Revista Eletrônica Sistemas & Gestão
6 (2011), pp 91-116

Electrical Energy Losses Determination In Low Voltage – A Case Study

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Abstract

Along the last years, electrical energy distribution companies have already done many investments in order to identify and calculate energy losses along a distribution network. Although these big efforts, most approaches for clearly identifying and solving the related problems still remain rather inefficient. The accurate identification and the precise calculation of electricity losses enables the clear specification of the critical points and segments in the networks and, consequently, the effective prioritization of actions and interventions in order to reduce those electricity losses and problems. Moreover, the work already performed on this issue, the existing approaches focus mainly on empirical and probabilistic data. Hence, there is still a clear gap between real information and the considered one, which tends to be poor and imprecise. Due to this reality and the lack of appropriate software applications, in this paper we propose a web platform for the management of the whole network of electrical energy distribution, from medium voltage (MV) down to low voltage (LV), including billing on the transformation centers (TCs), electricity losses calculation and proposals for solving actions, by means of a fuzzy decision-making model.

Key-words: Electrical energy, distribution network, fuzzy-based decision system, information and losses calculation and solving actions support.

Programa de Pós-Graduação em Sistemas de Gestão, TEP/TCE/CTC/PROPP/UFF
DOI: 10.7177/sg.2011.v6.n2.a2

Revista Eletrônica Sistemas & Gestão
Volume 6, Número 2, 2011, pp. 91-116
DOI: 10.7177/sg.2011.v6.n2.a2

1. INTRODUCTION

During the last decades electrical energy distribution companies have developed several improvements to their power distribution systems. Due to the high costs involved in electrical energy generation, transmission and distribution, the efficient usage of the available energy along with the efficient management of the network are fundamental issues to be tackled. Furthermore, concerns with environmental issues must also be considered during the management and decisions processes. Companies are aware of the strong competition they are currently facing, largely driven by the liberalization of the electrical energy markets. Energy efficiency measures can represent the difference between having power quality at affordable prices, or having energy shortages and/ or with poor quality.

Another big concern is how to minimize network energy losses. This leads not only to higher revenues, but also to improvement on the quality of the product offered to consumers. In addition, companies can expect to gain new markets and to afford expanding network capacity. For those reasons, the loss of power and energy, which may occur in electrical systems, is still a major concern, both for electrical energy distribution companies and to Regulators. In fact, Energy Regulators are responsible for: proposing measures concerning the quality and maintenance of the assets of the distributor; to ensure the promotion of power quality; and to regulate tariffs for the market.

Electricity losses are divided in two main categories: technical and non-technical ones, which are have to be precisely identified and calculated (Meffe, A., 2001, ERSE, 2009).

Therefore, in this paper we put forward a methodology and computational implementation based on real data, obtained through telemetry instead of empirical and probabilistic data, which enables to obtain precise results, namely in terms of losses determination. Moreover, the proposed system enables to clearly identify the losses in the distribution network points and activate a mechanism for analyzing and accurately solve the identified problems, by proposing corresponding repairing actions. The system architecture and its main functionalities are presented and briefly described in this paper. The system architecture follows a Peer-to-Peer (P2P) structure and includes a Data Base, where all relevant information, including parameters and data about diverse electrical energy losses types are stored, in order to enable an effective and efficient electrical energy information and losses management. The main system functionalities also include modules for billing and payment processing. The system is at a final step of development, and is already being used for testing purposes and an example of use is put forward in this paper, regarding energy losses determination. Moreover, a comparative analysis is also included, in terms of total amount of losses along a distribution network, with some reference value provided by a electrical energy distribution company of Portugal. A brief literature review about some existing approaches is also included, in order to enable to better contextualize and clarify the importance of the proposed system.

2. ELECTRICAL ENERGY

The growth of world population and economic conditions in developing countries necessarily implies an increase in energy consumption. However, energy production increase should be bounded by sustainable development and environmental responsibility. The graph in Figure 1 (Leão, R., 2009) shows the growth in global electricity generation by fuel. According to this data, electricity generation is expected to grow by more than 50% during the next 20 years (Leão, R., 2009).

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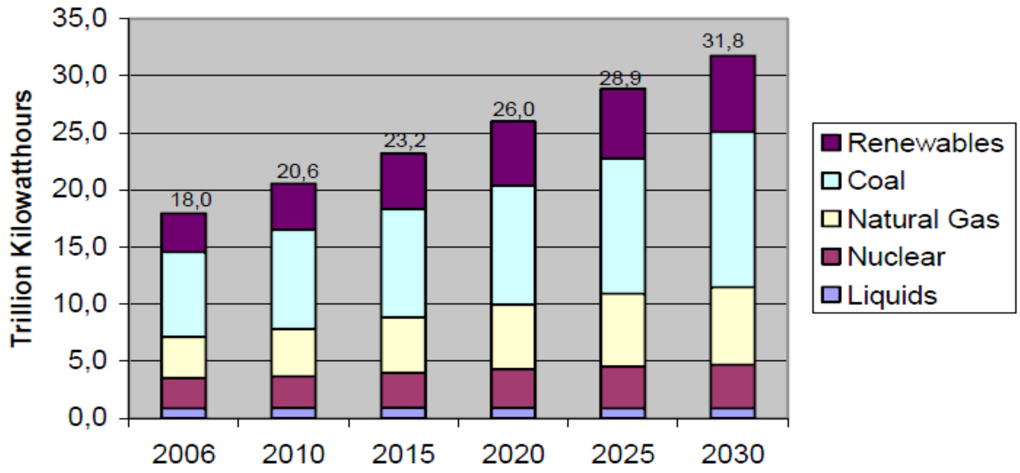

Figure 1. Generation of Electrical Energy Worldwide.

For example, in Portugal, although increasing concerns with energy efficiency have taken place, we can observe an increasing trend for energy consumption (see Figure 2 below) (Leão, R., 2009).

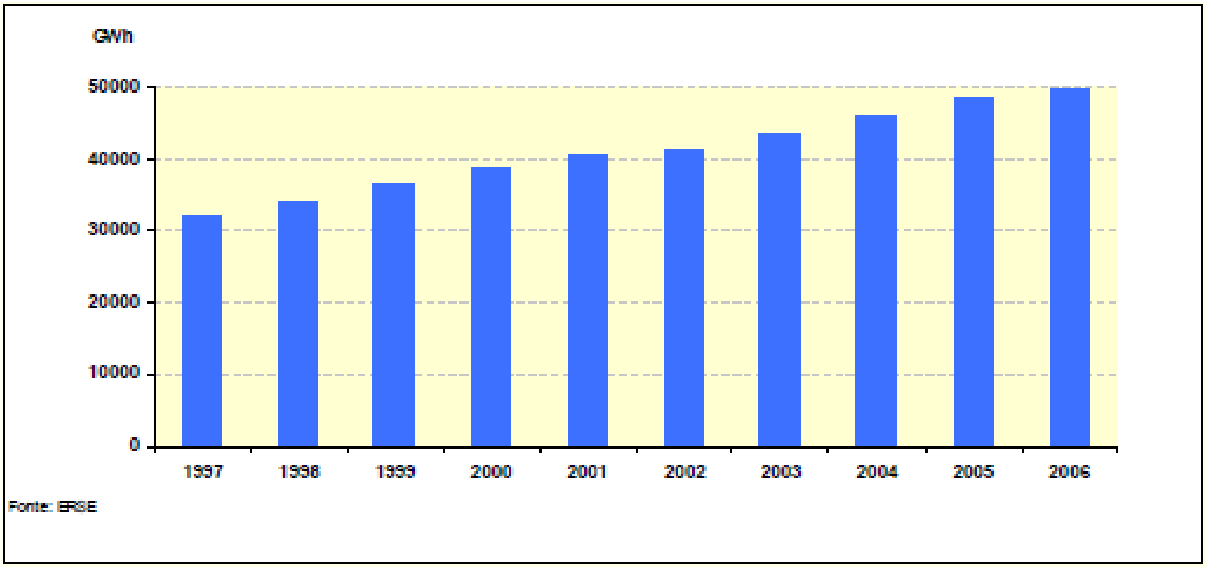

Figure 2. Evolution of Energy Consumption in Portugal.

The increasing energy consumption over time may partially explain the rising awareness with the quality of electricity. Namely, in Portugal, considerable improvements on the power systems quality and supply were achieved. The promotion of adequate levels of service quality in the electricity sector is a precondition for the welfare and needs of populations as well as increases on economic activities to become globally competitive (ERSE, 2010).

The quality of service in the electrical energy sector can be analyzed in its two components:

- Quality of service, regarding its technical nature;
- Quality of service, regarding its commercial nature.

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The quality of technical service in the electrical energy sector, also known as power quality, is associated with the analysis of (ERSE, 2009b):

- Reliability of electrical energy supply (continuity of service) measured by the number and duration of interruptions in supply.
- Characteristics of the waveform of AC voltage (voltage waveform quality), measured through the evolution of their values of frequency, amplitude, harmonic distortion, unbalance, and others.

Figure 3 (Esteves, J., 2010) shows the indicator of continuity of service, in other words, the number of minutes of interruption per customer in different European countries. Analyzing the chart it may be seen that Portugal, although not being yet at the same level of some European countries, has recorded a very marked improvement in the number of interruptions of service over time, which confirms the concern that exists in Portugal regarding service quality (Esteves, J., 2010).

