Proceedings of the First ELECON Workshop

Towards Efficient European and Brazilian Electricity Markets

ELECON

ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY

September 24-25, 2013
Institute of Engineering - Polytechnic of Porto
Porto, Portugal

www.elecon.ipp.pt

Towards Efficient European and Brazilian Electricity Markets

First ELECON Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, September 24-25, 2013.

Contents

ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY
www.elecon.ipp.pt

Towards Efficient European and Brazilian Electricity Markets
First ELECON Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, September 24-25, 2013.

Evolution of Distribution Grid Planning Rules Considering the New Smart Grids Paradigms

Victor Gouin[a], Marie-Cécile Alvarez-Hérault[a], Bertrand Raison[a]

[a]*G2ELab, 11 rues des Mathématiques, 38402 Saint Martin d'Hères, France*

Abstract

The planning of distribution networks consists in choosing the necessary investments to satisfy the electricity supply respecting the technical, economic, environmental and social constraints. Until now those choices corresponded to the former networks: big and centralized energy plants feeding in a unidirectional way conventional and passive loads. With the development of renewable energies, information and communication technologies, storage technologies and electric vehicles, the major technical choices for distribution grids can be questioned since new solutions appear to ensure the good operation of the network. Thus rules for planning have to be adapted to those new paradigms in order to answer the new challenges while taking into account this new operation modes.

Keywords: Smart Grids ; Distribution Networks ; Planning ; Architectures ; Distributed Generation ; Optimization ; Monte Carlo

1. Optimization of traditional planning

The choice of the architecture – i.e. choosing the way to build lines between the loads (MV loads and MV/LV substations) and the sources (HV/MV substations) – is one of the main steps of the planning. The studied networks are French and take place in urban area, so the reference architecture is the secured feeder architecture because of its extensive use and its simplicity. Each line goes from a source, then feeds several loads and finally ends in the same or another source. This structure guarantees a good quality of supply thanks to the possibility of switching the sources when a fault occurs, by changing the location of the normally opened switch along the line.

1.1. Objective functions and settings

Algorithms to optimally build the architecture of distribution grids have been developed. The main objective for those algorithms is to reduce the total length of conductors in the network because it strongly influences the investments costs – conductors and trenches – and the costs of technical losses and energy not supplied. In order to well evaluate the real length of conductors, streets were taken into account. Location of loads and topology of the streets allow the creation of a graph and the use of methods from the Graph Theory. Thereby optimal paths between the different loads are evaluated and the right orders to connect loads with lines are given by solving the Travelling Salesman Problem.

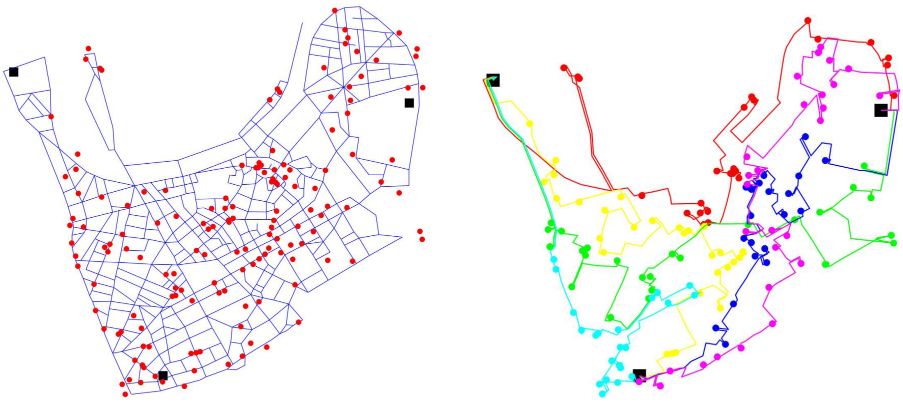

Fig. 1. (a) Map of streets and MV/LV substations; (b) Secured feeder architecture

1.2. Algorithms used for architecture building

The partitioning problem – i.e. the allocation of each load between the different lines – is solved with meat-heuristic methods. The example of the French city Grenoble is used and the results are compared to its real distribution network. The simulated annealing algorithm is chosen because it offers the best results with easy parameters setting, a low variance of results and a low computation time. The gain of length is almost seven kilometers, which represents 17,5 % gain. The weak point of the tested heuristic methods is that the optimality of results is not guaranteed. That is why other methods from the combinatory optimization are currently studied.

Table 1. Comparison between the Grenoble Network and the results of different optimization algorithm.

	Total length of conductors	Cost of cables and trenches	Cost of technical losses over 30 years	Cost of switches and energy not supplied over 30 years	Total cost
Grenoble Network	38,70 km	4 461 k€	134 k€	194 k€	4 789 k€
Ant Colony Algorithm	37,38 km	4 325 k€	146 k€	205 k€	4 676 k€
Genetic Algorithm	35,92 km	4 156 k€	137 k€	194 k€	4 487 k€
Taboo Search	32,84 km	3 795 k€	147 k€	176 k€	4 118 k€
Simulated Annealing	31,90 km	3 696 k€	132 k€	168 k€	3 996 k€

2. New paradigms of Smart Grids

Automatic tools have been developed in order to help the distribution system operator obtain architectures with minimized costs of investment and operation while respecting the constraints of the traditional planning. The second objective is to propose new type of architectures and rules for planning that will increase the insertion rate of distributed generators (DG) and none-conventional loads in the distribution networks.

