee 3 (TC3) of the Information Technology Industry Council (formerly known as the Computer & Business Equipment Manufacturer's Association). The ITI (CBEMA) Curve and the Application Note describe an AC input voltage envelope which typically can be tolerated (no interruption in function) by most Information Technology Equipment (ITE), see figure 1.3.

1.4.4 SEMI F47-0706 Standard

The SEMI F47 entitled "Specification for Semiconductor Processing Equipment Voltage Sag Immunity" defines the threshold that a semiconductor tool must operate through without interruption. The recognizing semiconductor factories

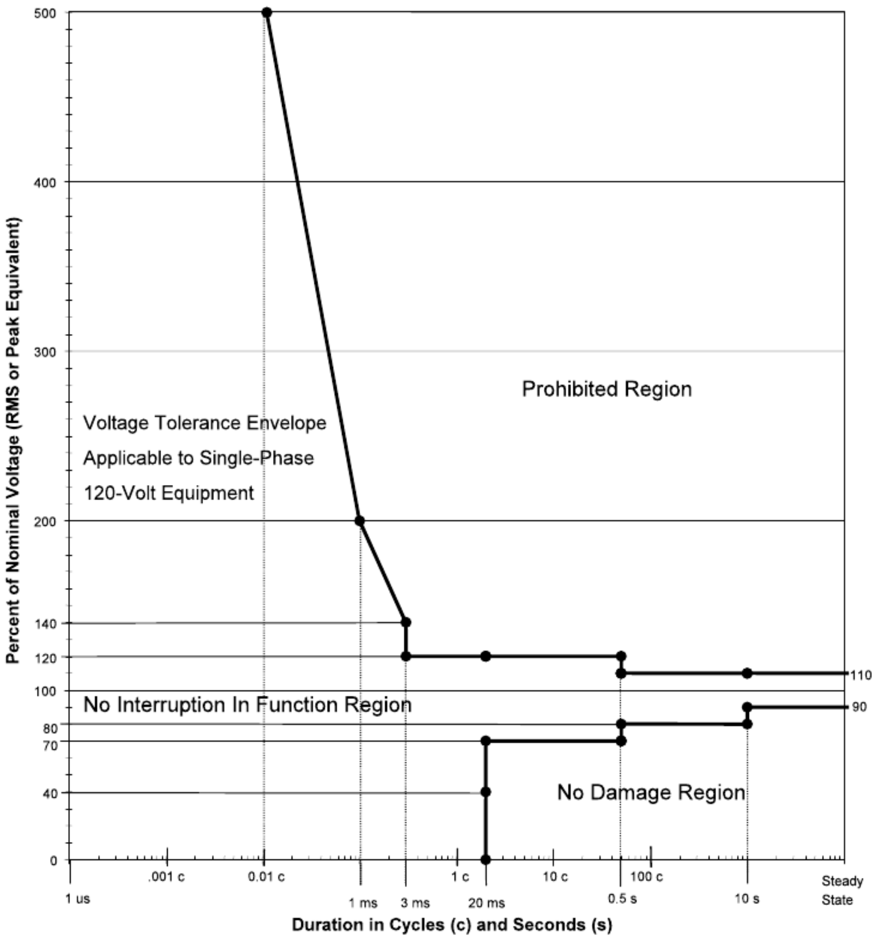


Figure 1.3: ITI (CBEMA) Curve – Revised 2000

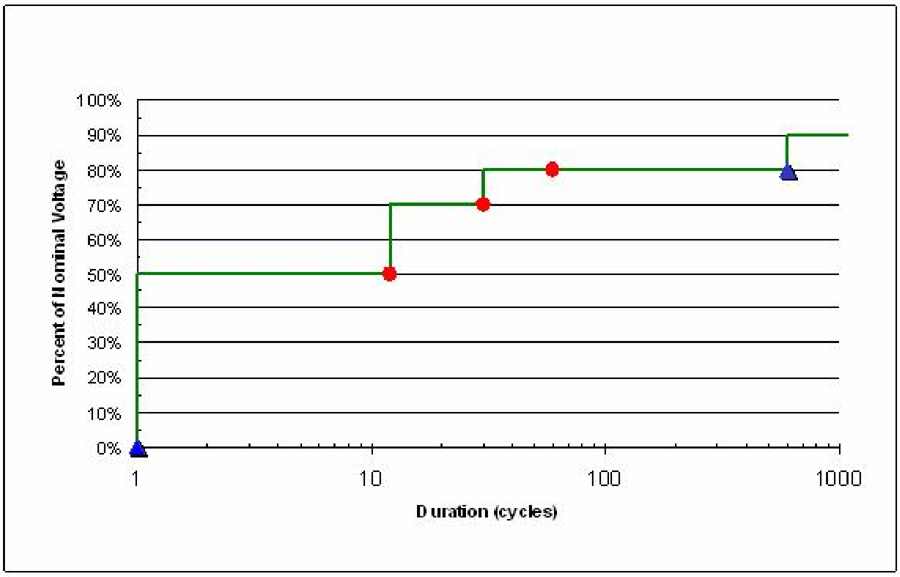


Figure 1.4: SEMI curve
Note: Red Dots – Required Test Points, Blue Triangles – Recommended Points

require high levels of power quality due to the sensitivity of equipment and process controls. As semiconductor processing equipment is especially vulnerable to voltage sags, the SEMI F47 document defines the voltage sag ride-through capability required for semiconductor processing, metrology, and automated test equipment.

The resulting voltage sag ride-through capability curve also known as the SEMI curve is provided in figure 1.4.

1.4.5 IEC 61000-4-11 and IEC 61000-4-34 Standards

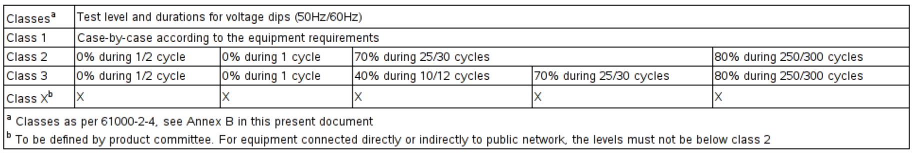
IEC 61000-4-11 and IEC 61000-4-34 Standards are refered as “Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests”. The IEC 61000-4-11 applies to electrical and electronic equipment having a rated input current not exceeding 16 A per phase, for connection to 50 Hz or 60 Hz a.c. networks and the IEC 61000-4-34 for electrical and electronic equipment having a rated input current higher than 16A per phase.

The object of both standards is to establish a common reference for evaluating the immunity of electrical and electronic equipment when subjected to voltage dips, short interruptions and voltage variations.

The IEC defines 4 clases of equipment based on the reaction of the equipment in a test with different voltage dips, see figure 1.5.

Figure 1.6 presents the classification in the different cathegories based on the reaction to short interruptions.

Figure 1.7 represents a voltage variation time with a transition time to the dip voltage from 2 seconds to an abrupt time.

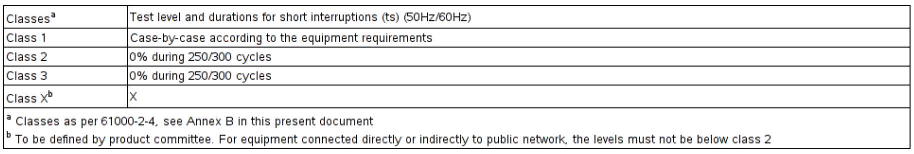


Classes[a]	Test level and durations for voltage dips (50Hz/60Hz)			
Class 1	Case-by-case according to the equipment requirements			
Class 2	0% during 1/2 cycle	0% during 1 cycle	70% during 25/30 cycles		80% during 250/300 cycles
Class 3	0% during 1/2 cycle	0% during 1 cycle	40% during 10/12 cycles	70% during 25/30 cycles	80% during 250/300 cycles
Class X[b]	X	X	X	X	X

[a] Classes as per 61000-2-4, see Annex B in this present document

[b] To be defined by product committee. For equipment connected directly or indirectly to public network, the levels must not be below class 2

Figure 1.5: Test level and durations for voltage dips (50Hz/60Hz)

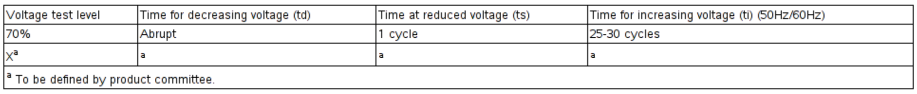


Classes[a]	Test level and durations for short interruptions (ts) (50Hz/60Hz)
Class 1	Case-by-case according to the equipment requirements
Class 2	0% during 250/300 cycles
Class 3	0% during 250/300 cycles
Class X[b]	X

[a] Classes as per 61000-2-4, see Annex B in this present document

[b] To be defined by product committee. For equipment connected directly or indirectly to public network, the levels must not be below class 2

Figure 1.6: Test levels for voltage dips and interruptions



Voltage test level	Time for decreasing voltage (td)	Time at reduced voltage (ts)	Time for increasing voltage (ti) (50Hz/60Hz)
70%	Abrupt	1 cycle	25-30 cycles
X[a]	[a]	[a]	[a]

[a] To be defined by product committee.

Figure 1.7: Test level and durations for short interruptions

Although these standards are similar to the SEMI F47 standard, they use slightly different dip depths.

1.5 Conclusions

This chapter has investigated the main perturbations in power quality and their effect on equipment. The different standarts for electromagnetic compatibility by IEEE, ITIC, SEMI and IEC has also been researched.

In the next chapters the different methodologies for evaluating economical losses due to voltage sags and short interruptions will be analyzed and a new methodology will be proposed and validated.