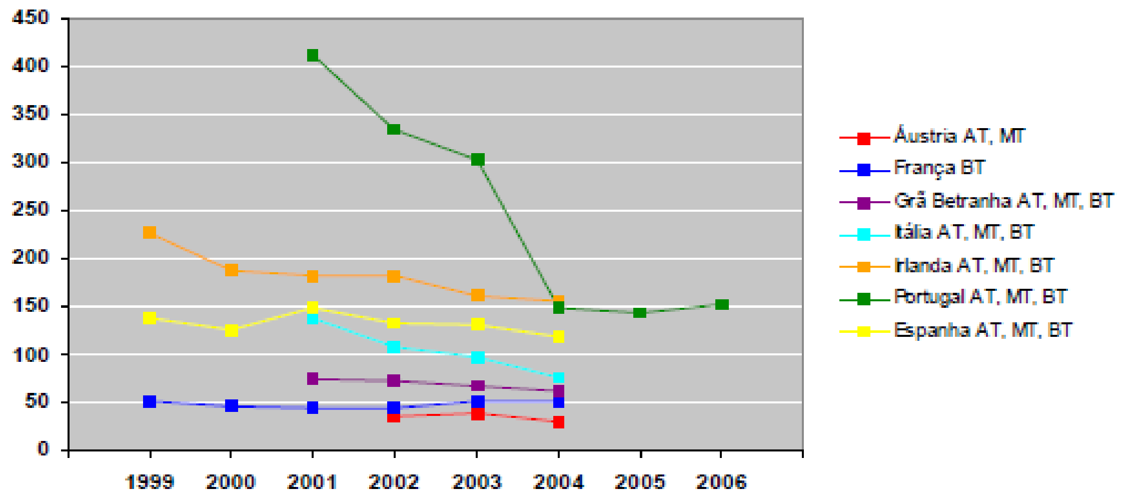

Figure 3. Evolution of the Indicator about Service Continuity.

To proceed with the characterization of voltage in the networks, exploited by operators of transmission and distribution, the system operators must perform the following tension measurements (ERSE, 2009c):

- Frequency;
- Value of effective tension;
- Cavas voltage;
- Jitter (flicker);
- Imbalance of three-phase system of voltages;
- Harmonic distortion.

The quality of commercial service provided to customers by businesses, whether network operators or retailers, encompasses a range of topics such as: the speed of service, the response to several requests, the meter reading and evaluation of customer satisfaction (ERSE, 2010b).

Regarding the percentage of losses in the Portuguese electrical distribution network, although energy consumption has increased over time (Figure 2, (Esteves J., 2010b)) the percentage of energy loss followed a downward trend, although there is some fluctuation over time (Esteves J., 2010b).

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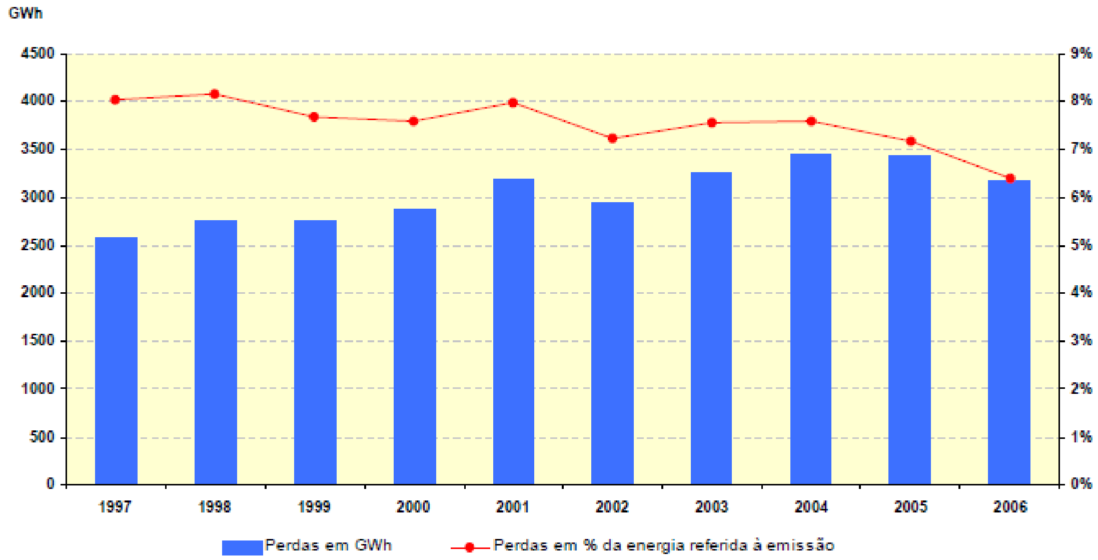

Figure 4. Evolution of Electrical Energy Losses in a Distribution Network.

3. DISTRIBUTION NETWORK

The current system of electrical energy distribution is based on large central power generation, which transmits power through systems of high voltage transmission, which is then distributed to distribution systems in medium and low voltage. In general the energy flow is unidirectional and the power is checked and controlled by the center (s) in an order based on pre-defined requirements. Figure 5 shows a general outline of an electricity distribution network.

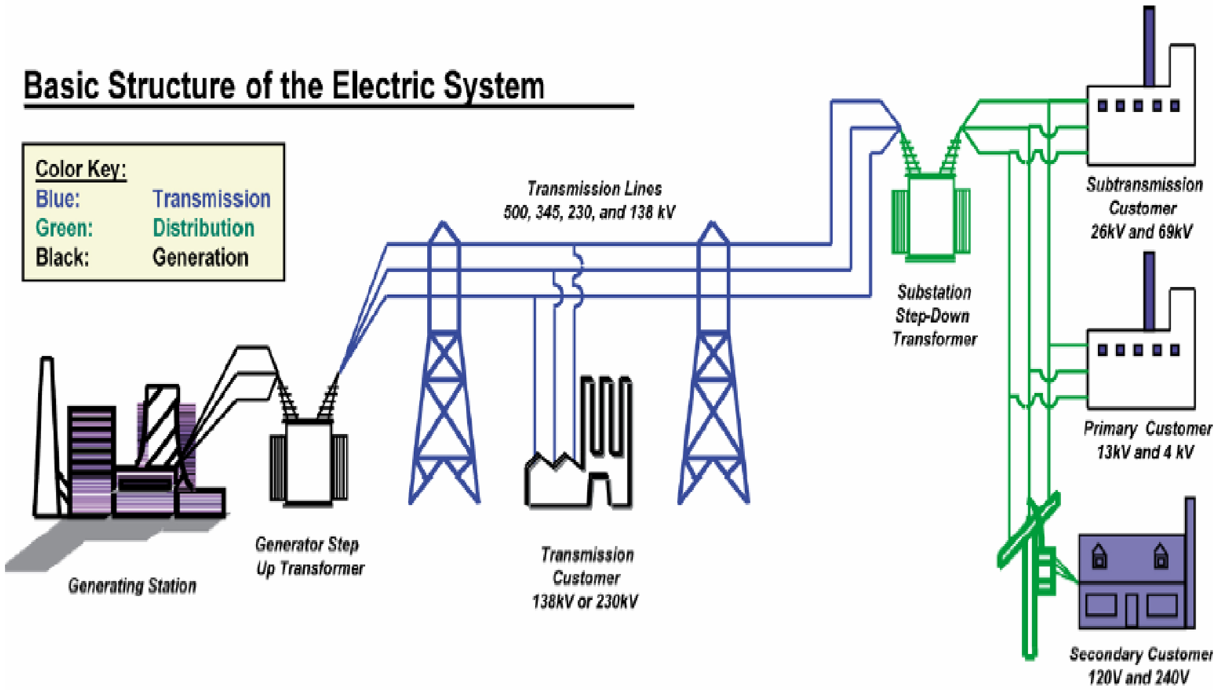

Figure 5. Electricity Distribution Network.

The share of electrical energy distribution is a segment of the electrical system, consisting on the primary electrical networks (distribution networks of medium voltage) and secondary networks (distribution networks for low voltage). Electrical energy distribution companies are in charge of the construction, operation and maintenance of these networks.

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The primary distribution networks are electrical circuits with three-phase three-wire (three phase), connected at distribution substations and are usually built in the classes of voltage of 15 KV, 23 KV or 34.5 KV.

In these classes of tension, the nominal operating voltage may be 11 KV, 12.6 KV, 13.2 KV, 13.8 KV, 21 KV, 23 KV, 33 KV and 34.5 KV. The levels of voltage: 13.8 KV and 34.5 KV are standardized by law; the other levels exist and continue to operate normally. Primary distribution networks are installed with distribution transformers, fixed on poles, whose function is to lower the voltage level to the primary side voltage level (e.g., for download from 13.8 KV to 220 volts). The secondary distribution networks are electrical circuits with three-phase four wires (three phases and neutral), typically operate at voltages (phase - phase / phase - neutral) 230/115 volts, 220/127 volts and 380/220 volts. These networks are connected consumers, including residences, bakeries, shops, and so on, and also the fixtures for street lighting. These networks serve the large consumption centers (namely, population and large industry, among others). Establishments such as large buildings, shops and markets consume more power, and require individual processors of 75 kva, 112.5 kva and 150 kva. In some cases, the tension between supplies is 380/220 volts or 440/254 volts.

The entire distribution system is protected by a system composed by circuit breakers at the substations where the primary networks are connected, and with key fuse in distribution transformers, which in case of short circuit switch off the power grid (Sánchez-Jiménez, M. 2006, Todesco, J. L. et al., 2005).

4. STATE OF THE ART

Although there are many methodologies in the literature with the purpose to manage an electrical distribution network by calculating the energy losses in a power distribution network in low voltage (LV), all they have several "gaps" either in their development, often due to being based on empirical data and probability, and/or in its implementation, because although much discussion about energy losses has been carried out along the last decades, great improvements have not yet been implemented over the time in terms of the software development for supporting to manage electrical distribution networks, which makes it very difficult to make a comparison of what already exists in this area and what is clearly still necessary to be developed and researched, since unfortunately there is still not much information available.