The first step to build new architecture more robust to a massive insertion of DGs is to use analyzing tools that can evaluate the insertion capacity of a distribution network. Stochastic tools were already developed[1]. They are based on Monte Carlo method. Each experience of Monte Carle consists on a randomly generated case of insertion of DGs. The number, the location and the power of the generators and randomly chosen. The only parameter is the insertion rate of DGs in the network, which is:

$$\tau = P_{GED} / P_{Network}.100 \text{ (in \%)} \quad (1)$$

Where P_{GED} is the maximal total power of the DGs and $P_{Network}$ the maximal total consumption of the network. For example, an insertion rate equal to 50 % means that half of the consumed power in the network is produced by the DGs. For each insertion rate, the probability that the network operates correctly is evaluated and corresponds to:

$$P(\tau) = N_{success} / N_{test}.100 \text{ (in \%)} \quad (2)$$

Where N_{test} is the number of experiences of Monte Carlo and $N_{success}$ is the number of cases for which technical constraints – i.e. voltage and current limitations – are respected. In the following figures we can identify the lines of the networks – for an insertion rate τ equal to 100% – that are more or less sensible to a massive insertion of DGs:

The next step is to locate the risk areas and proceed to reinforcement, creation of new dedicated lines, rebuilding the architecture or anticipate the future operation plan in those areas.

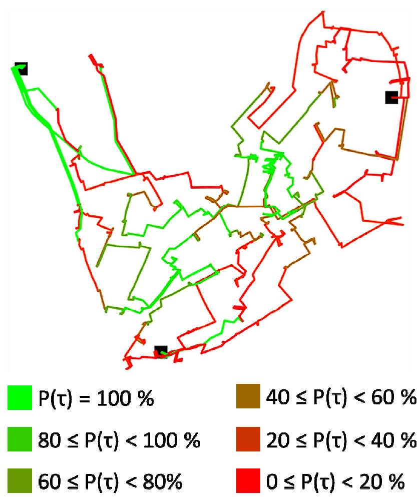

Fig. 2. Probability of good operation for each line of a network for an insertion rate equal to 100%.

References

1. "Architectures of distribution network regarding the penetration of distributed generation", thesis, Marie-Cécile Alvarez-Hérault, 2009

2. "Métaheuristiques pour l'optimisation difficile", J. Dréo, A. Pétrowski, P. Siarry, E. Taillard

3. Acknowledgement

This work is part of the project Greenlys. The Project Greenlys is one of the first large scale Smart Grid demonstrators that will cover the entire electrical system chain. It responded to a call made by the ADEME (Agency of Environment and Control of Energy) in 2009. The investment is 40 M€ and the project will last 4 years and gathers a consortium of complementary partners and representative of the energetic system. Greenlys will test and deploy innovative solutions for the electrical system with setting up of a technological showcase by developing two technological experimental platforms in Lyon and Grenoble to prepare a generalized deployment by 2015.

The future travel of researchers and the research following these results will received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912 (PIRSES-GA-2012-318912).

ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY
www.elecon.ipp.pt

Towards Efficient European and Brazilian Electricity Markets
First ELECON Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, September 24-25, 2013.

Real Time Pricing Approaches to Deal With Unexpected Wind Power Variations

Pedro Faria*, Zita Vale

Polytechnic of Porto
Rua Dr. António Bernardino, 431, 4200-072 Porto, Portugal

Abstract

The use of renewables have been increased I several countries around the world, namely in Europe. The wind power is generally the larger renewable resource with very specific characteristics in what concerns its variability and the inherent impacts in the power systems and electricity markets operation. This paper focuses on the Portuguese context of renewables use, including wind power. The work here presented includes the use of a real time pricing methodology developed by the authors aiming the reduction of electricity consumption in the moments of unexpected low wind power. A more specific example of application of real time pricing is demonstrated for the minimization of the operation costs in a distribution network. When facing lower wind power generation than expected from day ahead forecast, demand response is used in order to minimize the impacts of such wind availability change. In this way, consumers actively participate in regulation up and spinning reserve ancillary services through demand response programs.

Keywords: Demand response, Real time pricing, Renewable energy resources, Wind power.

1. Introduction

Several countries in Europe have increased the electricity generation based on wind power and other renewables in order to meet European Union energy policy goals [1]. As can be seen in Figure 1, Portugal is the third European country with higher renewables use.

* Corresponding author.
E-mail address: pnfar@isep.ipp.pt.