Chapter 2

Economical evaluation of Power Quality

The evaluation of economical loses derived from disturbances in the power quality has been matter of several studies, mostly applied to individual cases. This problem can obviously be solve by investing in a range of different technologies from a contract with the supply company ensuring high power quality supply if available; until installing own supply systems. If the investment is excesive it would definitely avoide power quality problems but at a higher cost than the produced by the original problem. That means that finding the real cost of the perturbances impacts in a very sensitive way on the company incomes. The solution of this problem is not trivial and different studies have been performed in order to find solutions. Most of these studies are focusing on particular cases, in order to either limitate the probable variables or also very often with the objective of decreasing a determined company loses in a particular environment. In every one of those cases, the different studies have developed a range of methodologies in order to proper evaluate economical loses due to power quality disturbances.

This chapter firstly defines and analises different existing methodologies for the evaluation of financial losses due to power quality issues. The power quality issues being considered are voltage sags and short interruptions.

The second part of the chapter focuses on the development of a new methodology based on macroeconomic parameters recollected in the National Countability Register, in order to generalize the methodologies above with a more broad application. The result of this research will provide a more generalize method for power economics evaluation, which can be easily extrapolated to different environments. Results of the application of this methodology will be also provided.

2.1 Introduction

The Economical Evaluation of Power Quality issues is one of the main problems the power system is facing. In a world every day more depending on electronic devices connected to the power grid and with the power quality necessities of those devices increasing day after day, a bad quality of power can have a devastating impact on industries and particulars [8]. The factors responsible for this impact are sometimes unclear and very often of difficult evaluation. Therefore, the economical evaluation of this impact is even more confuse.

Different methodologies are being developed, some of them giving a reference to the general steps that should be followed in a correct evaluation [2], [14] and [15]. Some others are focussing on a particular case and solving this case, not being the methodology exportable to other environments [17], [18]. Some others are dealing with information which have confidentially issues [12]. Some others too complicates to be applicable [16] and [20]. And, some others provide just a very rough approximation of these economical loses [11], [13]. There is at the present no clear solution which can solve this problem in a general mode.

The interest of this work is directly related with analysing and proposing a general solution for the exposed problem. This solution will be based on macroeconomic factors which are public and free of confidentiality issues. The parameters which the method is based on are recollected in the National Countability Register. The European Commission, through the EUTOSTAT agency establishes a frame for the application of the National Accounting System for all the member states, which ensures the availability of the necessary data for the use of this methodology in other environments. The approach may be general but the results will show a respectable reliability with the results of more particularized methodologies.

2.2 Analysis of existing methodologies

Among the different power quality disturbances that can affect the supply voltage; outages and voltage sags are particularly harmful for industrial plants since they can stop production and cause large related costs – the so-called Customer Interruption Cost (CIC). The calculation of this CIC in order to evaluate the necessity of voltage conditioning devices or contracting a higher power quality to the supply company has been matter of constant study. Although the problem of its calculation remains unsolved, several approximation-methods are discussed in this section.

The accuracy in the result of the approximation method depends mostly on the available data. An accurate evaluation will need the following inputs:

- Voltage sags profile at busbars - provides information about the density of events.
- Customer load susceptibility - provides information about the reaction of the customer loads to the different events.

These data are difficult to obtain. Therefore, the different methodologies have been developed to estimate more or less rigorously the losses without the availability of real measured data.

The different methodologies are described in this section and a pros and cons dicussion for every one provided.

2.2.1 IEEE Recommended Practice for Evaluating Electric Power System Compatibility With Electronic Process Equipment [2]

This IEEE Standard develops a technical and financial analysis of voltage sag compatibility between process equipment and electric power systems. It is intended to be applied at the planning or design stage of a system where power supply and equipment choices are still flexible and incompatibilities can be resolved. Basically, it consists on a three-steps-process. First step: The development of a coordination chart, a relation between the probability of a sag (considering time and magnitude) and the disruption region for every component of the process. The sag-data is recommended to be recollected at the feeder and the data of equipment susceptibilities (voltage tolerance curves) is usually provided by the manufacturer. From the coordination chart, the number of disruption events that the most sensitive equipment will have to support will be identified. Second step: The assumption of fixed cost per sag. The value of the cost will be obtained from a survey on the different actors of the process chain. Taking as an input a scenario with a failure of the complete chain. Third step: Multiplying the value of the cost obtained from the survey per the number of events identified in the chart.

Pros and cons

Positive is that it is a simple and easy methodology to apply and provides an approximative idea of the real value of the losses.

Negative, it is the need of a huge amount of data, some of them difficult to gather together and some of them dealing with confidentiality issues of the company. Also, it is only based on the reaction of the most sensitive equipment. If it does not affect completely to the process chain, the methodology fails to give a reliable output. Although it is intended to be applied at the planning or design stage of a system, the date used is based on the experience of the different actors of the process (by means of the survey) which makes difficult its goal.

2.2.2 The Pirjo Heine method [11]

This method was developed by the Helsinki University of Technology. It consists in estimating the three variables of the equation 2.1.

$$Cost = V \cdot N \cdot C \tag{2.1}$$

Where V, N and C are described as follows:

Voltage sag frequency (V) The estimation requires a probabilistic approach and network reliability data. These data are typically derived from permanent faults. The authors develop a probabilistic method to estimate the average annual sag frequency (for voltage sags less or equal to 50%) that the LV customers of five different distribution companies will experience because of faults in radially supplied medium voltage (20 kV) distribution networks.

Number of customers (N) It was a data provided to the study. The customers where categorized into five different groups: domestic, agricultural, industrial, commercial services and public services. In order to assume similar behaviors to every component of a group.

Cost per sag (C) The cost per sag was obviously estimated for every one of the five groups of customers. The value per sag was calculated from the evaluation of real direct and indirect economic consequences of the sag. This evaluation was made by different surveys on households, agricultural and industrial customers. From the combination of the results of the three surveys an approximative cost per type of customer was found.

Pros and cons

Positive is that the method uses available data form statistics originally prepared for other purposes in order to extrapolate costs in the case of voltage sags and short interruptions.

Negative is the inaccuracy in the evaluation of the sag frequency. The evaluation of the cost per sag is based on a big sample of real data, which is usually difficult to gather. It is assumed that the enormous quantity of data will be enough to give an approximation of the real costs, not even giving a clear statistical approach of the treatment of those data. It may be more desirable a small and more accurate sample focused on the objective. The results of this paper can not be extrapolate out of its context.

2.2.3 The Quaia and Tosato method [17]

This method was developed by the University of Trieste. It consists in estimating costs of MV (10 to 20 kV) fed industrial plants (up to 2-3 MW peak plants). The authors also apply it to a real case (plastics sector middle sized industry) in [18]. The data required is obtained by direct survey on the target industry. However, this survey do not exclusively focus on cost estimation questions but other data concerning to plant operation, structure of the productive system, equipment sensitivity, restart procedures and many other aspects related to the interruption consequences. The reason behind is that a direct cost estimation survey presents several dangers: customers not willing to provide cost information; the data resulting is not controllable and customers tend to overestimate them; and only sensitive users are really affected by interruptions and they may be considered one third of the total MV industrial plants.

The method proposed is a complete analysis of the target industry. The pattern is developed by assuming a reference plant with n machines or production groups. Each performing different serial productive processes. In general, each machine will cause a different interruption cost, but also for any given machine the interruption cost will depend on the individual process interrupted. Then, the interruption costs calculation should be repeated for each individual machine. It is assumed that trying to represent costs versus sag severity would be unrealistic and that outages and severe sags have the same effect on equipment operation and therefore cause equal CIC. The costs contemplated in the CIC equation 2.2.

$$Cost = C_{LP,D} + C_{LP,R} + C_{WM} + C_{IP} + C_{DE} + C_{EM} - S_M \tag{2.2}$$

Where:

$C_{LP,D}$ = Cost of lost production during the supply disturbances

$C_{LP,R}$ = Cost of lost production during the restart time

C_{WM} = Cost of wasted material

C_{IP} = Cost of imperfect products

C_{DE} = Cost of _ d equipment

C_{EM} = Cost of extra maintenance

S_M = Saving on raw materials

S_E = Saving on energy not consumed

All these costs and saves are estimated in [17] and approximative values provided in [18].

Pros and cons

Positive, it is an accurate method to analyse costs produced by voltage sags or short interruptions in a middle sized industry, also providing standard values for some of the variables proposed. No data about the voltage sags frequency estimation, which means that the costs evaluation would be per sag.

Negative, there is no reference to the sag magnitude, which calculation is assumed to be unrealistic. The outages and severe sags are considerate as having the same effect on the operation. This is not true. But the author expect the error introduced to be reasonably low.

2.2.4 The Lee, Albu and Heydt method [12]

This method consists in the definition of a power quality index to quantify the supply voltage quality of each duration class (defined by IEEE 1159) based on the impact of that class of disturbances. A series of measured voltage disturbances are represented as points on the CBEMA curve (this curve represents the sensitivity of a device to voltage sags) and grouped according to common disturbance duration class. The calculation consist in the application of two different indexes: average load drop index (LDI) and average load drop cost (LDC). The method for the calculation requires as inputs:

1. The sensitivity curves of every different load present in the load composition.
2. The percentage of every load presents in the process.
3. The voltage sag profile in the busbar
4. The average cost of every class of disturbance defined by IEEE 1159

Pros and cons

Positive, it is an elegant method to evaluate power quality costs and it considers different costs for different sag severities.

Negative, it needs the sensitivity curves for every load. It is not represented the relation between loads and if a load can impact the failure of others. The costs of every class of disruption is taken as a constant value which can be just a rough approximation to the real cost.

2.2.5 Crozier and Wisdom [8]

More than a methodology it is the statement of the necessity of a relation between CIC and kWh sold for energy producers to proper evaluate the expenditure decisions. It relates existing PQ&R measures with its failure to approx costs. While a CICs/ kWh approach could be a good estimation of costs as well as be also applied to evaluate PQ problems.

Pros and cons

It is just the justification of the need of a more economical oriented approach to the PQ problems.