Although the lack of information put available about this subject, some work is already being made and the paper developed by (Strauch, M. T., 2007) present a software for calculating electrical energy losses in distribution networks, in terms of low voltage power, resulting in a flexible business tool, which allows the user to make calculations based on typical data for modeling their networks, based on measurements made on the ground. In (Manhães, L. R. et al., 2008) an approach is used based on expert systems, to assist in managing the distribution of LV power, knowing that these systems generally treat a very large variety of variables, many of which expressed through natural language, which turns the systems treatment strongly influenced by experience, trial, human perception and reasoning.

The work in (Aranha, N., Edison, A. C., Coelho, J., 2008) presents a methodology for calculating the energy losses in the secondary network, the primary network and distribution transformers, already implemented and in use at "Companhia Paulista de Força e Luz" (CPFL), in Brazil, along with the GISD system, which is a database for geo-referencing with engineering applications (Planning, Design, Maintenance and Operation).

In (Méffe, A. et al., 2005) the work presents an extensive discussion on fraud and non-technical losses in Brazil, a collection of papers, resolutions and technical documents describing a systemic view on non-technical losses, by identifying the main types of fraud and theft and also shapes and equipment used to minimize or eliminate them. Finally, they analyzed the forms of combat that can also be applied to distributors in other countries.

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The work done by (Méffe, A. et al., 2005) presents a methodology and computational implementation for the calculation of technical losses in the various segments of a distribution system, and some comments about the most critical elements are made, also including some discussion about possible actions to reduce losses.

Moreover, the paper in (Netto, et al., *2005*) presents the development of a 3D graphical interface based on virtual environments technology. The referred interface is intended to assist decision making in a computer system for loss reduction in electricity distribution networks, but the authors refer that the system is still under development and important work has to be carried out.

5. PROPOSED SYSTEM AND INTEGRATION WITH OTHER SYSTEMS

5.1. System Architecture

The proposed system for managing an electrical energy distribution network includes a very comprehensive software architecture (as illustrated on Figure 6) One of the main purposes of this work consists on making a demonstration of the primary needs among the system's users and the common server, describing the input information for the supporting database. In this database information about the whole distribution network is being stored, from the transformer to the final consumer. This information comprises the secondary network, the connection extensions, micro-generation billing of TCs, the compensating reactive power and the various types of acquisitions regarding parameters readings on TCs and end consumers, in particular, estimated readings and company lectures, including manuals, telemetry readings and lectures by PDA.

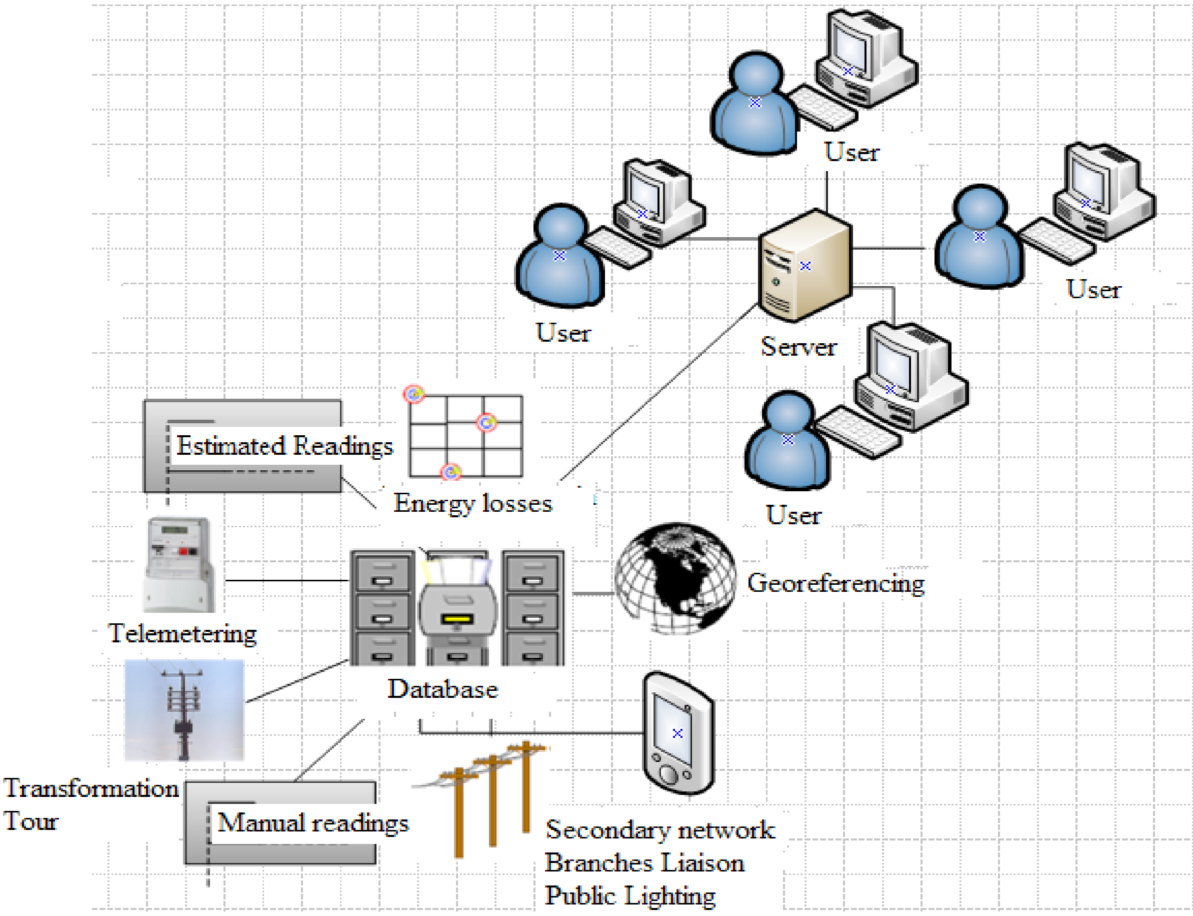

Figure 6. General System Architecture.

The system's underlying database follows a relational-based model and was developed through SQL Server. SQL Server is a database management system (DBMS) for relational databases management, created by Microsoft, and consists on a platform for enabling reliable data manipulation. Moreover, it is a very

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robust platform and used for corporate systems about different dimensions (Strauch , M. T., M. T, 2007). The Relational databases contain three main components, a collection of data structures, especially links, tables or more informal structures, a collection of operators, relational algebra and calculus and a collection of integrity constraints, defining the set of consistent states of the database and changes of states.

The integrity constraints can be of four types, domain (also known as type), attribute, sward (relation variable) and restrictions on the database. Unlike the hierarchical and network-based approaches, in this development environment there are no links, and according to the principle of information, the whole information must be represented as given, and any attribute represents relationships between data sets. The relational databases allow users, including programmers, to write queries that were not anticipated by those who designed the database. With this, the relational databases can be used by multiple applications in a way that the original designers or programmers did not anticipate, which is especially important in databases that can have be used for decades, dealing with a large amount of information, which contributed to turn the relational databases very popular, namely in different kind of business domains.

5.2. Systems Integration

The database developed under the relational modeling paradigm, was "split" into various diagrams in the SQL server that work linked together through their identity relations. Some important diagrams descriptions include information for the perception of the database schema, the transformer diagram, the network diagram about secondary liaison branch diagram, a diagram about micro-generation, an energy measurement diagram, a diagram for batteries capacitors, and also public lighting diagram, among others and three of the most important ones are going to be described next and illustrated through the Figures 7, 8 and 9.

Diagram about technical connection and communication

The technical diagram about connection and communication shows various kinds of links that exist with the system's components. In TC we have the indicator about the electricity supply, the analyzer indicator in parallel, the hub, to serve as a connection to the final customer counters, the counters of Micro-BTE production and billing system and the TC. This diagram also describes the alerts that are sent via SMS, GPRS or email if the system detects the existence of any anomaly.

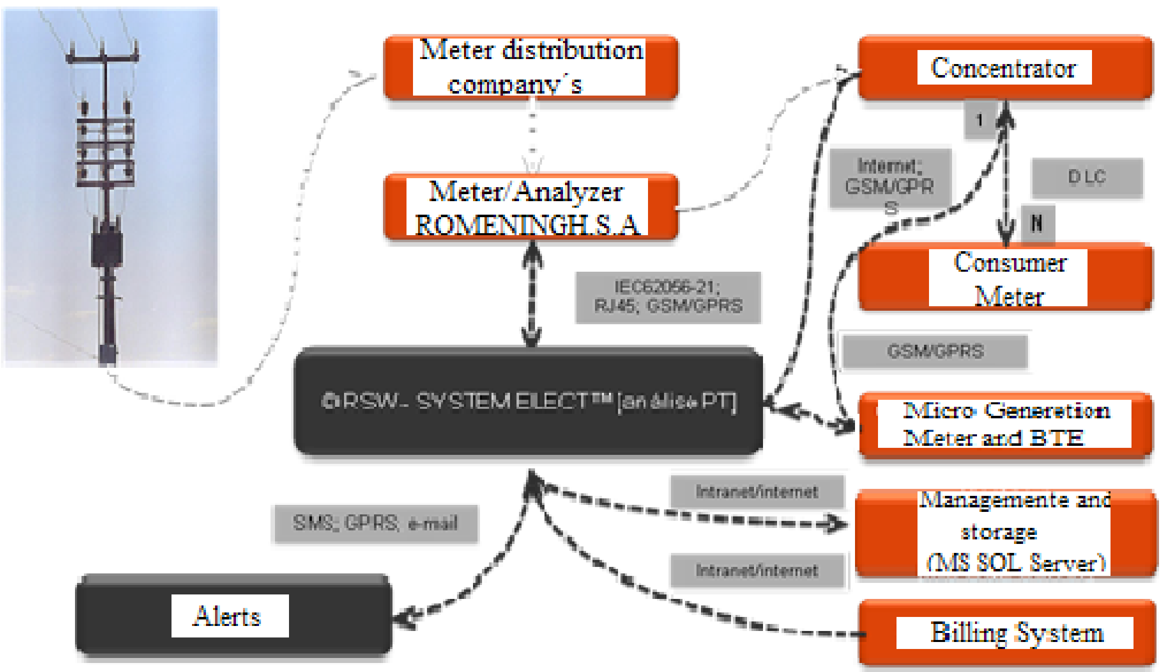

Figure 7. Technical Connection and Communication.