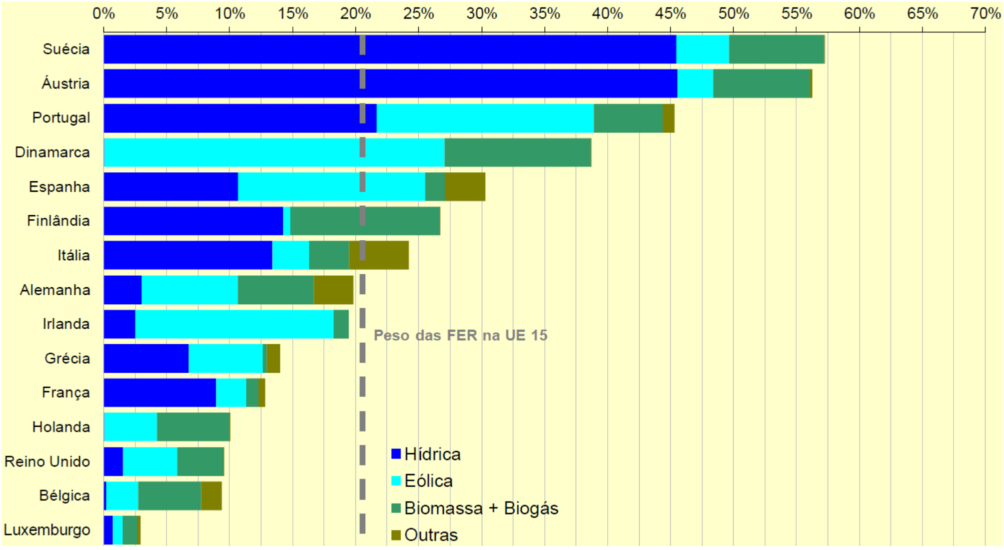

Fig. 1. Renewables use by country in 2011 [2]

Following the European Union tendencies and directives, Portugal is currently one of the countries with higher wind energy penetration (percentage of demand covered by wind energy). The evolution of wind power generation, from 2003 to 2011, in Portugal is presented in Figure 2 [2]. 8000 MW of wind power generation are expected for 2020, which corresponds to an increase of 100% in the value of the year 2010 [3].

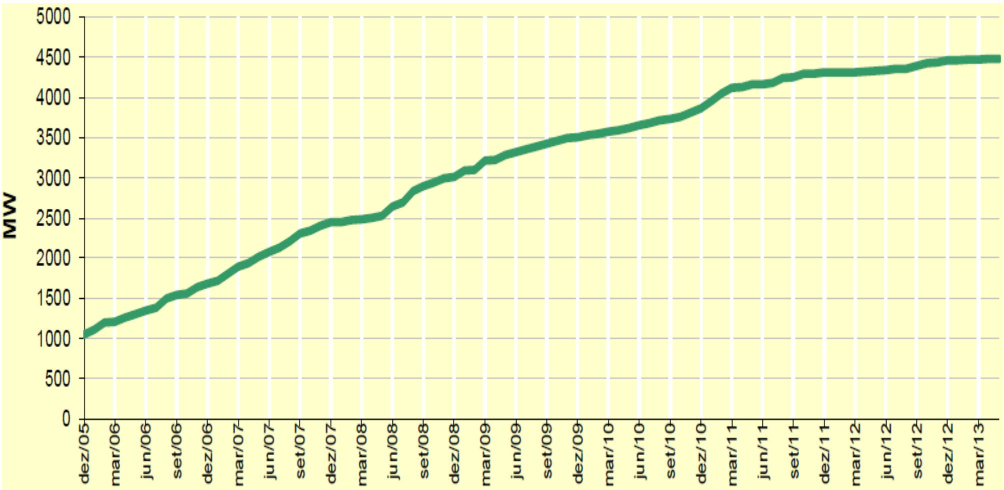

Fig. 2. Wind energy use in Portugal [2]

Focusing on distribution power grids, and on electric power systems in general, one can also note that the increasing use of Distributed Generation (DG), the creation of Demand Response (DR) programs [4], and the increasing requirements in terms of energy quality and network reliability aim at bringing to practice the concept of smart grid (SG) [5]. The aggregation of small-scale distributed resources, as well as their operation, in a competitive environment leads to the creation of Virtual Power Players (VPP) [6]. VPP can aggregate

diversity of players and of energy resources, including DR, making them profitable.

An important issue related to wind power generation is the large variability of wind power and the lack of accuracy in day ahead wind forecast. Demand response can be efficiently used to address this problem [7-10]. Adequate concerns must be given to the provision of reserve in order to maintain adequate levels of security in the power systems' operation [11].

Real Time Pricing (RTP) can be used in order to give signals to the consumers aiming a desired consumption increase or reduction. The methodology presented in this paper uses RTP to address the problem of unexpected low wind power situations.

After the introductory section, Section 2 presents some facts concerning the unexpected low wind power situations in Portugal. Then, in Section 3 the methodology is explained. A case study based on a real scenario adapted to a distribution network is presented in Section 4. Finally, Section 5 presents the main conclusions of the paper.

2. Wind power and renewables in Portugal

The present section includes some facts concerning renewables use (sub-section 2.1) and low wind power situations (sub-section 2.2) in Portugal.