2.2.6 The McGranaghan and Roettger method [14]

It presents a conventional approach for the evaluation of cost savings experienced by different PQ-solution technologies (Also a custom power approach is presented in [15] with an example solved by the same authors). The methodology consists on a four steps process.

Step 1: The characterization of the system power quality performance. Basically the analysis of the frequency of occurrence of mainly voltage sags and short interruptions.

Step 2: The estimation of costs for power quality variations. Dividing the costs in three main categories: product related loses, labor-related loses and ancillary costs. It refers to IEEE 1346 Standard for a more accurate list of factors to be considerate. These costs must be evaluated by survey on the actors of the process or approx data. Costs will typically vary with the severity (magnitude or duration) of the PQ disturbance. This relationship is defined by a matrix of weighting factors.

Step 3: Characterizing the cost and effectiveness for solution alternatives. It considers four main options: Supply system modifications and equipment that affect multiple customers; Service entrance technologies that affect a single targeted customer; Power conditioning at equipment locations within a facility and; Equipment specifications and design.

Each technological solution must be characterized in terms of cost and effectiveness. For costs the paper adds a table with typical costs per technology and for effectiveness also a table which relate this effectiveness with the severity of the PQ disturbance.

Step 4: Performing comparative economic analysis. First the total annual cost for each alternative must be determined. This annual cost is represented by the costs associated to the power quality variations as well as the implementation cost of the solution. With the annual cost determined, a comparison between technologies will be done. The best rated solutions will need more detailed investigation.

Pros and cons

Positive is that it is a useful and clear method which takes into account the main points presented in PQ economics. The paper gives also some typical data but only applicable to a particular case of industry.

Negative, there is just a rough explanation of how to calculate the different factors presented and no references to more detailed documentation about.

2.2.7 The Pohjanheimo and Lehtonen method [16]

The method is a probabilistic approach to the determination of the best solution in PQ disturbances mitigation. The method takes into account: technical and economical impact, annual frequency of sags and effect of possible mitigation devices already available in the process. The author proposes a combination of two-dimensional arrays (rows representing the remaining voltage during a sag / columns representing sag duration), everyone representing different characteristics of the system.

Example :

array E: Weighted event cost array;

array P: Sensitivity of a process;

array I: Frequency of sag oriented plant interruptions.

Mathematical equations are proposed for evaluating the different parameters of the system. The parameters defining the characteristics of the system inside the array can be discrete states (0,1) or probabilistic values (0 to 1).

Pros and cons

Positive, it creates a platform able to integrate all the parameters presents in PQ technical and economical evaluation. The result seems easy to implement on a spreadsheet or any software suitable to calculate with mathematical arrays.

Negative, the method needs many factors as input, most of them difficult to calculate. It does not give any approach to the calculation or approximation of parameters.

2.2.8 The Wang, Chen and Lie method [20]

It is a method for estimating the load performance and obviously economical impact due to voltage sags. The main point of the study is that it uses fault tree analysis to estimate the response of the load (built up of different equipments with different sensitivities) to a voltage sag. The main focus is to convert the voltage sag disturbance in a reaction of the individual components of a system and after linking them to the load performance.

Pros and cons

Positive, it is a simple idea applicable only to the assembling of a global load composed by many different equipments with different sensitivities (another way to see the weighting factors).

Negative, it that as always, it does not give any clue to estimate the loss per case studied. If the process is complex, the fault tree analysis becomes very complicated.

2.2.9 WTP and WTA method [13]

The Willingness to pay and the willingness to accept are two methodologies based on indirect evaluation of costs. In the WTP method, the customers are asked to inform how much they are ready to pay in order to avoid an voltage sag or a short interruption. The difficulty with the method is that the customers usually are not aware about all the activities or functions which are interrupted by that. They also tend to consider planned outages, which leads to the underestimation of the costs of unexpected interruptions. An alternative approach is to ask the customers their willingness to accept compensation for having had an outage (WTA). In a normally working market situation the WTA and WTP methods should give identical results. However, in actual studies, the WTA values have been substantially higher than WTP values.

Pros and cons

They are useful especially for such customer categories, the outage costs of which are difficult to estimate directly in monetary terms.

2.3 Conclusions

From all the methodologies evaluated, it can be stated that the methodologies can be classified in four main groups:

- First, the methodologies that provide a simple and easy to apply methodology but needing a great amount of data in order to provide an approximation to the real value of the losses. With the added problem that gather some of this data has to do with dealing with confidentiality issues.
- Second, the methodologies that are not a general methodology but a complete analysis of a target industry, based therefore on a particular case. The more sofisticated ones even need the sensitivity curves for every load present in the target industry.
- Third, the methodologies that try to give a general approach to be applied to different kind of industries but only giving the main parameters considered for a few particular cases. And not enough information of how to calculate such parameters for other industries.
- Fourth, the last group are methodologies that are based on subjective parameters which are difficult to evaluate and quantify.

It can be concluded that non of the above methodologies provides a simple, easy and general way to evaluate economical losses due to power quality problems in a target industry.

In the next chapters a new methodology will be developed, this methodology will not deal with the calculation of the tehcnical consequences of the power quality on the industry but on the economical consequences of this lack of power quality.

Chapter 3

Proposing a new methodology

3.1 Introduction

This work proposes to separate the technical evaluation of the consequences of the lack of power quality from the economical evaluation of those losses see figure 3.1.

Therefore the work will be divided in two different parts:

1. First one will consist in develop a methodology for calculating the hours of non production with the input of the kind of industry and the voltage sag or short interruption signal.
2. Second one will consist in develop a methodology for calculating the losses with the input of the kind of industry and the hours of non production.

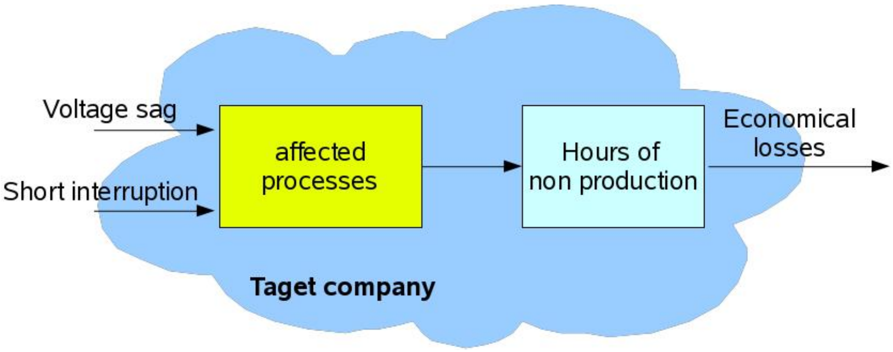


Figure 3.1: How to evaluate losses because of power quality issues in a target industry

3.2 Hours of non production

The inputs to this section are the function of voltage sags and short interruptions and the output is the hours of non production of the target industry.

ESTA SECCIÓN TODAVIA NO ESTÁ PLANTEADA!!!

3.3 Economical losses

The methodology proposed in this point is based on the evaluation of power loses as benefit not produced. The benefit produced by the different activities which composed the economical system in Spain is evaluated and accounted by the Spanish National Countability (CNE)[1] system. The CNE provides a list of parameters which conforms basic statistics. The data used for constructing these statistics are provided by different sources which are confronted by a single countable frame.

The statistics are given annually, but three times a year the estimations are examined and evaluated until they became definitive. All this proceeding targets to obtain a reliable source of data to estimate the national accounts, in an effective and reliable way. The statistics are gathered together in three groups of activity branches disaggregation.

The given data depends on the degree of disaggregation of the activity branches, listed below:

5 activity branches disaggregation The data provided in this case is used in calculation of the added value at basic prices (current prices and volume variations) and total employment in the estimations with advance character (A) and first estimation character (1E).

22 activity branches disaggregation The data provided is used for the variation of volume of the gross added value at basic prices in the definitive and provisional estimations.

27 activity branches disaggregation The data provided is used for the added value at basic prices (current prices), remuneration of salaries, gross exploitation surplus / gross income and total employment calculation in the definitive and provisional estimations.

Based on the statistical information provided by the 27 activity branches disaggregation, the benefit per hour of the different activity branches is provided. This benefit per hour can also represent the lack of benefit (or losses) if one hour the activity stops. Therefore, the lack of energy supply would produce the activity to stop and therefore produce those losses.

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[1] www.ine.es

3.3.1 Mathematical model

The mathematical model proposed will be defined as follows:

$$[A] = [B] \cdot [C] \cdot [D] \tag{3.1}$$

Where:

[A] is the matrix of economical losses.

[B] is the matrix of time interruption in power supply.

[C] is the matrix of VoLL (Value of Lost Load).

[D] is the matrix of lost power.

Matrix B can be formulated from the data available by the statistics of the Spanish government as well as Matrix C. First one based on parametres of the power sector and second one on parameters directly taken from the industry. Non of this data are affected by confidentiality issues and are free downloadable directly from the government's website. This is the main advantage of this methodology.

3.3.2 Boundary conditions

The statistical information available does not provided data for calculating the losses due to recovery process after a short interruption or sag. Therefore, the methodology proposed does not include partial loses. The production in the industry is also evaluated as constant per hour, not considering different impacts of an interruption or sag at different hours.

3.3.3 Example of application

An example of application of the methodology is provided as follows for the evaluation of losses in five representative regions in Spain: Andalucía, Cataluña, Galicia, Madrid and País Vasco during the year 2006.

As data input for the mathematical model the equivalent time of interruption of middle voltage (1kV $<$V $\leq$ 36kV) transmission service (in Spain called TIEPI) will be used. This data is provided by the statistics database of the Spanish Ministry of Industry[2].

With the data of the production of the industry in those regions for the year studied and the equivalent interruption time for every one of those regions, an aproximative calculation of losses for the industry of those regions can be performed.

Although the problem can be mathematically solved, the results can not be validated with real data from the Spanish industry since there is no single study providing reliable data of this economic evaluation.