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Diagram about communication with the telemetry system

The diagram of communication between the "RSW System - SYSTEM ELECT TM análisePT" and "RSW - ELECT SYSTEM TM telemetry" are used to display the type of information sharing that exists between the two systems. The "RSW - ELECT SYSTEM TM telemetry" makes the collection of indicators readings, making a request to the hub. The hub enables to make a connection to the counters to collect the readings and send a reply with the indicator readings for the "RSW - ELECT SYSTEM TM telemetry", recording the same in this database. The "RSW - ELECT SYSTEM TM análisePT", enables the connection to the hub for the collection of indicator readings exactly in the same way as the "RSW - ELECT SYSTEM TM telemetry".

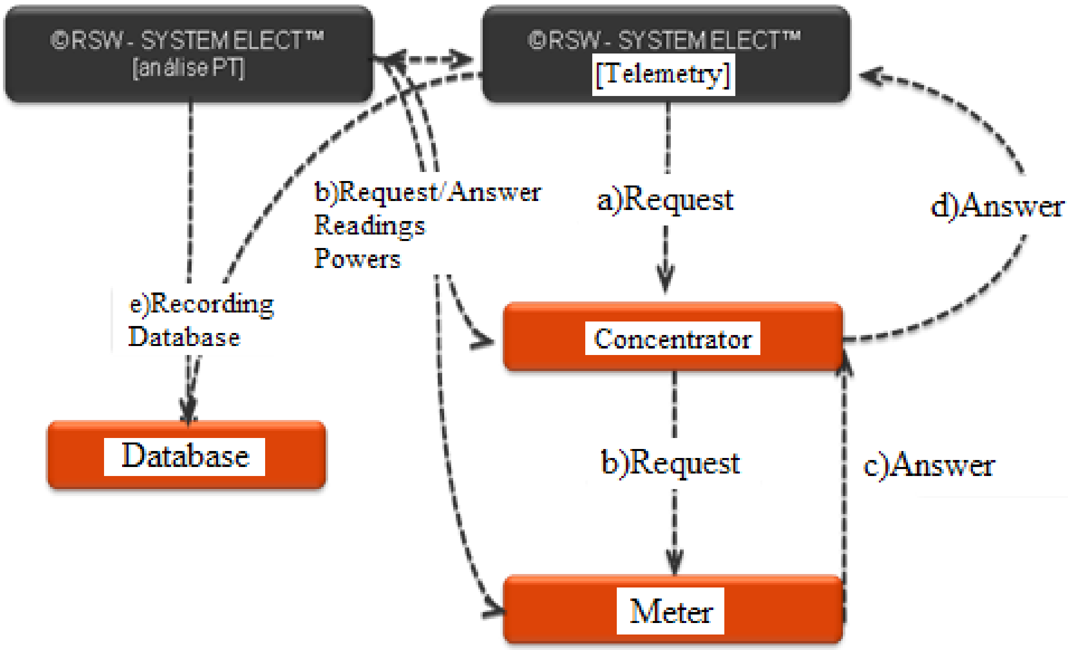

Figure 8. Communication with the Telemetry System.

Diagram about integration with other systems

The proposed system "Romeningh Software" (or RSW, by short), namely the "SYSTEM ELECT TM análisePT" system's component, enables to integrate with other system's components already developed, exponentially increasing their capacity to use several functionalities that these systems already include. The diagram in Figure 9 shows the possible integration of system's components to which the "RSW - SYSTEM ELECT análisePT TM", is able to be connected, in particular, "RSW - ELECT SYSTEM TM energy", "RSW - ELECT SYSTEM TM telemetry", "RSW - ELECT SYSTEM TM website" and "RSW - SYSTEM ELECT TM mobile".

5.3. Systems Functionalities

The proposed system includes several functionalities (as shown in Figure 10) to provide essential responses to questions and problems arising under the scope of electrical energy distribution networks. Some requests are about electrical power and quality and others are about parameters measurement or even with losses identification and calculation. The latter conduces to decision-making actions and intervention to solve the problem. <the whole system falls under the scope of global concerns including sustainability ones (Todesco, J. L., et al., *2005*).

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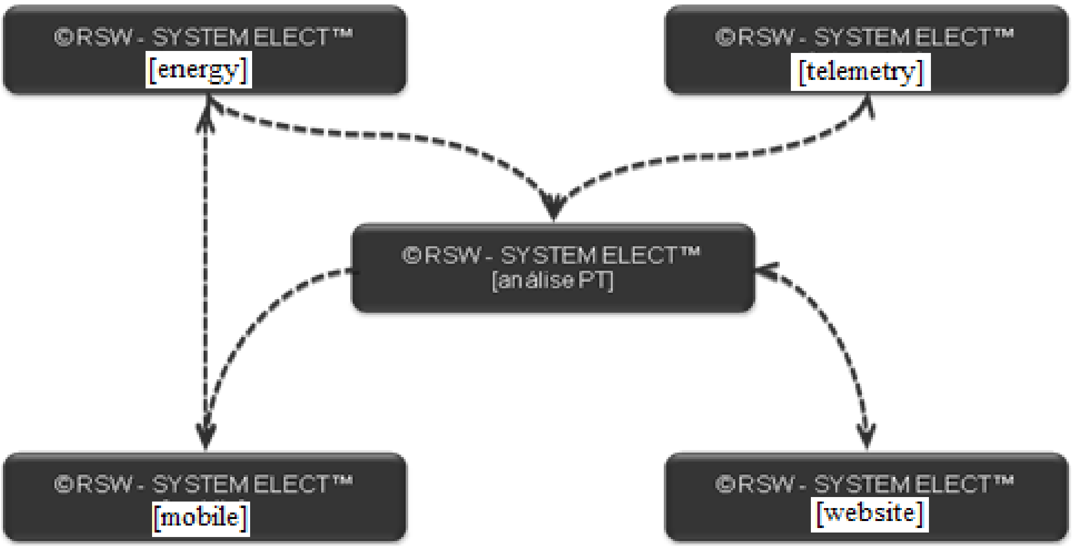

Figure 9. Integration with Other Systems.

In general, the aims are: a) the identification of all TC's; b) their geographical location (map with TC's in Google Maps with photograph of the site; c) the control of leakages and losses on TC; d) the identification of types of clients at any given TC; e) the emission of several different kind of reports, namely related with electrical energy consumption per day and respective tariff. This last feature is expected to support the analysis of the consumption time pattern. Other system features include the possibility of sending early warnings via SMS, GPRS or email in case of failure or other problems arise.

The system is also of great importance for collecting readings between previously defined time intervals, e.g., every 15 minutes from all counters, or to control the time of technical interventions for repairing and/ or maintaining the TC's, including the index points of failures, consumption, losses, and necessary interventions management.

Summarizing, the main capabilities of the system are:

- Identification of all TC's. Geographical location (map with TC's in Google Maps with photograph of the site, used "snapshot" and contracted power), with information on the type of TC urban distribution (in cash), rural distribution, air (suspended pole) with cooling dry or oil), public or private.

- Control of electrical energy leakages and losses, namely on TCs (global, technical and nontechnical ones).

- Identification of the types of clients at each TC (micro ordinary consumers or producers) to detect whether there is injecting electricity network, or just usage.

- Reports with consumption per day and respective tariff to allow analyzing the times of highest consumption, compared to the same period (e.g. month) last year. This capability allows appropriate consumption management and analysis of the evolution over time through graphical and / or table results for future prediction.

- Reports to the average monthly consumption for information and verification of the months of greatest consumption, and thus know if there is a power surge at a given time interval and prevent any failure of distribution and/ or marketing of energy.

- Reports to compare the number of customers in the previous year, for information and verification of developments over time.

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- View existing records to request a new network connection, which shows the power that the consumer requests and the voltage level of the request. Based on the information in the completed form online, the network manager can determine the need to conduct a study (which integrates the data contained in the request) in order to support the implementation of the budget to present to the requester.

- Early warning system via SMS, GPRS or email in case of failure, inconsistency of consumption, fraud, power and voltage exceeded the maximum permitted by the TC, among others.

- Collection of readings every 15 minutes from all counters, at a certain time automatically or by user request in real time and instantaneous.

- Control the time of intervention of technicians to repair and/ or for maintaining each TC.

- Conducting comparative analysis about all TC's installed, including the index points of failures, consumption, losses, and necessary interventions, among others.

- Management of phases in case of failure or technical assistance for improved performance in cutting time.