2.1. Renewables in Portugal

In order to illustrate these resources amount in the past years, Figure 3 shows the renewable-based installed power and the generated energy per year since 1995, whereas Figure 4 focuses on the wind generation since 2009.

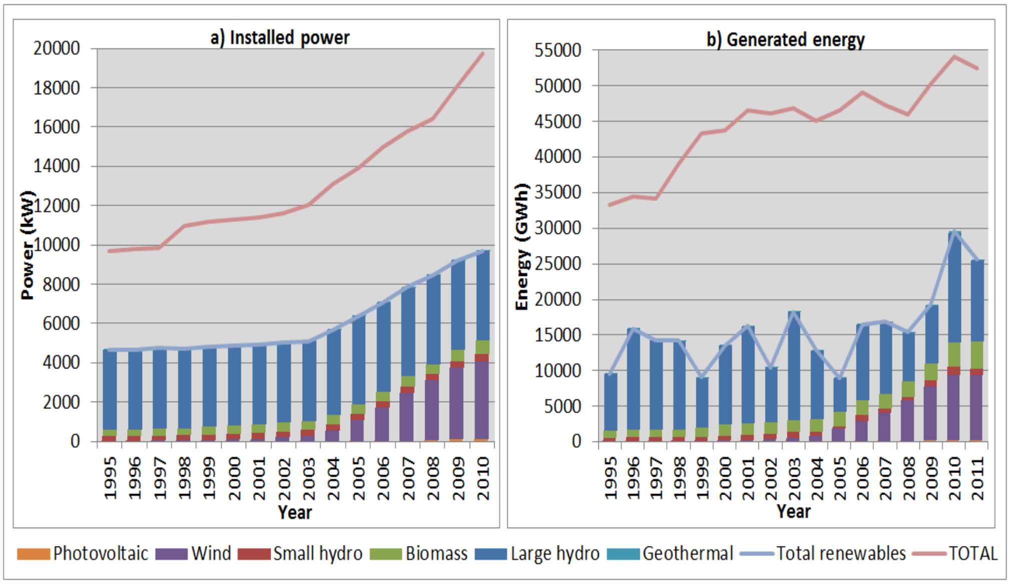

Fig. 3. Renewables installed power (a)) and generated energy (b)) in Portugal in past years [12].

In what concerns the renewables integration and contribution in the Portuguese power system, it can be seen that renewables are very significant. The large hydro power plants, which have been installed even before the recent year's environmental concerns and policies, are the most significant resources. Looking at the remaining resources, it is concluded that the wind power is the resource with higher contribution.

Focusing on the wind power over the recent years in Figure 4 one can see that winter months are generally the ones with higher generation. Note that in April 2013 there was a huge generation when compared with the values in the same month of other years.

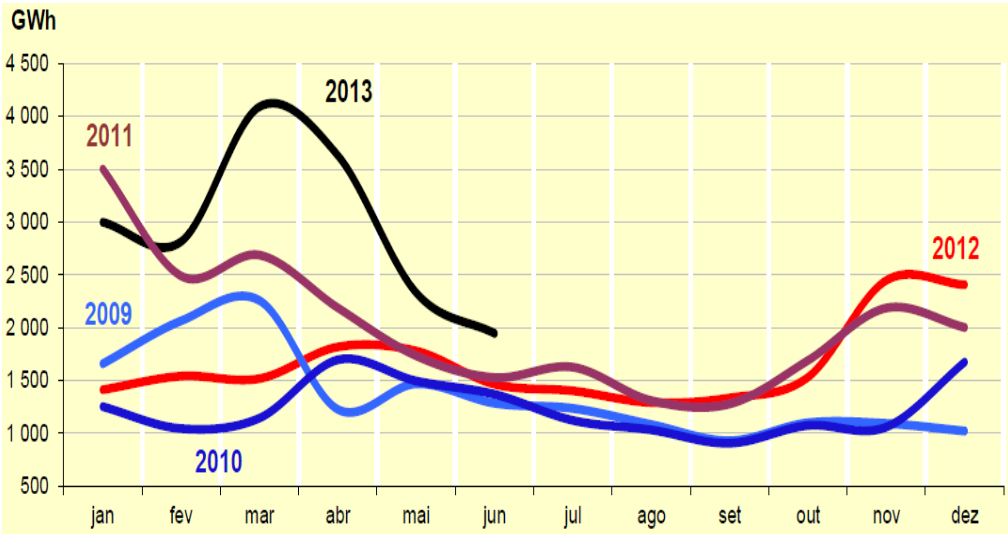

Fig. 4. Wind generation in Portugal since 2008 [2]

Concerning the generation mix in October 2012, the total amount of electricity generation was 3155 GWh. The installed power was 12053 MW [13]. Portugal has exported 40 GWh of energy to Spain, while Spain has exported 852 GWh to Portugal, during October 2012.

It is important to note that the generation mix regarding PRE is not negligible (about 30 %). As PRE producers are benefiting from special tariffs, it is important to take the most possible advantage of the energy available from these producers.