The validation of this methodology will be done based on particular cases and facing therefore an error depending on the deviation of the model from the average data provided by the Spanish government statistical data.

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[2] www.mityc.es

Equivalent interruption time data

The TIEPI is defined as:

$$TIEPI = \frac{\sum_{i=1}^{K}(PIi * Hi)}{\sum(PI)} \tag{3.2}$$

Where:

PIi is the installed power in the MV/LV transformer plus the contracted power in MV, which is affected by the interruption i with a H duration.

Hi interruption time of the supply that affects the power PIi.

K number of interruptions during the periode.

$\sum PI$ total installed power in the MV/LV transformer plus the contracted power in MV.

The interruptions considered are those larger than 3min. The data recollected concerning to the value of TIEPI for the 5 regions studied are given in table 3.1. Data from every region has been divided in 4 different zones: urban (more than 20,000 supplies), semiurban (between 2,000 and 20,000 supplies), rural concentrated (between 200 and 2,000 supplies), rural dispersed (less than 200 supplies).

The TIEPI 80% is the reference used by the Spanish government in order to valorate the deviation in TIEPIs of the different communities. It is the boundary permited by the system and no zone in Spain is allowed go over this TIEPI 80% for more than two consecutives years. The data of the TIEPI 80% is given in table 3.2.

Table 3.1: 2006 TIEPI

ZONE	Catalunya	Galicia	Andalucia	Madrid	Euskadi
Urban	1.13	0.67	1.27	0.98	0.88
Semiurban	1.91	3.32	2.15	2.01	1.76
Rural concentrated	2.94	5.86	4.69	3.84	4.23
Rural dispersed	3.69	3.66	5.75	6.52	13.12
Total	1.78	2.62	2.38	1.26	1.89

Source: Statistical data of the Spanish Ministry of Industry.
Dowloadable from: *https://oficinavirtual.mityc.es/eee/indiceCalidad/ccaa2.aspx*

Table 3.2: Limits of the TIEPI 80% for 2006

ZONE	TIEPI 80%
Urban	3
Semiurban	6
Rural concentrated	12
Rural dispersed	18

Source: Real Decreto 1955/2000, de 1 de diciembre.

Number of equivalent interruptions of the power supply

The number of equivalent interruptions of the power supply (NIEPI) is defined as:

$$NIEPI = \frac{\sum_{i=1}^{K}(PIi)}{\sum(PI)} \tag{3.3}$$

Where:

PIi is the installed power in the MV/LV transformer plus the contracted power in MV, which is affected by the interruption i with a H duration.

K number of interruptions during the periode.

$\sum PI$ total installed power in the MV/LV transformer plus the contracted power in MV.

The interruptions considered are those larger than 3min. The NIEPI data for the different regions analysed is given in table 3.3.

Table 3.3: 2006 NIEPI

ZONE	Catalunya	Galicia	Andalucia	Madrid	Euskadi
Urban	1.63	1.06	1.79	1.62	0.78
Semiurban	2.12	3.38	2.83	3.06	1.24
Rural concentrated	2.66	5.24	5.18	5.80	1.93
Rural dispersed	2.75	3.03	5.26	6.57	4.73
Total	2.00	2.72	2.82	2.01	1.20

Source: Statistical data of the Spanish Ministry of Industry.
Dowloadable from: *https://oficinavirtual.mityc.es/eee/indiceCalidad/ccaa2.aspx*

Average duration of power interruptions

The average duration of power interruptions is usually evaluated with the indice CAIDI. An estimation of the CAIDI average value with no major event days can be considered as 53.57min, see reference [3].

The average value of this indice could be estimated as:

$$CAIDI = \frac{NIEPI}{TIEPI} \tag{3.4}$$

The result of the calculation is given in table 3.4.

Table 3.4: 2006 CAIDI

ZONE	INTERRUPTION DURATION [hours]				
	Catalunya	Galicia	Andalucia	Madrid	Euskadi
Urban	1.44	1.58	1.41	1.65	0.89
Semiurban	1.12	1.02	1.32	1.52	0.70
Rural concentrated	0.90	0.89	1.10	1.51	0.46
Rural dispersed	0.75	0.83	0.91	1.01	0.36
Total	1.12	1.04	1.14	1.60	0.63

Limitation of the power interruptions number and duration

The Spanish law limites the number of hours and number of interruptions in MV and LV, as given in table 3.5

Table 3.5: Limits of duration and number of interruptions for 2006

ZONE	MV		LV	
	Hours	Interruptions	Hours	Interruptions
Urban	3.5	7	5	10
Semiurban	7	11	9	13
Rural concentrated	11	14	14	16
Rural dispersed	15	19	19	22

None of the CAIDI presented in table 3.4 exceeds the allowed limits. Therefore all of them will be subjected to the calculation. If one of them would be above limits, then it should be subjected to special consideration since there is a financial aid from the government for theses cases.

Matrix B

Matrix B is constructed based on the data of the CAIDI calculated coeficient.

$$[B] = \left(\begin{array}{cccc|c} \textit{urban} & \textit{semiurban} & \textit{rural concentrated} & \textit{rural dispersed} & \textit{total} \end{array} \right)$$

In the studied case, $Matrix\ B$ would correspond to:

$$[B] = \begin{pmatrix} Catalunya \\ Galicia \\ Andalucia \\ Madrid \\ Euskadi \end{pmatrix} = \left(\begin{array}{cccc|c} 1.44 & 1.58 & 1.41 & 1.65 & 0.89 \\ 1.12 & 1.02 & 1.32 & 1.52 & 0.70 \\ 0.90 & 0.89 & 1.10 & 1.51 & 0.46 \\ 0.75 & 0.83 & 0.91 & 1.01 & 0.36 \\ 1.12 & 1.04 & 1.14 & 1.60 & 0.63 \end{array} \right)$$

Added value in current prices

The added value of the production of the Spanish industry per year and in current prices will be obtained from the statistics of the Spanish government.

In the present case the data for the different sectors considerated: agriculture, energy, industry, construction and services is presented in table 3.6 for the 5 regions considered and for the year 2006.

Those industry sectors and subsectors in order to apply the different TIEPIs has to be refered to a zone, meaning: urban, semi-urban, rural concentrated and rural dispersed.

The correspondence between those areas is not direct but it will be assumed as follows:

1. Agriculture can be considered as mainly rural dispersed but fishing could be considered as rural concentrated.
2. In the energy sector, extraction of fuels could be considered rural dispersed but power industry, water and gas are mainly urban or semi-urban. Therefore it will be divided in between the two sectors 50% and 50%.
3. The industry sector is mainly urban and semi-urban. Also 50 % and 50%.
4. The construction sector has afected all the zones. It will be divided in the four different zones 25% for each.
5. The services sector is also spread over the four different zones but maily urban and semi-urban. Also 50% for each.

While accepting these assumptions, table 3.6 can be redivided in zones instead of sectors, see on table 3.7.

Table 3.6: 2006 Spanish regional contability data. Added value in current prices (in thousands of euros).

SECTOR	SUBSECTOR	CATALUNYA	GALICIA	ANDALUCIA	MADRID	EUSKADI
Agriculture sector		2,518,548	2,282,502	5,723,366	285,665	641,463
	Agriculture	2,394,762	1,503,001	5,448,237	275,858	555,455
	Fishing	123,786	779,501	275,129	9,807	86,008
Energy sector		3,301,912	1,754,792	3,297,258	3,892,279	1,977,288
	Extraction of fuels	871,840	480,211	1,317,204	230,039	466,616
	Power industry, water and gas	2,430,072	1,274,581	1,980,054	3,662,240	1,510,672
Industry sector		33,833,907	6,905,038	11,090,408	17,053,475	13,971,032
	Food, drink and tobacco	3,740,877	1,043,146	2,757,419	1,298,326	835,504
	Textil	2,330,313	469,878	380,242	497,447	82,697
	Wood and cork	496,732	396,098	276,038	195,559	167,612
	Paper	3,595,048	412,668	613,954	3,514,296	754,048
	Chemical	5,386,937	281,226	870,249	2,232,961	614,403
	Plastics	1,581,521	166,227	209,541	440,611	986,631
	Mineral products no metals	1,708,354	562,541	1,385,756	918,427	477,668
	Metals	4,594,255	1,243,193	1,934,358	1,987,423	5,510,673
	Mechanic	2,717,061	307,766	466,130	1,201,357	1,948,362
	Electric equipment	2,579,821	245,738	523,749	1,963,023	704,513
	Transportation material	3,624,319	1,514,835	955,824	2,095,280	1,376,267
	Manufacture diverse	1,478,669	261,722	717,148	708,765	512,654
Construction sector		17,228,046	6,125,246	17,940,269	16,615,353	5,404,325
Services		106,905,646	27,783,089	82,852,875	117,053,082	31,997,090
	Commerce and reparations	18,839,545	4,437,806	13,170,558	16,763,527	5,016,729
	Hotels	11,929,357	2,625,691	8,585,019	9,907,416	3,311,496
	Transportation and communications	11,529,823	2,339,777	6,790,625	16,341,719	3,311,780
	Financial intermediary	8,021,935	1,760,524	4,678,393	10,833,345	2,414,995
	Real state agencies	28,864,734	6,508,262	20,786,877	32,039,952	7,462,809
	Public administration	6,309,109	2,934,203	8,774,828	9,912,326	2,940,659
	Education	6,203,173	2,498,935	7,040,890	5,874,474	2,551,404
	Sanitary and social services	8,201,2006	2,684,610	7,429,656	7,045,877	2,942,144
	Other services	5,838,693	1,593,287	4,525,198	6,366,990	1,716,647
	Domestic service	1,167,702	399,994	1,070,831	1,967,456	328,427
Total Gross Added Value		163,788,059	44,850,667	120,904,176	154,899,854	53,991,198

Table 3.7: Zonal added value in current prices (in thousands of euros) for 2006

ZONE	CATALUNYA	GALICIA	ANDALUCIA	MADRID	EUSKADI
Urban	75,891,824	19,512,666	52,446,736	73,038,237	25,090,478
Semi-urban	75,891,824	19,512,666	52,446,736	73,038,237	25,090,478
Rural concentrated	4,430,798	2,310,813	4,760,196	4,163,645	1,437,089
Rural dispersed	7,573,614	3,514,524	11,250,508	4,659,735	2,373,152
Total Gross Added Value	163,788,059	44,850,667	120,904,176	154,899,854	53,991,198

Annual energy consumption per regions

The data of the annual energy consumption per regions is available in the statistics published by REE, see on table 3.8.