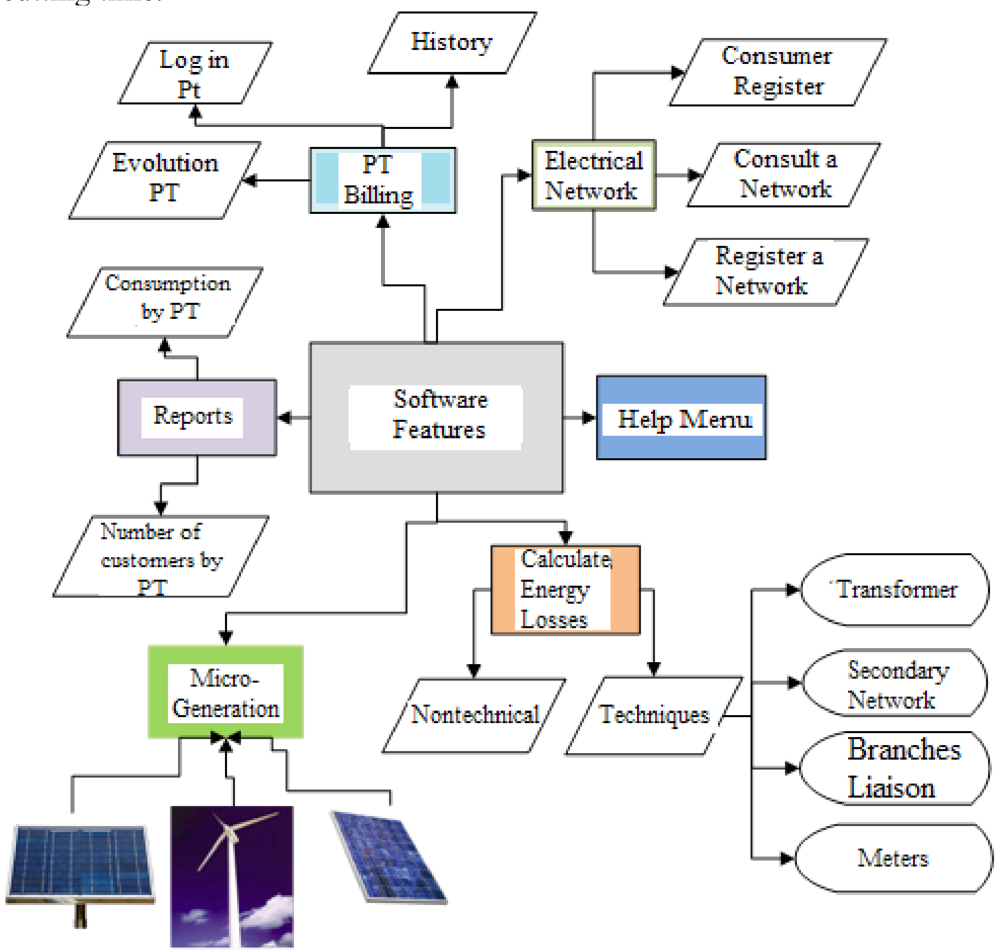

Figure 10. Main System Functionalities.

5.4. Systems Illustration

The software was developed in Visual Basic 6.0, which serves as a connection to the relational database developed in SQL Server. Considering the distance from consumers it was necessary to develop a friendly and intuitive graphic interface, enabling the reading of data from a geo-referenced database.

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The system's main menu interface is illustrated on Figure 11, were we can see the various areas where the system is able to intervene, from TC billing, characterization of all the electrical energy grid, energy losses, micro-generation, data and the whole electrical energy network management, which is going to be illustrated next, among some kind of reports about various relevant information gathering about several parameters that are useful regarding the use requirements of the system.

The electrical energy network management menu enables to specify the main general and specific characteristics of the distribution network. These features include the identification of the electrical energy distribution centers, namely transformation centers.

Moreover, it is possible to identify the project type, in terms of ownership. In the example given the electrical energy distribution entity is identified as being the "Cooperativa Roriz". The type of the installation can also be specified as urban or rural as well as its construction model, in the area "Modelo do Posto" (Figure 12).

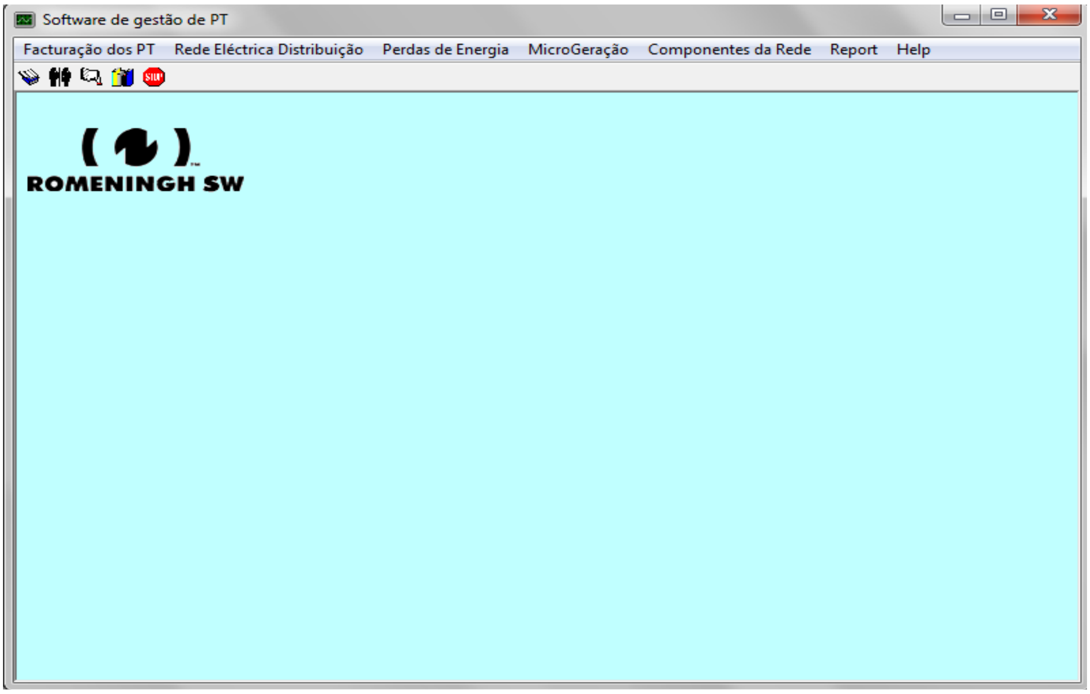

Figure 11. Main System's Graphical Interface.

In terms of client type, the system also enables to identify it, for example, as a "micro-generation" client.

The system can be used to define MV or LV electrical energy distribution. As shown Figure 12, in case o MV it is possible to specify the service tension level (ex: 10), the level of isolation (ex: 12) and the number of TCs (ex: 1).

The system enables to identify, for each TC the output type, in LV ("Saídas/ Baixa Tensão/Tipo de Transformador"), among other relevant data and store it on the corresponding database component. Figure 10 above illustrates the most important data input areas, in terms of electrical energy network specification and management. The system also allows specifying more detailed information for each particular case, through subsequent menus.

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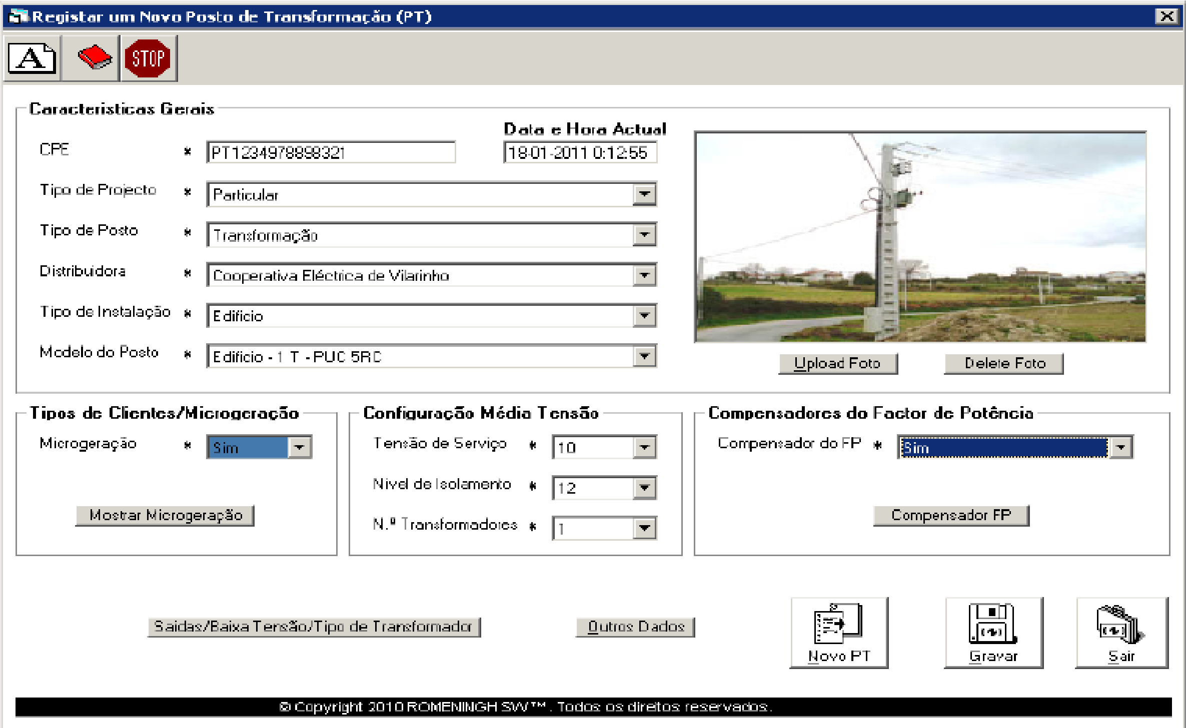

Figure 12. Register a New TC.