From the facts above, one can say that the wind power generation is not negligible and adequate importance must be given to the integration of this resource.

2.2. Specific low wind power days

The present sub-section shows some real examples of unexpected low wind power situations in Portugal. A certain error is acceptable in the forecast of the resources based in renewables. The specific case of wind is of most difficulty of prediction. Moreover, due to its huge integration in power systems, the errors in the wind forecast are very important.

Figure 5 presents some examples of the difference between the forecast (in grey color) and the actual (in blue color) wind power generation in Portugal. The three specific examples belong to a) April 29th 2013; b) March 23rd 2013; c) March 28th 2013. The green line in Figure 5 represents the total installed wind generation capacity.

It can be seen that the huge differences between the forecast and the actual values can occur in any period of the day, and any wind power generation level, i.e. in periods of low and high wind power generation.

In the present paper, the scenario of October 17th has been selected in order to ilustrate the application of the proposed methodology, which is intended to make use of real time pricing in unexpected wind power situations in order to reduce the consumption and meet the actual wind power value.

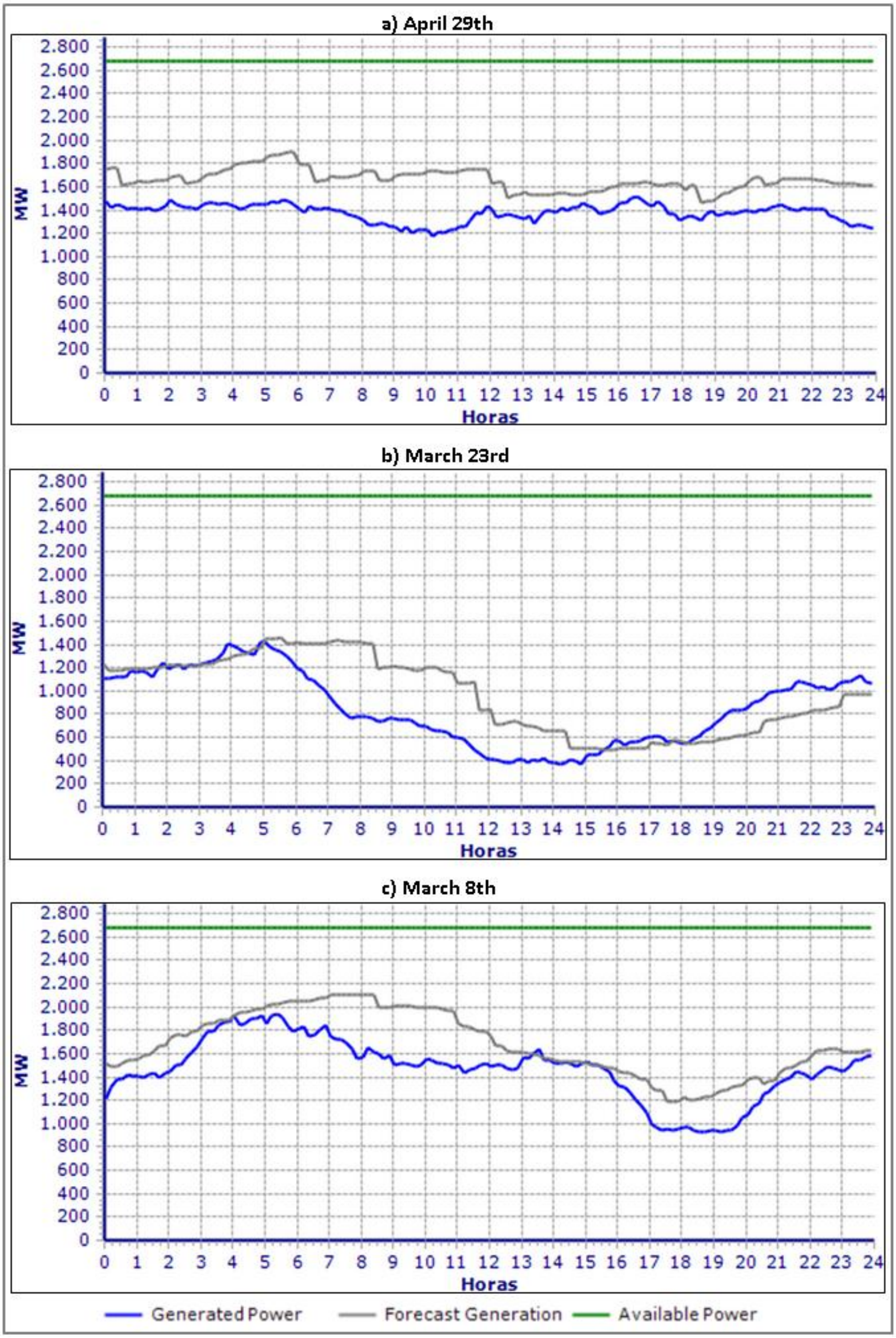

Fig. 5. Examples of wind power generation forecast and actual values in 2013

3. Resources scheduling model

The present section explains the developed demand response methodology, which is based on real time pricing. It aims to reduce the unexpected low wind power generation impacts. Figure 6 presents the conceptual design of the methodology. As the wind generation and other natural sources based generation are wasted if not used, and their generation is anyway paid, and, moreover, its amount is lower than the envisaged load demand, the real time pricing application envisages making the demand equal to actual values of generation.