Table 3.8: Energy demand per regions for 2006 [GWh]

CATALUNYA	GALICIA	ANDALUCIA	MADRID	EUSKADI
46,379	19,082	38,926	30,468	20,703

Peak power demand [MVA] per zones and regions

The peak power demand per zones and regions is given in 3.9

Table 3.9: Peak power demand in 2006

ZONE	Peak demand [MVA]				
	Catalunya	Galicia	Andalucia	Madrid	Euskadi
Urban	12,409.95	2,285.73	9,512.82	11,536.26	2,559.59
Semiurban	7,914.41	2,883.55	6,525.72	2,714.81	2,971.67
Rural concentrated	2,169.67	724.79	1,203.58	435.2	1,063.59
Rural dispersed	2,467.76	78.79	2,847.65	15.8	45.41
Total	24,961.79	5,972.86	20,089.77	14,702.07	6,640.26

Annual energy consumption per regions per zones

The distribution per zones will be done by supposing the same distribution of energy consumption as for power demand, see on table 3.10.

Value of Lost Load (VoLL)

The VoLL represents the losses per hour of energy not supplied.

$$VoLL = \frac{GeneratedAddedValue[e]}{Energyconsumed[kWh]} \tag{3.5}$$

Table 3.10: Energy consumption in 2006 [GWh]

ZONE	CATALUNYA	GALICIA	ANDALUCIA	MADRID	EUSKADI
Urban	23,057.68	7,302.41	18,432.06	23,907.29	7,980.28
Semi-urban	14,704.97	9,212.32	12,644.25	5,626.06	9,265.07
Rural concentrated	4,031.24	2,315.54	2,332.06	901.89	3,316.06
Rural dispersed	4,585.09	251.71	5,517.61	32.74	141.57
Total	46,379	19,082	38,926	30,468	20,703

Matrix C

The matrix C correspondes to the VoLL per zone and per region.

The result of this calculation is provided in *Matrix C*.

$$[C] = \left(\begin{array}{c} Urban \\ Semi-urban \\ Rural\ concentrated \\ Rural\ dispersed \\ \hline Total \end{array}\right)$$

$$\begin{array}{c} \begin{array}{ccccc} Catalunya & Galicia & Andalucia & Madrid & Euskadi \end{array} \\ [C] = \left(\begin{array}{ccccc} 3.29 & 2.67 & 2.85 & 3.06 & 3.14 \\ 5.16 & 2.12 & 4.15 & 12.98 & 2.71 \\ 1.1 & 1 & 2.04 & 4.62 & 0.43 \\ 1.65 & 13.96 & 2.04 & 142.33 & 16.76 \\ \hline 3.53 & 2.35 & 3.11 & 5.08 & 2.61 \end{array}\right) \end{array}$$

Matrix D

Corresponds to the load lost, since the worst case would be to loose supply when the peak power is required, matrix D will represent the peak power.

$$[D] = \left(\begin{array}{c} Urban \\ Semi-urban \\ Rural\ concentrated \\ Rural\ dispersed \\ \hline Total \end{array}\right)$$

$$\begin{array}{c} \begin{array}{ccccc} Catalunya & Galicia & Andalucia & Madrid & Euskadi \end{array} \\ [D] = \left(\begin{array}{ccccc} 12,409.95 & 2,285.73 & 9,512.82 & 11,536.26 & 2,559.59 \\ 7,914.41 & 2,883.55 & 6,525.72 & 2,714.81 & 2,971.67 \\ 2,169.67 & 724.79 & 1,203.58 & 435.2 & 1,063.59 \\ 2,467.76 & 78.79 & 2,847.65 & 15.8 & 45.41 \\ \hline 24,961.79 & 5,972.86 & 20,089.77 & 14,702.07 & 6,640.26 \end{array}\right) \end{array}$$

Matrix A

The calculation of the *Matrix A* (matrix of losses) is done by applying equation 3.1.

$$[A] = \begin{pmatrix} Catalunya \\ Galicia \\ Andalucia \\ Madrid \\ Euskadi \end{pmatrix} = \left(\begin{array}{ccccc|c} 109,769.14 & X & X & X & X & 98,731.240 \\ X & 17,436.76 & X & X & X & 14,600.260 \\ X & X & 81,881.49 & X & X & 71,134.670 \\ X & X & X & 117,028.49 & X & 119,592.93 \\ X & X & X & X & 13,281.59 & 10,909.760 \end{array}\right)$$

Matrix A shows in the left side the calculation of losses for every region analysed taking into account the different TIEPIs for urban, semi-urban, rural concetrated and rural dispersed. On the right side it shows the losses applying the average TIEPIs given by the government.

Results

The total results of the calculation for every zone and for every region are given in 3.11.

Table 3.11: Results of the calculation for the diferent zones and regions in 2006 [k€]

ZONE	CATALUNYA	GALICIA	ANDALUCIA	MADRID	EUSKADI
Urban	58,818.22	9,650.11	38,165.67	58,152.56	7,162.27
Semi-urban	45,747.50	6,229.81	35,729.56	53,570.90	5,633.24
Rural concentrated	2,146.24	643.74	2,702.41	3,033.79	212.02
Rural dispersed	3,057.16	913.09	5,283.83	2,271.22	274.03
Total	109,769.14	17,436.76	81,881.49	117,028.49	13,281.59
Using average data	98,731.24	14,600.26	71,134.67	119,592.93	10,909.76

3.3.4 Analysis of results

The results obtained in *Matrix A* are the losses in thousands of Euros for every region analyzed on one side applyng different TIEPIs depending on the zone (rural or urban) and and on the other side just applying the average numbers for TIEPI and production given by the Spanish government. Table 3.12 shows the results.

The accurary of the calculation is heavily depending on the TIEPI on rural zones. Some of the regions which are mainly based on urban and semi-urban industry, are penalized by higher TIEPI in rural zones. This fact directly impacts on a much higher losses than expected. This achieve an extreme in the case of the Madrid region but also can be seen in the case of Euskadi. On the contrary, in more rural regions like Galicia and Andalucia the losses that could be predicted by using average numbers are higher than the losses calculated with a more accurated mathematical model. In the case of Catalunya, it seems that rural and urban are treated similar –In other words, the differences between

Table 3.12: Results: losses per region in thousends of euros

REGION	LOSSES [k€]	
	TIEPI/NIEPI depending on area	Average value for TIEPI/NIEPI
Catalunya	109,769.14	98,731.24
Galicia	17,436.76	14,600.26
Andalucia	81,881.49	71,134.67
Madrid	117,028.49	119,592.93
Euskadi.	13,281.59	10,909.76

urban and rural TIEPIs are not as extreme as in Madrid or Euskadi–. Therefore the losses calculated by applying different TIEPIs are pretty consistents with the calculation done by using the average data of the government.

3.4 Conclusions

This chapter has developed a new methodology for calculating the losses of an industry due to voltage sags and short interruptions.

FALTAN LAS CONCLUSIONES SOBRE LA SECCIÓN DE HORAS NO PRODUCIDAS

The calculation of economical losses are based on data provided by the statistics of the Spanish government, which are both downladable and free of confidentiality issues. An example of application of this calculation has also been provided for 5 regions in Spain. This example takes into account the calculation based on average data directly retrieved from the statistics and a second calculation where the location of the industry has been taking into account.

The methodology is easy to apply and can be used for any industry, in the example provided for the Spanish industry the data of the Spanish government has been used, but the same methodology would apply for the rest of the European territory.

In the next chapter the validation of the methodology will be presented.

Chapter 4

Validation of the methodology

4.1 Introduction

In this chapter a theoretical validation of the methodology is proposed.

There are four different basic methodologies (based on references [9], [6]) for valuating the economical damage of power interruptions for the economical development of a region.

Surveys/interviews . This evaluation is based on the WTP and WTA methodologies.

Productions-function approach . This is based on estimating the consequences of the outages through a lost of production. The methodology developed in this work can be framed in this point.

Market behaviour . It is an indirect methodology based on analysing the expenditures on backup facilities and use of interruptible contracts. Although, it could be considered as part of WTA methodology.

Case studies . The direct analysis of a case. The problem of this methodology is dealing with confidential information of the company.

The validation of the proposed mehtodology is done in the following sections. The validation is done using three different methodologies. The two first are based on surveys. Although, the interruption cost estimates obtained from the survey respondents vary widely for different customers and with different interruption related characteristics, such as interruption duration, frequency, time of occurrence, etc. The third validation is based on a productions-function approach methodology.

4.2 Validation using the IEEE-reliability test system (IEEE-RTS) data

Reference [10] gives a comprehensive state of the art of the economical evaluation of interruptions. Defining a customer damage function which indentifies the losses per customer depending on the lenght of the interruption. It also estimates the interruption cost expressed as $/kW of annual peak demand see table 4.1 per different sectors as result of the aplication of the IEEE-reliability test system (IEEE-RTS). Since the paper was publish in september 2005 and the data being treated is from 2006, the value of the money must be updated in order to make the validation reliable.