6. ENERGY LOSSES DETERMINATION

Energy losses management consists on one of the major problems arising under the scope of electrical energy distribution networks. Therefore, it is of greatest importance to identify which portion of the losses may be included in the tariffs and charged to consumers. Technical losses are inherent to the process, and therefore assumed to be liable to pay. However, besides of commercial losses, although technical ones, they are related with the need of necessary investments in the electrical energy network (maintenance, expansion of capacity, reconfiguration, upgrading, etc.). If these losses exist the problem of lack of maintenance of the electrical distribution network must be assessed and properly tackled.

To be succeeded on the energy losses reduction objective, there is a need for identifying and accessing the losses throughout the distribution system. Energy losses can be classified as to their origin and location (Méffe, A., 2001). Regarding their origin, a loss can be categorized into technical and non-technical one. A technical loss is the energy that is lost during distribution. This kind of loss is inherent to the process and occurs on the materials used during the distribution, such as transformers, cables, and network connections, before the point of delivery. A non-technical loss is the energy actually delivered to the consumer, through their own or another distributor, but for some reason it was not billed, which are commonly associated with fraud energy consume, by some consumers along the network.

Moreover, the losses can be classified into global losses, losses in transmission and distribution losses. The global losses include losses in the generation, transmission and distribution. The transmission losses are associated with the systems for generation and transmission, distribution losses occur only within the distribution system.

The system underlying to this work takes into account all these losses. The most important features are already implemented, namely the losses identification, along the electrical energy distribution network and energy losses determination. Regarding this last operation, a user is able either to introduce precise data, obtained from several distinct sources, such as by direct measuring along the distribution network or from

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other more imprecise specification, for instance by defining some distribution function or through fuzzy parameters specification (Ribeiro, R. A., Pires, F. M., 1999). In this last scenario, triangular functions are used to specify a set of different kind of parameters for losses determination, namely related with the estimation of losses associated to cable lengths and other parameters related to each kind of cable losses determination, since these are not always known precisely and they exist along the whole distribution network, from medium to low voltage. Moreover, other uncertain parameters, for losses determination, may occur, as for example the ones related with end users' electrical energy meters losses estimations. All these are also treated under the scope of fuzzy sets approach (Ribeiro, R. A., Pires, F. M., 1999).

Although there are various ways to calculate energy losses in the sector of energy distribution, the methodologies defined by (Méffe A. 2001), enables the calculation of energy loss to be considerably accurate.

This method, proposes a model to calculate energy loss in the whole sector of energy distribution, namely within the transformer, the secondary network, the condensers, household connections and in the energy meters. The same method was used in the development of the software entitled, SystemRSW_AnalisePT, for the calculation of technical electrical losses in distribution networks.

6.1 Losses in the Distribution Transformer

Besides the losses in the copper coils (due to the resistance), the transformers and coils have magnetic losses in the nucleus.

Hysteresis losses: The iron-magnetic materials are magnetically susceptible, through the stabilization of the magnetic field around the nucleus. That takes place when applying a variable field (like a generated one for an inducer or the primary in case of a transformer). This process consumes energy, and when applying a variable field, the material tries to accompany it, and so suffers successive movements in one way and the other, making thus heating up. Once interrupting the field, the material generally remains magnetized, known as remanent field.

Foucault losses: These are due to the conductivity of the nucleus that forms, in the closed path of the nucleus, a short breath that consumes energy from the field. To minimize these losses are used materials of low-conductivity, for example, a ferrite and sheets of steel-silicon that are isolated one from the other by varnish. In various cases, where large inducers are not required, the nucleus contains a separator or opening in the path of the nucleus, that eliminates this kind of loss.

In the Figure 13, we can see the divisions of distribution transformer, for calculating the electrical energy losses.

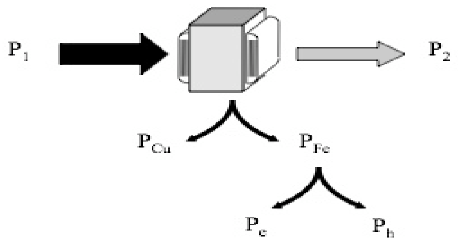

Figure 13. Energy Distribution Transformer Losses.

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Losses in Iron

The way in which the losses in the iron nucleus is cetermined is given through:

$$Pfe = Pe + Ph \quad (1)$$

Where,

- Pfe – Energy losses in the iron of the distribution transformer;
- Pe – Eddy energy losses;
- Ph - Hysteresis energy losses.

Eddy losses

$$Pe = ke * (f * Bm * d * 10^{-3})^2 \quad [W / kg] \quad (2)$$

Hysteresis losses

$$Ph = kh * f * Bm^{1,5 \text{ a } 2,5} \; [W/kg] \quad (3)$$

Where,

- Bm – maximum value of flux density;
- f - frequency in Hz;
- Kh – Steimmetz coefficient (depends on material type and thickness of the layers of the according nucleus);
- Ke – Eddy constant;
- d - plate thickness in mm;

The calculation, agreed with the tariff, i.e., the quantity of lost energy in the transformer is given through the following formula:

$$\text{Total Losses (PT)} = Pfe + Pcu * Fu\ 2 \quad [KW] \quad (4)$$

Where,

- Pfe = constant of the transformer or else calculated using the formulas of Pe and Ph [KW];
- $Pcu = I^2 * R$ [KW];
- Fu (Load Factor) = Maximum power (kW) / Nominal power transformer (KVA) [KW].

Loss factor:

$$Fp = K * Fc + (1 - K) * Fc^2 \quad (5)$$

Where,

- K = Constant between 0 and 1;
- Fc (Load factor) = Consumption (months) [kWh] / (maximum power consumption [kW] * 730 [h] (*));
- (*)Relates to the period considered (96-15m 48-30m 24-60m, etc.);

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Power Factor:

PF = Active power / Apparent power = KWh / kVar (6)

6. 2 Losses in Capacitors

The relative losses for equipments of the reactive allowance, (fixed condensers and controlled) are given in relation to the grade of use by the distribution companies. In cases where the use is not highly significant, an affected bibliography study indicates its inclusion in the various losses.
The losses from the condensers are measured in Watts per kVar installed and varied relating to the typed of isolation used in its fabrication. Condensers that use a film isolator have specific losses of the order of 0.25 W/kVar. Condensers that use an infused paper isolator have specific losses around the order of 2 to 3 W/kVar.

The calculation of the losses in condensers can be made through the following formula:

$$\Delta P_{cap} = \Delta_{pcap} \times kVar \qquad (7)$$

Where,

- ΔPcap - Potential loss in the condenser;
- ΔPpcap - Specific loss within the type of isolator;
- kVar - nominal power of capacitor installed.

For a group of distribution condensers, the energy losses can be defined by:

$$\bar{\Delta W}_{cap} = \Delta P_{cap} f \times \bar{T} + \Delta P_{cap} c \times t \qquad (8)$$

Where,

- ΔWcap - Energy losses in the capacitors;
- ΔPcap f- Potential loss in the fixed capacitors;
- ΔPcap C - Potential loss in the controlled condensers;
- T - Analysis period;
- t - Connection time of the controlled capacitors.

6.3 Losses in the Secondary Network

The distribution network of the three-phase system of electrical energy companies is normally used for feeding of routes and public or private buildings, generally supplying 230V between phases, being aerial or subterranean kind.

General Considerations

The proposed model allows, from the acquired data from the concessionary relative of the consumers and the topology of the secondary network and the given data for the typical curve of the residential consumer charge, commercial and industrial, estimates the losses in all the sectors of the secondary network, by phase, such as the use of TC's (Transformation Centers). The methodology allows for a determination of the consumption of each point of charge (post), in 96 intervals of 15 minutes that compound a typical 24-hour day, once they are known there are charge curves in kW of all the consumers connected to the secondary network. Knowing which point of charge a certain consumer is connected to, it is easy to determine the curve of charge for each point in the network.

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Representation of the Network

For the electrical calculation of the secondary network, considering that the network is radial and that each end is represented by the phase and neutral conductors (phases A, B, C, and neutral N). The following figure illustrates an end of the secondary network, in which there are supposedly known as currents in three phases (IA, IB, IC) and a neutral current (IN). These currents are obtained from the knowledge of the charge in each one of the points of charge (posts) in the secondary network.

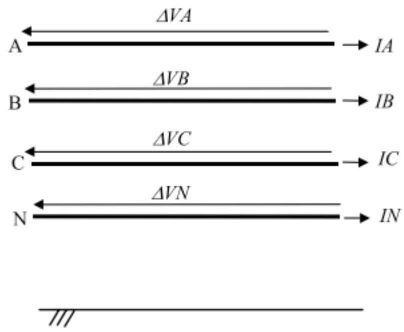

Figure 14. Cables of Secondary Network.

Since the secondary circuit consists of a network cable as the previous Figure shows, to determine the current consists on simply accumulate the current per phase and neutral, relative to the loads corresponding to the downstream sections, as illustrated in Figure 15.

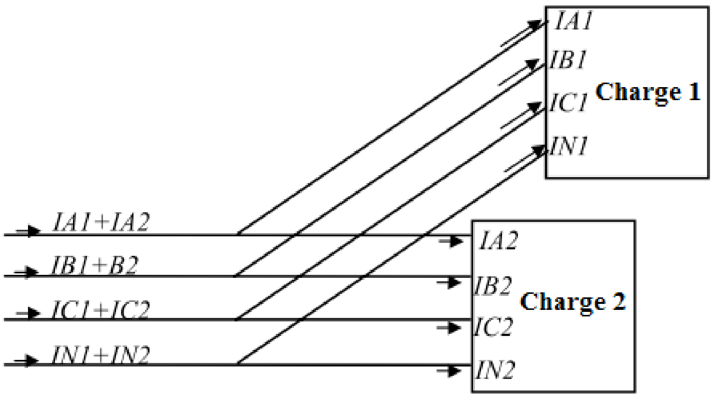

Figure 15. Calculation of Chain Cables.