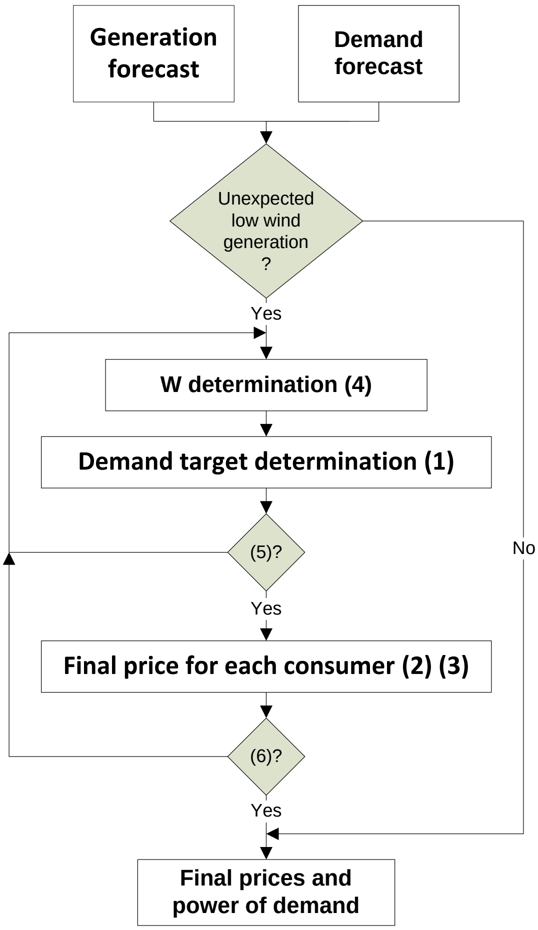

Fig.6. Proposed methodology diagram

In the day-ahead planning of the operation of the system, the forecast of both demand and generation are performed. For the periods in which the wind power generation is, in the hour-ahead operation planning, lower than the day-ahead wind power forecasted generation, an increase in the price of electricity is calculated in order to induce a reduction in the consumption. The consumer response to the changes in the electricity price is performed using the concept of price elasticity of demand.

The first step to calculate the variation in the electricity price (i.e. the final price), considered equal in this methodology for the consumers of each consumer type, is to determine the weight (W) of each consumer type in the load diagram. After this, using the

expression (1), it is possible to determine the demand variation (*reduction*) target for each consumer type. It is important to verify if the determined demand variation targets respect the maximum permitted variation for each consumer type (5). This value is based on the impossibility of consumers largely reduce the demand. If some violation is verified, the consumer types weights (*W*) are updated.

$$Demand_{Var(Type)}^{Target} = \left(PRE - Demand_{Initial}^{Total}\right) \times W_{(Type)}, \forall Type \quad (1)$$

$$Price_{Var(Type)} = \frac{Demand_{Var(Type)}^{Target}}{Demand_{Initial(Type)} \times Elasticity_{(Type)}}, \forall Type \quad (2)$$

$$Price_{Final(Type)} = Price_{Initial(Type)} + Price_{Var(Type)}, \forall Type \quad (3)$$

$$\sum_{Type=1}^{NType} W_{(Type)} = 1 \quad (4)$$

$$Demand_{Var(Type)}^{Target} \leq Demand_{Var(Type)}^{Max}, \forall Type \quad (5)$$

$$Price_{Var(Type)} \leq Price_{Var(Type)}^{Max}, \forall Type \quad (6)$$

where,

$Demand_{Var(Type)}^{Target}$	Demand variation target for each consumer type [MW]
PRE	Power available from special PRE generators [MW]
$Demand_{Initial}^{Total}$	Total initial demand for all the consumers types [MW]
$W_{(Type)}$	Weight of each consumer type in the load diagram
$Type$	Each one of consumer types
$NType$	Total number of consumer types
$Price_{Var(Type)}$	Electricity price variation for each consumer type [€/MWh]
$Demand_{Initial(Type)}$	Initial value of demand for each consumer type [MW]
$Elasticity_{(Type)}$	Price elasticity of demand in each consumer type
$Price_{Final(Type)}$	Final value of electricity price, for each consumer type [€/MWh]
$Price_{Initial(Type)}$	Initial value of electricity price, for each consumer type [€/MWh]
$Price_{Var(Type)}^{Max}$	Maximum permitted electricity price variation, for each consumer type [€/MWh]
$Demand_{Var(Type)}^{Max}$	Maximum permitted demand variation for each consumer type [MW]

After determining the demand variation target for each consumer type, it is possible to determine the price variation (*increase*) to be applied to each consumer type, using expression (2) that considers the referred concept of price elasticity of demand. As the price of electricity can't be largely increased, it is necessary to verify if the determined price variations respect the maximum established price variation values (6). If some violation is verified, the consumer types weights (*W*) are again updated. The results of the application of the model are the final electricity prices and the update demand forecast, for each consumer type.