Table 4.1: Sector interruption cost estimates experessed as $/kW of annual peak demand

SECTOR	INTERRUPTION DURATION [hours]				
	1min	20min	1h	4h	8h
Large users	1.005	1.508	2.225	3.968	8.240
Industrial	1.625	3.868	9.085	25.163	55.808
Commercial	0.381	2.979	8.552	31.317	83.008
Agricultural	0.060	0.343	0.649	2.064	4.120
Residential	0.001	0.093	0.482	4.914	15.690
Govt. and inst.	0.044	0.369	1.492	6.558	26.040
Off and bldg.	4.778	9.878	21.065	68.830	119.160

4.2.1 Data for the validation

In order to validate the results given in chapter 3, the data provided must be adapted to be compared with the data from the IEEE-reliability test system (IEEE-RTS).

Peak power demand

The annual peak demand in Spain in 2006 was 42,153MW see reference [4]. The data available from the statistics of the Spanish government are refered to the contracted power of the companies. It will be assumed that this contracted power is coincident with the peak power demand for every sector. Table 3.10 showed the peak power demand per zone in the 5 regions analyzed in 2006.

4.2.2 Application of the IEEE-RTS

In order to validate the results obtained in chapter 3, table 4.1 must be updated to current €, and adapted to the 4 zones defined by the Spanish government statistics: Urban, semiurban, rural concentrated, rural dispersed. The type of companies which are majority in the urban sector will be industrial and commercial. The type of companies for the semiurban will be large users and industrial.

For rural concentrated commertial and agricultural. For rural dispersed mostly agricultural.

The values of the column IEEE-RTS are calculated using linear interpolation from the data of table 4.1 entering with the CAIDI data. The results are translated from 2005 dolars to current euros. The peak power column is the value of the sector divided in equal parts beetween the raws.

Tables of losses for the different regions

The losses of the different regions using the data based on IEEE-RTS are given in tables 4.2, 4.3, 4.4, 4.5 and 4.6. In order to make the comparison feasible and since the peak power data provided by the statistics was per zones and not kind of customers, it has been assumed a equal distribution of installed power in every zone for the 4 kind of users: industrial, large users, commercial and agricultural. The error derived of this assumption is expected to be low.

Table 4.2: 2006 Losses for Region 1: Catalunya

SECTOR	SUBSECTOR	CAIDI [hours]	IEEE-RTS data [$/kW]	DEFLATOR [€/kW]	PEAK POWER [MW]	LOSSES [k€]
Urban	Industrial	1.44	11.443	9.00	6,204.975	55,829.02
	Commercial	1.44	11.890	9.35	6,204.975	58,009.88
Semiurban	Large users	1.12	2.294	1.80	3,957.205	7,137.76
	Industrial	1.12	9.567	7.52	3,957.205	29,767.64
Rural concentrated	Commercial	0.90	7.758	6.1	1,084.835	6,617.49
	Agricultural	0.90	0.602	0.47	1,084.835	513,5
Rural dispersed	Agricultural	0.75	0.536	0.42	2,467.76	1,040.03
Total						158,915.32

Table 4.3: 2006 Losses for Region 2: Galicia

SECTOR	SUBSECTOR	CAIDI [hours]	IEEE-RTS data [$/kW]	DEFLATOR [€/kW]	PEAK POWER [MW]	LOSSES [k€]
Urban	Industrial	1.58	12.190	9.58	1,142.865	10,954.15
	Commercial	1.58	20.541	16.15	1,142.865	18,458.51
Semiurban	Large users	1.02	2.23	1.75	1,441.775	2,528.03
	Industrial	1.02	2.23	1.75	1,441.775	2,528.03
Rural concentrated	Commercial	0.89	7.818	5.57	362.395	2,017.93
	Agricultural	0.89	0.600	0.47	362.395	170,97
Rural dispersed	Agricultural	0.83	0.599	0.47	78.79	37,11
Total						36,694.73

Table 4.4: 2006 Losses for Region 3: Andalucia

SECTOR	SUBSECTOR	CAIDI [hours]	IEEE-RTS data [$/kW]	DEFLATOR [€/kW]	PEAK POWER [MW]	LOSSES [k€]
Urban	Industrial	1.41	11.282	8.87	4,756.41	42193.48
	Commercial	1.41	11.663	9.17	4,756.41	43618.38
Semiurban	Large users	1.32	2.410	1.89	3,262.86	6182.94
	Industrial	1.32	10.799	8.49	3,262.86	27705.24
Rural concentrated	Commercial	1.10	9.310	7.32	601.79	4405.29
	Agricultural	1.10	0.696	0.55	601.79	329.33
Rural dispersed	Agricultural	0.91	0.600	0.47	2,847.65	1343.43
Total					125778.13	

Table 4.5: 2006 Losses for Region 4: Madrid

SECTOR	SUBSECTOR	CAIDI [hours]	IEEE-RTS data [$/kW]	DEFLATOR [€/kW]	PEAK POWER [MW]	LOSSES [k€]
Urban	Industrial	1.65	11.349	8.92	5,768.13	51472.19
	Commercial	1.65	13.464	10.59	5,768.13	61064.55
Semiurban	Large users	1.52	2.527	1.99	1,357.405	2697.08
	Industrial	1.52	11.871	9.33	1,357.405	12670.01
Rural concentrated	Commercial	1.51	12.422	9.77	217.6	2125.35
	Agricultural	1.51	1.361	1.07	217.6	232.86
Rural dispersed	Agricultural	1.01	0.650	0.51	15.8	8.08
Total						130270.13

Table 4.6: 2006 Losses for Region 5: Euskadi

SECTOR	SUBSECTOR	CAIDI [hours]	IEEE-RTS data [$/kW]	DEFLATOR [€/kW]	PEAK POWER [MW]	LOSSES [k€]
Urban	Industrial	0.89	8.254	6.49	1,279.795	8305.86
	Commercial	0.89	7.665	6.03	1,279.795	7714.09
Semiurban	Large users	0.70	2.003	1.57	1,485.835	2340.08
	Industrial	0.70	7.471	5.87	1,485.835	8728.29
Rural concentrated	Commercial	0.46	4.066	3.20	531.795	1700.16
	Agricultural	0.46	0.404	0.32	531.795	168.93
Rural dispersed	Agricultural	0.36	0.343	0.27	45.41	12.24
Total						28969.69

4.2.3 Comparison of results

In this section a comparison of the results obtained by the methodology developed in chapter 3 and the validation proposed in this point is provided, see on table 4.7 using data from every zone.and table 4.8 using average data for the different regions.

Table 4.7: Comparison of results obtained calculating data per zone and region in thousends of euros

REGION	LOSSES [k€]		DEVIATION
	Methodology developed [k€]	IEEE-RTS methodology [k€]	[%]
Catalunya	109,769.14	158,915.32	30
Galicia	17,436.76	36,694.73	52
Andalucia	81,881.49	125,778.13	34
Madrid	117,028.49	130,270.13	10
Euskadi	13,281.59	28,969.69	54
Average deviation			36

Table 4.8: Comparison of results obtained with average data per region in thousends of euros

REGION	LOSSES [k€]		DEVIATION
	Methodology developed [k€]	IEEE-RTS methodology [k€]	[%]
Catalunya	98,731.24	158,915.32	37
Galicia	14,600.26	36,694.73	60
Andalucia	71,134.67	125,778.13	43
Madrid	119,592.93	130,270.13	8
Euskadi	10,909.76	28,969.69	62
Average deviation			42

4.3 Validation using data from a survey performed by EPRI and Duke Power Company

Most of data available of interruption costs are from surveys. One of those surveys was performed on a random sample of three different kind of customers: residential (1584), large industrial and commercial (210) and small and medium industrial and commercial (1080). The interruption lasted one hour. The study is available in reference [19]. The results of the survey regarding to the costs of the outage are given in table 4.9. The cost is evaluated in 1992 dollars and must be updated to current euros.

Since the data is only for a 1hour duration interruption, the validation performed can only be a rought approximation. The deviation is expected to be high.

Table 4.9: Customer outage cost per type of customer

MARKET SEGMENT	MEAN OUTAGE COSTS	
	[$(1992)/kWpeak]	[€(current)/kWpeak]
Residential customers	2.07	1.51
Commercial customers	45.82	33.45
Industrial customers	7.61	5.55

4.3.1 Data for the validation

The data of peak power demand see table 4.10. The data of power peak is base on the power distribution of peak power presented in tables 4.2, 4.3, 4.4, 4.5 and 4.6.

Table 4.10: Peak power demand for industrial and commercial customers for every region

MARKET SEGMENT	INSTALLED POWER PER REGION [MWpeak]				
	Catalunya	Galicia	Andalucia	Madrid	Euskadi
Commercial customers	10,162.18	2,584.64	8,019.27	7,125.535	2,765.63
Industrial customers	11,247.015	2,947.035	8,621.06	7,343.135	3,297.425

4.3.2 Comparison of results

In this section a comparison of the results obtained by the methodology developed in chapter 3 and the validation proposed in this point is provided, see on table 4.11 using data from every zone.and table 4.12 using average data for the different regions.

Table 4.11: Comparison of results obtained applying survey data and calculating data per zone and region in thousends of euros

REGION	LOSSES [k€]		DEVIATION
	Methodology developed [k€]	EPRI survey data [k€]	[%]
Catalunya	109,769.14	402,345.85	72
Galicia	17,436.76	102,812.25	83
Andalucia	81,881.49	316,091.46	74
Madrid	117,028.49	279,103.55	58
Euskadi	13,281.59	110,811.03	88
Average deviation			75

Table 4.12: Comparison of results obtained with average data per region in thousends of euros

REGION	LOSSES [k€]		DEVIATION
	Methodology developed [k€]	EPRI survey data [k€]	[%]
Catalunya	98,731.24	402,345.85	75
Galicia	14,600.26	102,812.25	85
Andalucia	71,134.67	316,091.46	77
Madrid	119,592.93	279,103.55	57
Euskadi	10,909.76	110,811.03	90
Average deviation			77

4.4 Validation using a productions-function approach

Reference [9] evaluates the cost of interruptions in terms of lost of production for the industry. It uses the Value of Lost Load (VoLL) variable, calculated by dividing the added value generated by a determined activity between the energy consumption used for this activity, see on table 4.13. It has to be taken into account that the results are valid only for the Netherlands industry.