The procedure for the calculation of the currents in the cables is carried out from the final end cables to the transformation post. Once the currents are determined in all the cables (phases and neutral) the losses in the secondary network can then be calculated. For each cable of the network, the daily energy loss (es) is calculated by:

$$e_s = \frac{1}{1000} \cdot \sum_{t=1}^{96} \left(\sum_{i=1}^{N_{cond}} \left(R_i \cdot I_{i,t}^2 \right) \right) \cdot \Delta t \ \text{[kWh]} \qquad (9)$$

Where,

- Ri - Is the ohms resistance of the conductor i;
- Ii - Is the current in conductor i in the time interval t;
- Δt - Is the interval duration of the daily charge. For a daily curve charge with 96 points, Δt = 0,25h;
- N - Is the number of conductors in the section (including the phase and neutral conductors).

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It is important to note that in the above expression, are considered the possible imbalances that may exist in the secondary network, since it performs electrical calculations per phase.

6.4 Distribution Bands

For the calculation of losses in the connections bands, a typical household per consumer should be defined, with length and ohms resistance of the pre-determined conductors. An example is presented in the following table with typical values.

Table 1: Resistance and lenght of cables used in distribution bands

Class of final consumers	Resistance (ohm/km)	Length (m)
Residential (m)	3,08	15
Commercial	0,77	20
Manufacturing		
Parte superior do formulário		
CountrifiedParte inferior do formulário		
Others		

In this way, the daily energy loss (e_r) in the connection band of a consumer will be obtained by:

$$e_r = \frac{k \cdot R \cdot L \cdot \Delta t \cdot \sum_{i=1}^{N_t} I_i^2}{1000} \text{ [kWh]} \qquad (10)$$

Where,

- K - Number of conductors in the connection band that takes the current;
- R - Is the ohms resistance of the conductors;
- L - The average length of the band;
- Ii - The current in the band from the period i of the day;
- Δt - Duration of the interval of the charge curve;
- Nt - Number of periods of the day.

The value of the current in each period of the day will be obtained through telemetry that gains the monthly energy consumption and its daily curve of the typical charge in 96 points that results in an interval (Δt) equal to 0.25 h (15 min). In the case of the telemetric meters will be obtained through the previously described method. Considering the model of the adopted charge, the neutral conductor will present no current for the dual-phase consumers (supplied by a mono-phase transformer or delta) and tri-phase thus uses k = 2 for mono-phase and dual-phase consumers supplied by mono-phase and delta transformers and k = 3 for three-phase consumers and dual-phase supplied by three-phase transformers.

The consumer loss by counter normally varies between 1.2 to 1.5 W. A pair of coils for each phase composes the active energy meters. Therefore, the mono-phase and tri-phase meters have respectively, 1 and 3 coil pairs. A potential coil and a current coil constitute each coil pair. The loss that occurs in the current coil is payed by the consumer, once the meter registers this loss. Although the potential loss in the coil is assumed by the energy distributor. The potential consumer loss in the coil does not vary at different periods of the day, as it is already under constant tension, which means that the consumer loss in the counter is assumed as independent from the charge. Therefore, to calculate the consumer energy loss in the sections of the energy meters, it is enough to know the value of the consumer loss by the element indicator and total quantity of the mono-phase, dual-phase and tri-phase meters.

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Therefore, the calculation of the loss in the energy meters is obtained by the following formula:

$$Ptc = \frac{k * Nc * (j1 + 3*j3)}{1000} \quad [KW] \qquad (11)$$

Where,

- Ptc - Total energy loss of the electro mechanic meters;
- K - Consumption of the electro mechanic conductors;
- Nc - Total number of meters;
- J1 - Percentage of mono-phase meters;
- J2 - Percentage of tri-phase meters.

Supposing that the quantity of the mono-phase and tri-phase conductors were, respectively, N1 and N2. We are able to calculate j1 and j2, by using the following equations, being Ntotal the total numbers of meters or rather, N1 + N2:

$$j1 = N1 / Ntotal \quad (12)$$

$$j2 = N2 / Ntotal \quad (13)$$

As the consumption loss in the energy meters is constant (or rather the counters are always connected), the loss factor is equal to 1.0 and the energy loss is calculated by using the following formula:

$$PEc = PTc * \Delta t \ [kWh] \quad (14)$$

Where,

- PEc - Energy loss in the meters in a temporal space;
- PTc - Is the consumption loss in the energy meters;
- Δt - Is the time of analyse.

Telemetry Meters

Due to the various sources, the energy meters using telemetry, with the supplied tension up to 120 V have a consumption of 2.5 W.

The indicators with the supplied tension up to 240 V present a consumption of 5.1 W. Having said this, they should sum 0.07 W for each phase of the current in order to know the total consumption of the counter. The above-indicated values are just for the energy counter.

It should be noted that, owing the limitation of the current and the tension of the counter, the measurement should be taken indirectly, or rather, with the relief of the transformer currents (TC) and potential transformers (PT). The advantage of this type of conductor is the significant reduction of fraud by the way it proportionates the measuring, allowing for a reduction in the non-technical losses.

7. CASE STUDY

In this case study we will determine the energy losses associated with a post processing in a given month, analyzing all segments from the post processing to the final consumer, using the formulas described in the previous chapter, where we can identify the various existing segments of a distribution network in LV (low voltage).

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7.1 Calculation of Total Energy Losses

The first point to consider is the comparison between the energy injected into the TC before the transformer (EDP – Energias de Portugal invoice, in this case study, regarding Portugal country or other distributor of energy) and the total charged to the final electrical energy consumers.

$$\text{Pt Energia} = \text{TEir} - \text{TEfcf} \qquad (15)$$

Where,

- Pt Energia - Total energy losses;
- TEir - Total energy injected into the network before the post processing
- TEfcf - Total Energy charged to final consumers.

The table and graph below show the value of (TEir) for the four elements measured during the (01/09/2011 to 30/09/2011):

Table 2: Value of TEir (KWh/Kvar/KW)

Measured elements	TEir (kWh / Kvar / KW)
Full Active Energy	9.137,283
Active Power Tip	1.402,687
Energy Super Active Empty	2.405,678
Normal Power On Empty	4.953,551

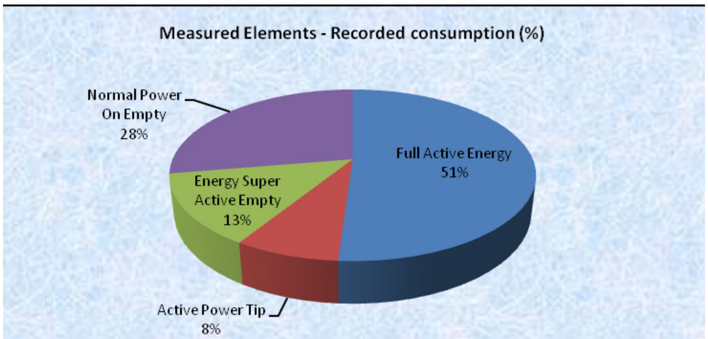

Figure 16. % of Measured Elements (TEir).

The table and figure below show the value of (TEfcf) for the four elements measured during the period (01/09/2011 to 30/09/2011):

Table 3 : Value of TEfcf (KWh/Kvar/KW)

Measured elements	TEfcf (kWh / Kvar / KW)
Full Active Energy	8.223,555
Active Power Tip	1.262,418
Energy Super Active Empty	2.165,110
Normal Power On Empty	4.458,196

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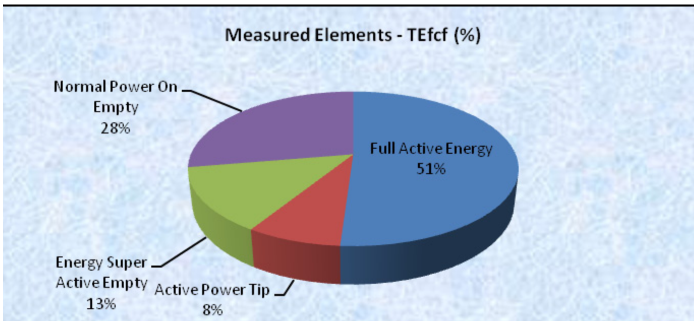

Figure 17. % of Measured Elements (TEir).

With the Table 4, we make a comparison of TEir with TEfcf and we can calculate the electrical losses of energy.

Table 4: Calculations of Pt Energia (KWh/ Kvar / KW)

Measured elements	TEir (kWh / Kvar / KW)	TEfcf (kWh / Kvar / KW)	Pt Energia (kWh / Kvar / KW)
Full Active Energy	9.137,283	8.223,555	913,728
Active Power Tip	1.402,687	1.262,418	140,269
Energy Super Active Empty	2.405,678	2.165,110	240,568
Normal Power On Empty	4.953,551	4.458,196	495,355

In the following table we can see the expected range of technical losses in the distribution network at low voltage through the segment of the distribution network we are considering.