The authors have also developed an improved model already presented in [14]. It aims to reduce the impacts of wind generation largely lower than the forecasted value, optimizing the operation of a VPP. Figure 7 presents a scheme that represents the use of each resource.

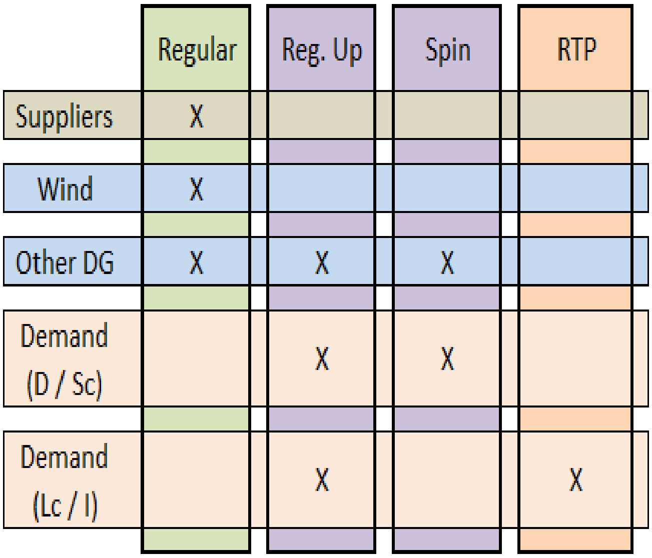

Fig. 7. Proposed resources use methodology diagram [14]

The available resources (energy supplier, wind generation, other distributed generation units, and demand response) are participating in the resources scheduling as a regular resource, as providing regulation up (Reg. Up) and spinning (Spin) reserves, and in the case of consumers, participating in real time pricing demand response programs.

Regulation up and spinning reserves, and real time pricing are used to meet the variations in the wind power value. The regulation up service is used in lower variations in wind power, whereas spinning reserve is used for higher wind power variations. The two reserve services (regulation up and spinning reserve) when provided by consumers, belongs to the group of incentive-based demand response programs. Real time pricing belongs to the group of price-based demand response programs.

The objective function of the proposed Mixed Integer Non Linear problem aims at the minimization of the Operation Costs (OC). It considers the values of both generation and demand (consumers divided in Domestic (D), Small commerce (Sc), Large commerce (Lc), and Industrial (I)) resources.

The results of the application of the model are the final electricity prices and the scheduling of each one of the energy resources, including the information of the context of using the resource (regular, Reg.Up, Spin, and RTP).

4. Case study

The present section illustrates the application of the proposed methodology to a distribution network in which the authors have implemented a scenario that corresponds to the real conditions of a certain day in Portugal (sub-section 4.1). The results of the case-study are presented in sub-section 4.2.

4.1. Scenario

The defined scenario is based on a 33 bus distribution network, also used in [15] by the authors of this paper. Both the generation and the demand were updated in order to implement a scenario in the context of a especially lower wind power generation when compared with the forecasted value in the day-ahead planning.

In this case study, the same price variation is considered for all consumers types. The values regarding the initial electricity price, the price elasticity of demand (or simply elasticity), and the initial consumption weights (W), in percent, for each consumer type, are shown in Table 1.

Table 1. Demand parameters for each consumer type

Consumers characteristics	Type of Consumer			
	D	*Sc*	*Lc*	*I*
Initial consumption (%)	20	30	30	20
Elasticity	0.27	0.33	0.41	0.53
Initial price (€/MWh)	130	100	80	60

The consumer types are: Industrial (I), belonging to very high voltage level consumers in Portugal; Large commerce (Lc), belonging to medium voltage level consumers in Portugal; Small commerce (Sc), belonging to special low voltage level consumers in Portugal; and Domestic (D), belonging to low voltage distribution level consumers in Portugal. The rated demand value in this network is 6119 kW.

Regarding DG units capacities, the total amount of rated wind power in the network is 683 kW. The remaining DG has 1495 kW of rated power. There is no defined limit for the amount of energy acquired from the suppliers connected through the bus 0.

Figure 8 presents the resources availability values focusing on the last quarter of the day under study. The values of wind forecast are also shown in figure 8.

In order to ilustrate and validate the application of the porposed methodology to the real conditions of power systems, a special day in the portuguese power system, has been selected. The characteristics of the selected day of the Portuguese power system, namely in what concerns the PRE generation and demand, are presented in Figure 8.

The used energy resources includes, in addition to PRE, imports, coal, natural gas, and other renewables. In the periods in which the generation in Figure 8) is higher then demand, that exceeding generation was used for pumping in order to restore water in dams and use that resource in other periods.

This scenario ilustrates the conditions in which is possible to apply the proposed methodology. In the specific periods of wind power generation lower thatn the forecas, the distribution network operator (which is, in the present approach, a Virtual Power Player – VPP) becomes able to make use the proposed methodology.