Table 4.13: Value of Lost Load (VoLL) for the Netherlands industry

ACTIVITY	VoLL	
	[€(2007)/kWh]	[€(current)/kWh]
Agriculture	3.90	2.67
Energy sector	-0.32	-
Manufacturing	1.87	1.28
Construction	33.05	22.64
Transport	12.42	-
Services	7.94	5.44
Government	33.50	-
Firms and government	5.97	-
Households	16.38	-
Firmes, government and households	8.56	-

The VoLL is considered as a constant function and does not depend on the lenght of the interruption. In order to make the comparison feasible an hour interruption will be considered.

4.4.1 Data for the validation

The validation will be done only for industries, services and agriculture, using the distribution of peak power of tables 4.2, 4.3, 4.4, 4.5 and 4.6. Table 4.14 is the share of peak power for the activities defined by 4.13. Since it would be difficult to exactly define which peak power has every one of these activities, the error of considering an equal distribution among activities will be assumed.

Table 4.14: Peak power distribution per regions

ACTIVITY	REGION				
	Catalunya	Galicia	Andalucia	Madrid	Pais Vasco
Agriculture	3,552.595	441.185	3,449.44	233.4	577.21
Manufacturing	7,059.69	2,013.207	5,641.065	4,241.47	2,128.73
Construction	7,059.69	2,013.207	5,641.065	4,241.47	2,128.73
Services	7,289.81	1,505.26	5,358.2	5,985.73	1,811.59

4.4.2 Calculation of losses

In the worst case this peak power can be sustended during one hour of interruption. Therefore the units of peak power [MVA] are directly converted to energy units [MVAh] but the value remains the same for the calculation on table 4.15. Since the VoLL values are in €/kWh].

Table 4.15: Losses per type of industry and region

ACTIVITY	LOSSES m€				
	Catalunya	Galicia	Andalucia	Madrid	Pais Vasco
Agriculture	9485.42	1177.96	9210.00	623.17	1541.15
Manufacturing	9036.40	2576.90	7220.56	5429.08	2724.77
Construction	159831.38	45579.00	2891438.39	96026.88	48194.44
Services	39656.56	8188.61	29148.60	32562.37	9855.04
Total	218009.78	57522.48	173292.88	134,641.51	62315.42

4.4.3 Comparison of results

In this section a comparison of the results obtained by the methodology developed in chapter 3 and the validation proposed in this point is provided, see on table 4.16 using data from every zone.and table 4.17 using average data for the different regions.

4.5 Conclusions

Table 4.16: Comparison of results obtained applying survey data and calculating data per zone and region in thousends of euros

REGION	LOSSES [k€]		DEVIATION
	Methodology developed [k€]	Productions-Function approach [k€]	[%]
Catalunya	109,769.14	218,009.78	49
Galicia	17,436.76	57,522.48	69
Andalucia	81,881.49	173,292.88	52
Madrid	117,028.49	134,641.51	13
Euskadi	13,281.59	62,315.42	78
Average deviation			52

Table 4.17: Comparison of results obtained with average data per region in thousends of euros

REGION	LOSSES [k€]		DEVIATION
	Methodology developed [k€]	Productions-Function approach [k€]	[%]
Catalunya	98,731.24	218,009.78	54
Galicia	14,600.26	57,522.48	74
Andalucia	71,134.67	173,292.88	58
Madrid	119,592.93	134,641.51	11
Euskadi	10,909.76	62,315.42	82
Average deviation			56

Chapter 5

Comparison of the VoLL variable in the European environment

5.1 Introduction

In this chapter the VoLL variable for 15 European countries will be calculated and compared. After that, from these countries 7 will be selected. For the selected countries the related VoLL variable for industry, tranportation, services and households will be also calculated and compared.

5.2 VoLL variable for 15 countries in the European region

The countries chosen for this evaluation are Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Slovenia and Spain. The data required for the VoLL evaluation are Value Added at current prices and electricity consumption, both of them have been obtained from the statistics of the Eurostat agency and all the information is available and freely downloadable from their website.

5.2.1 Gross Domestic Product (GDP)

The GDP breakdown at current prices from the periode 1997 to 2007 for the selected countries is given in tables 5.1 and 5.2.

Table 5.1: GDP/breakdown at current prices in euros for the periode from 1997 to 2002

COUNTRY	YEAR						
	1996	1997	1998	1999	2000	2001	2002
Austria	161194392000	164855523000	171649646000	177487473000	186587173000	192038134000	197688158000
Belgium	189407500000	197605000000	205042700000	211972800000	223811900000	231458300000	239016500000
Cyprus	6847592660	7239700000	7869500000	8465900000	9147300000	9778200000	10035300000
Finland	86369000000	92913000000	101369000000	106213000000	115154000000	122484000000	125615000000
France	1098172291129	1129379262795	1175397983340	1219982000000	1290744000000	1344658000000	1392586000000
Germany	1697890000000	1734860000000	1778060000000	1810270000000	1856200000000	1904490000000	1933190000000
Greece	88562869299	97604104664	106314225980	111683202952	120382119000	128968511000	139115221000
Ireland	52575069200	60549068000	71213499600	80758512500	93976327100	105361677600	116445554800
Italy	906885870000	942436210000	975486740000	1005406610000	1064036710000	1122976780000	1165418780000
Luxembourg	14333823600	14762761000	15633530000	17827305000	19623334000	20273065000	21542155000
Malta	2778129513	2916794782	3112385278	3232720708	3518989052	3553053809	3732357326
Netherlands	287079000000	306539000000	324027000000	344335000000	373415000000	397556000000	414374000000
Portugal	79110600000	85662400000	92639300000	98991300000	106544900000	112817200000	117751000000
Slovenia	10216158925	11724603594	12930328924	14444000679	16091745524	18062356384	20145909920
Spain	436095960538	461682000000	491716000000	525075000000	570560000000	618252000000	661517000000

Table 5.2: GDP/breakdown at current prices in euros for the periode from 2002 to 2007

COUNTRY	YEAR				
	2003	2004	2005	2006	2007
Austria	202017374000	209949461000	220284221000	232903576000	245200053000
Belgium	245754700000	257703100000	268862100000	283059800000	297900300000
Cyprus	10638800000	11414500000	12106900000	12933900000	13818000000
Finland	126530000000	132516000000	136423000000	145023000000	156912000000
France	1434812000000	1490230000000	1547758000000	1614340000000	1697406600000
Germany	1949410000000	1998360000000	2024890000000	2093300000000	2171210000000
Greece	153276363000	167117935000	177496827000	188840462000	201769402000
Ireland	124245710600	131995064100	143284072000	156484889000	169760854000
Italy	1203739550000	1252018820000	1283339610000	1319500570000	1371834460000
Luxembourg	23235400000	24562600000	27052900000	30582500000	32780900000
Malta	3867654321	3905001165	4117950151	4370372700	4641274167
Netherlands	425256000000	436874000000	456182000000	478734000000	503088000000
Portugal	120462700000	125310400000	128362800000	133055200000	139938300000
Slovenia	21919828611	23684363587	25158732076	27187936020	30231184201
Spain	706932000000	75666900 0000	813776000000	874845000000	942002000000

5.2.2 Electricity consumption

The electricity consumption from the periode 1997 to 2007 for the selected countries is given in tables 5.3 and 5.4.

Table 5.3: Power demand in GWh for the periode from 1997 to 2002

COUNTRY	YEAR						
	1996	1997	1998	1999	2000	2001	2002
Austria	47531.81	48078.42	48857.63	50823.1	51427.86	53032.8	52637.38
Belgium	69861.41	71815.25	73955.17	74501.78	77537.21	78141.97	78444.35
Cyprus	2302.74	2384.15	2616.75	2767.94	3000.54	3105.21	3384.33
Finland	66511.97	70361.5	72803.8	74199.4	75443.81	77292.98	79677.13
France	355552.36	355168.57	367159.1	374672.08	384906.48	395780.53	393501.05
Germany	458012.66	461757.52	466479.3	467479.48	482598.48	505276.98	498845.59
Greece	35564.54	37216	39309.4	40879.45	43147.3	44531.27	46566.52
Ireland	15851.69	16712.31	17700.86	18852.23	20282.72	21027.04	21771.36
Italy	240206.02	247812.04	254743.52	261035.35	272549.05	277352.24	282306.62
Luxembourg	4919.49	5128.83	5291.65	5512.62	5710.33	5628.92	5675.44
Malta	1337.45	1360.71	1407.23	1465.38	1570.05	1570.05	1651.46
Netherlands	86189.93	89516.11	92749.25	94726.35	97936.23	99424.87	99738.88
Portugal	30226.37	31935.98	33843.3	36122.78	38367.37	39937.42	41472.58
Slovenia	9501.71	9850.61	10094.84	10362.33	10525.15	10943.83	11688.15
Spain	147177.65	159005.36	165169.26	177252.83	188464.15	200954.77	206537.17

Table 5.4: Power demand in GWh for the periode from 2003 to 2007

COUNTRY	YEAR				
	2003	2004	2005	2006	2007
Austria	54044.61	55242.5	56289.2	57487.09	57463.83
Belgium	79677.13	80607.53	80177.22	82584.63	82875.38
Cyprus	3640.19	3744.86	3954.2	4163.54	4372.88
Finland	80851.76	83131.24	80933.17	85771.25	86085.26
France	407212.82	420017.45	422610.94	426751.22	425902.23
Germany	509266.07	513324.94	517500.11	528025.26	530432.67
Greece	48601.77	49741.51	50904.51	52521.08	55195.98
Ireland	23027.4	23062.29	24353.22	25876.75	25865.12
Italy	290959.34	295041.47	300379.64	308299.67	308869.54
Luxembourg	6012.71	6373.24	6152.27	6524.43	6477.91
Malta	1814.28	1802.65	1721.24	1849.17	1849.17
Netherlands	100518.09	103123.21	104542.07	106030.71	106833.18
Portugal	43158.93	44670.83	46322.29	47764.41	49043.71
Slovenia	12048.68	12548.77	12746.48	13165.16	13200.05
Spain	219993.08	230669.42	242183.12	256581.06	260070.06

5.2.3 Value of Lost Load

The VoLL will be determined by dividing the GPD by the electricity consumption and the results presented in table 5.5.