Table 5: Expected range of Tp Técnicas (%)

Segment	Expected range of (Tp Técnicas) (%)
Distribution Transformer	50 - 80
Secondary Network	15 - 28
Branch lines	0,5 - 2,5
Meters	2 - 5,5
Orhers	4 - 10

We can describe the lost of energy by:

$$\text{Pt Energia} = \text{Tpte} + \text{Tpnte} \qquad (16)$$

Where,

- Pt Energia – Total energy lost in a specific month;
- Tpte – Total technical losses of electricity;
- Tpnte – Total non-technical losses of electricity.

7. 2 Calculation of Total Technical Losses of Electricity

$$\text{Tp Técnicas} = \text{Dt} + \text{Sn} + \text{Bl} + \text{Meters} + \text{Others} \qquad (17)$$

Where,

- Dt - Energy losses in distribution transformer electricity;
- Sn - Energy losses in the secondary network distribution system of electricity;
- Bl - Energy losses in the branches of the distribution of electricity;

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- Meters - Energy losses in energy meters of the distribution of electricity
- Others.

Calculation of Dt (Energy losses in distribution transformer electricity)

To calculate the value of Dt (kWh / Kvar / KW) we have to use all the formulas provided on section 6.1.

Table 6: Results of Dt (kWh / Kvar / KW)

Measured elements	Dt (kWh / Kvar / KW)
Full Active Energy	383,766
Active Power Tip	58,913
Energy Super Active Empty	101,038
Normal Power On Empty	208,049

Calculation of Sn

To calculate the value of Sn (kWh / Kvar / KW) we have to use the all formulas of section 6.2.

Table 7: Results of Sn (kWh / Kvar / KW)

Measured elements	Sn (kWh / Kvar / KW)
Full Active Energy	109,647
Active Power Tip	16,832
Energy Super Active Empty	28,868
Normal Power On Empty	59,443

Calculation of Bl

To calculate the value of Bl (kWh / Kvar / KW) we have to use all the formulas of section 6.3.

Table 8: Results of Bl (kWh / Kvar / KW)

Measured elements	Bl (kWh / Kvar / KW)
Full Active Energy	10,965
Active Power Tip	1,683
Energy Super Active Empty	2,887
Normal Power On Empty	5,944

Calculation of Meter Losses

To calculate the value of meters losses (kWh / Kvar / KW) we have to use all the formulas of section 6.4.

Table 9: Results of Bl (kWh / Kvar / KW)

Measured elements	Meters (kWh / Kvar / KW)
Full Active Energy	21,929
Active Power Tip	3,366
Energy Super Active Empty	5,774
Normal Power On Empty	11,889

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Estimated value of others kind of losses

Other kind of losses can be de considered as shown in Table 10.

Table 10: Results of Others (kWh / Kvar / KW)

Measured elements	Others (kWh / Kvar / KW)
Full Active Energy	32,894
Active Power Tip	5,050
Energy Super Active Empty	8,660
Normal Power On Empty	17,833

Analyse of results of calculated electrical energy losses

Through the following tables (11 and 12) and by observing figures 18 and 19 below, we can observe the Pt Energy (total loss of electricity) and associated technical losses, which are a part of the total losses, could be demonstrated to be some of the technical losses that represent the largest amount of energy losses along a LV distribution network.

Table 11: Results of each calculated measured elements of losses

Measured elements	Recorded consumption (kWh / Kvar / KW)	TEfcf (kWh / Kvar / KW)	Pt Energia (kWh / Kvar / KW)	Technical losses (kWh / Kvar / KW)
Full Active Energy	9.137,283	8.223,555	913,728	548,236
Active Power Tip	1.402,687	1.262,418	140,269	84,161
Energy Super Active Empty	2.405,678	2.165,110	240,568	144,340
Normal Power On Empty	4.953,551	4.458,196	495,355	297,213

Table 12: Analysis of energy losses and margin of error of calculations

Measured elements	Pt Energia (kWh / Kvar / KW)	Técnhnical losses (kWh / Kvar / KW)	Tpnte (kWh / Kvar / KW)	Calculated Error (kWh / Kvar / KW)
Full Active Energy	913.728	548.236,98	274.118,49	91,372
Active Power Tip	140.269	84.161,22	42.080,61	14,026
Energy Super Active Empty	240.568	144.340,68	72.170,34	24,056
Normal Power On Empty	495.355	297.213,06	148.606,53	49,535

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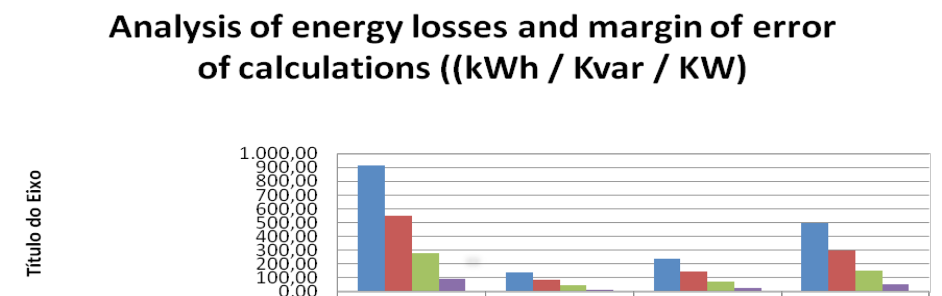

	Full Active Energy	Active Power Tip	Energy Super Active Empty	Normal Power On Empty
Pt Energia (kWh / Kvar / KW)	913,73	140,27	240,57	495,36
Técnhnical losses (kWh / Kvar / KW)	548,24	84,16	144,34	297,21
274,12 42,08 72,17 148,61	274,12	42,08	72,17	148,61
Calcule Error (kWh / Kvar / KW)	91,372	14,026	24,056	49,535

Figure 18. Analysis of Energy Losses and Margin of Error of Calculations.

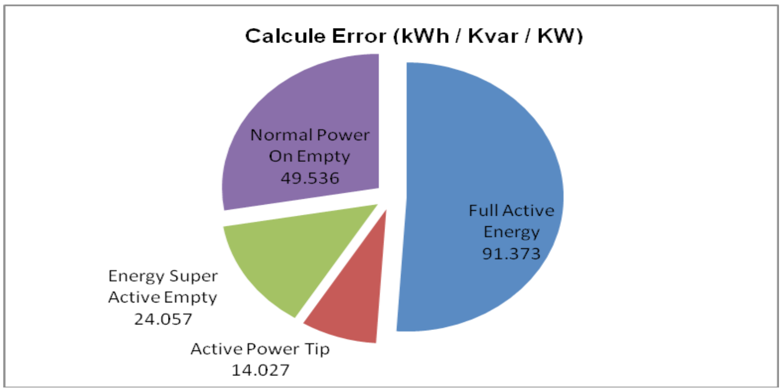

Figure 19. Margin of Error () of the Calculations for Determining Energy Losses.

Through the calculations throughout this case study we were able to verify that this application is a valuable tool for all power distribution companies that want to be able to properly manage an electrical energy distribution network, and in particular regarding electrical energy losses determination. As we can see by looking at the results provided in this paper, the margin of error for the calculation of energy losses are in the order of 1%, although that this value for the case study underlying to this work, which was applied to a relatively small context. However the developed application is being prepared for being further applied to a much bigger flow of information, for analyzing a large number of transformer centers simultaneously.

9. CONCLUSION

This work presented an ongoing project related with the development of a system for monitoring and managing an electrical energy distribution network. The system features allow for the definition of an interface for each user, customizing and configuring the system according to each interests and needs. The system can also to be easily adapted and new features may be implemented, according to future specific requirements. The work conducted so far allowed for the characterization of the distribution network, including the geodesic survey, the physical description in terms of infrastructure, the technical and behavioral characteristics of the network, and the assessment of connection points and ways of connecting networks and customers and technical information retrieval and calculation, namely regarding energy losses determination.

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The implementation of the system and the collection of main information, mainly related to various types of losses, technical and nontechnical ones have been a major effort required in this research work and this phase is already at an almost finished stage of development.

As the next step in order to come to an effective analysis of the quality of customer service, by the operator of the distribution network, the system will be fully implemented and put forward for a daily base use. The main objective is to allow, measuring and continuously localizing losses in order to obtain information about real-time behavior of an electrical energy distribution network, and thus about the power quality and the overall service provided to customers.

The ultimate goal of this system is to be able to offer various features that may help providing essential information about the quality of service to each individual customer, allowing them to be proactive on the resolution of potential problems.

Among the expected general benefits are the enhancement of the overall improvement in quality of service, the significant reduction in response time to failures of network management and better customer service line. The quality of service is a current need of the markets; the system service quality and efficiency record all complains cuts and changes in delivery of consumption, among other data. These data enable the customer to analyze and verify the service that is being provided as well enable the supplier to access the needs for action by using a combination of automatic and manual processes. The system is being implemented to allow a continuous acquisition and recording of events on file that result in the detection of anomalies related to power quality and its losses among other important electrical energy distribution control parameters. The information gained can, therefore, be viewed in tables and/ or graphics, and thereafter generate reports in order to support decision-making. The reports also can be sent directly to the printer and inserted into other windows applications or further use, and can also be accessed via the Internet by using a web browser.

Another important feature about the operation of this system is related to the possibility of being integrated with other systems or sub-systems, taking advantage of the potential it has for communicating with Internet applications based on web technology, for example, by implementing remote access to systems for data acquisition or even use wireless technology.

In this paper the use of the system developed has been illustrated through a case study, regarding energy losses determination along a distribution network in low voltage. Moreover, the calculations provided were compared with a reference value provided by a Portuguese electrical energy distribution and management company (EDP) and the proposed system enabled to formally calculate a total amount of energy losses along that distribution network and this total value was compared with the estimated value provided by the referred company, which was closely related to the one determined.

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