Table 5.5: VoLL in [€/KWh] for the periode from 1996 to 2007

COUNTRY	YEAR											
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Austria	3.39	3.43	3.51	3.49	3.63	3.62	3.76	3.74	3.8	3.91	4.05	4.27
Belgium	2.71	2.75	2.77	2.85	2.89	2.96	3.05	3.08	3.2	3.35	3.43	3.59
Cyprus	2.97	3.04	3.01	3.06	3.05	3.15	2.97	2.92	3.05	3.06	3.11	3.16
Finland	1.3	1.32	1.39	1.43	1.53	1.58	1.58	1.56	1.59	1.69	1.69	1.82
France	3.09	3.18	3.2	3.26	3.35	3.4	3.54	3.52	3.55	3.66	3.78	3.99
Germany	3.71	3.76	3.81	3.87	3.85	3.77	3.88	3.83	3.89	3.91	3.96	4.09
Greece	2.49	2.62	2.7	2.73	2.79	2.9	2.99	3.15	3.36	3.49	3.6	3.66
Ireland	3.32	3.62	4.02	4.28	4.63	5.01	5.35	5.4	5.72	5.88	6.05	6.56
Italy	3.78	3.8	3.83	3.85	3.9	4.05	4.13	4.14	4.24	4.27	4.28	4.44
Luxembourg	2.91	2.88	2.95	3.23	3.44	3.6	3.8	3.86	3.85	4.4	4.69	5.06
Malta	2.08	2.14	2.21	2.21	2.24	2.26	2.26	2.13	2.17	2.39	2.36	2.51
Netherlands	3.33	3.42	3.49	3.64	3.81	4	4.15	4.23	4.24	4.36	4.52	4.71
Portugal	2.62	2.68	2.74	2.74	2.78	2.82	2.84	2.79	2.81	2.77	2.79	2.85
Slovenia	1.08	1.19	1.28	1.39	1.53	1.65	1.72	1.82	1.89	1.97	2.07	2.29
Spain	2.96	2.9	2.98	2.96	3.03	3.08	3.2	3.21	3.28	3.36	3.41	3.62

5.2.4 Evolution and Comparison of VoLL for the 15 countries selected in the periode from 1996 to 2007

The evolution of VoLL for all th countries has a growing tendency in some countries this tendency is more notable such as Ireland and others are almost constant such as Cyprus, see figure 5.1

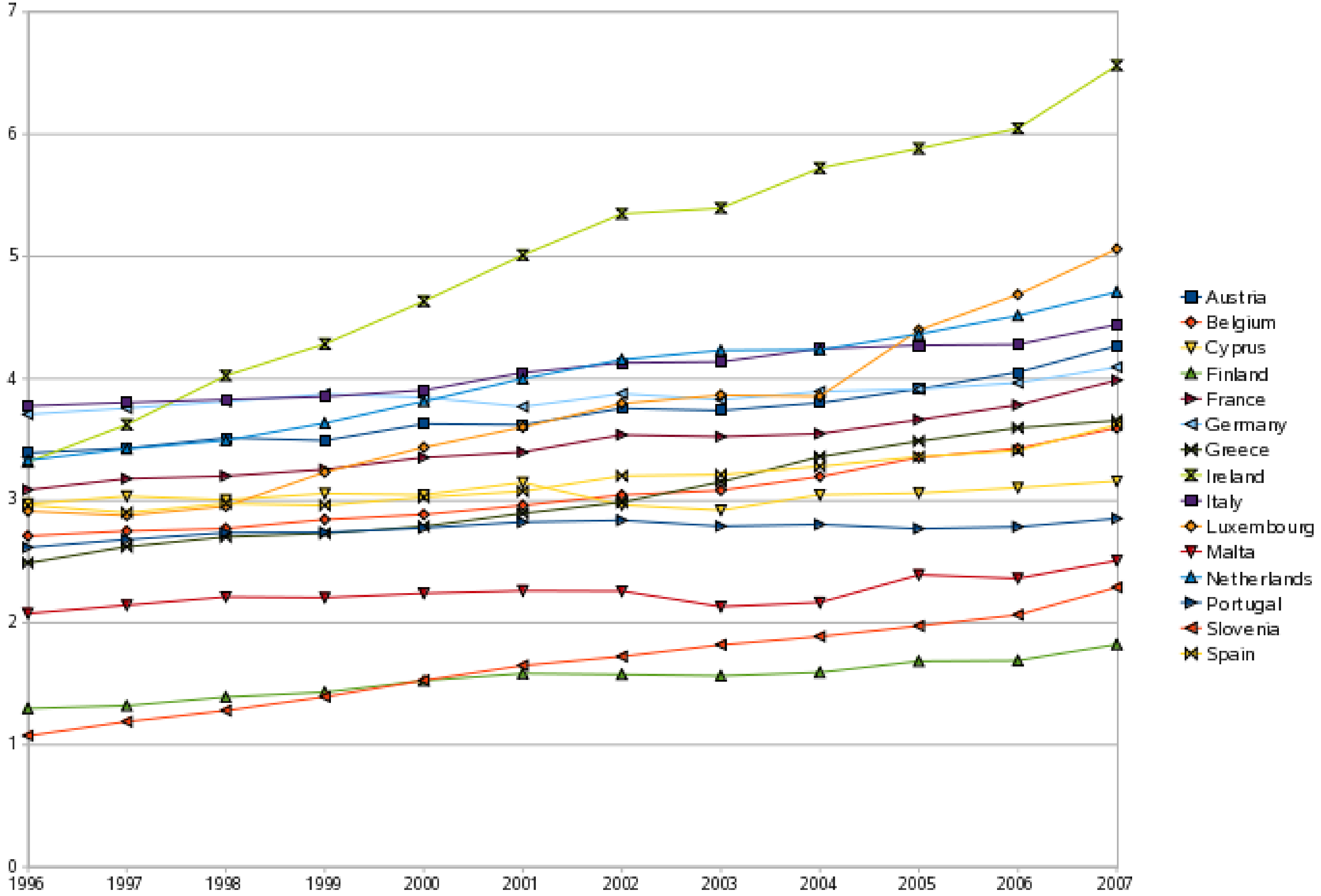

Figure 5.1: VoLL evolution for the periode 1996 to 2007

5.3 Comparison of VoLL for industry, tranport, services and households for 8 European Countries

Chapter 6

Case study 1: Application of the methodology for a power quality economical evaluation

La idea es si tenemos mediciones en una empresa concreta de huecos de tensión, sabiendo el tipo de empresa (Juan puede encontrar los datos económicos) y aplicando factores de ponderación según la profundidad del hueco, podemos tener las pérdidas económicas para una empresa determinada en un periodo de tiempo.

Sino tenemos nada mejor en los papers de Mark McGranaghan referencias [15] y [14] hay varias tabla con weighting factors for different voltage sags magnitudes, que pueden ser usados.

Chapter 7

Conclusions

Las conclusiones las podemos enfocar
1.- desarrollo de las metodologia

Glossary

CAIDI	CAIDI is the average duration of an interruption, calculated based on the total number of sustained interruptions in a year. It is the ratio of the total duration of interruptions to the total number of interruptions during the year. CAIDI = Total duration of sustained interruptions in a year/total number of interruptions.It can also be seen that CAIDI = SAIDI/SAIFI., 1
CAIFI	Consumer Average Interruption Frequency Index (CAIFI). CAIFI is the average number of interruptions for consumers who experience interruptions during the year. It is the ratio of the annual number of interruptions to the number of consumers affected by interruptions during the year. Consumer is counted only once regardless of the number of interruptions. CAIFI = Total number of sustained interruptions in a year/Total number of consumers affected., 1
CBEMA	Computer & Business Equipment Manufacturer's Association is the former name for the ITIC., 1
CENELEC	European Committee for Electrotechnical Standardization (CENELEC) issues both generic and product standards for the legally prescribed test requirements for EMC in the EU., 1
EMC	Electromagnetic compatibility., 1
IEC	The International Electrotechnical Commission (IEC) is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies., 1
IEEE	World's leading professional association for the advancement of technology in the electric and electronic sector, 1

ITIC	Information Technology Industry Council is a leading institution for the information and communications technology (ICT) industry., 1
LV	Low Voltage will be considerate as $V \leq 1kV$, 1
MAIFI	Momentary Average Interruption Frequency Index (MAIFI).MAIFI is the average number of momentary (less than 5 minutes) interruptions per consumer during the year. It is the ratio of the annual number of momentary interruptions to the number of consumers. MAIFI = (Total number of momentary interruptions in a year) / (Total number of consumers), 1
MV	Middle Votage will be considerate as $1kV < V \leq 36kV$, 1
SAIDI	System Average Interruption Duration Index (SAIDI) . SAIDI is the average duration of interruptions per consumers during the year. It is the ratio of the annual duration of interruptions (sustained) to the number of consumers. If duration is specified in minutes, SAIDI is given as consumer minutes. SAIDI = Total duration of sustained interruptions in a year / total number of consumers, 1
SAIFI	System Average Interruption Frequency Index (SAIFI). SAIFI is the average number of sustained interruptions per consumer during the year. It is the ratio of the annual number of interruptions to the number of consumers. SAIFI = (Total number of sustained interruptions in a year) / (Total number of consumers), 1
SEMI	Global industry association serving the manufacturing supply chains for the microelectronic, display and photovoltaic industries., 1

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