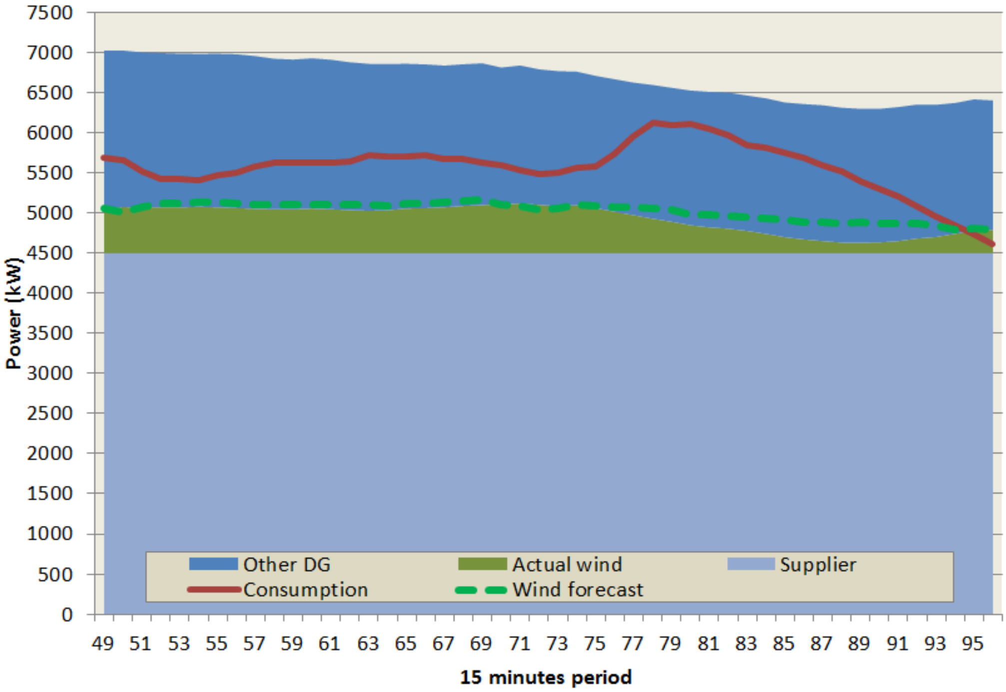

Figure 8: Resources availability values

4.2. Results

The present sub-section shows the obtained results. Figure 9 presents the resources' use after applying the proposed methodology. 15 minutes is the elementary period; the 48 periods in Figure 9 belong to the second half of the day.

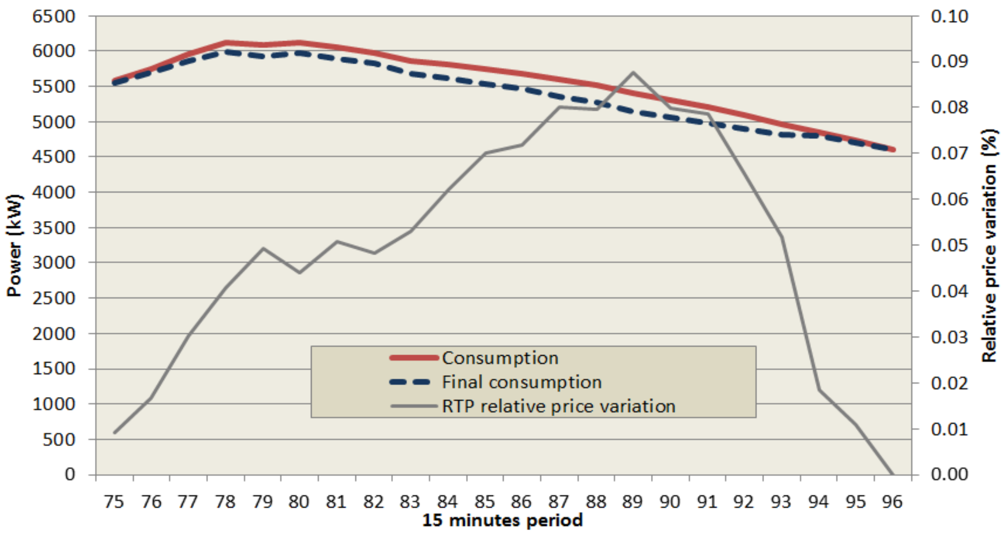

Figure 9: RTP use results between periods 73 and 94

Real time pricing is used in periods of reduced wind power, increasing the electricity price, and expecting a reduction in the demand value. Regulation up and spinning reserve services provided by several resources, are also used in distinct wind forecast errors amounts.

There are two main period sets of wind power lower than the forecast. The first occurs between periods 52 and 68 of the day. The second one corresponds to the period between periods 73 and 94. In the first periods set (between periods 52 and 68), the one with lower difference between the forecast and the actual values of wind power generation, regulation up was used, whereas in the second period it was used the spinning reserve.

Figure 10 shows the values concerning the real time pricing application. It includes the obtained demand after the application of RTP (represented by the dashed black line) in the secound identified period (between periods 73 and 94) instead of using spining reserve to increase generation.

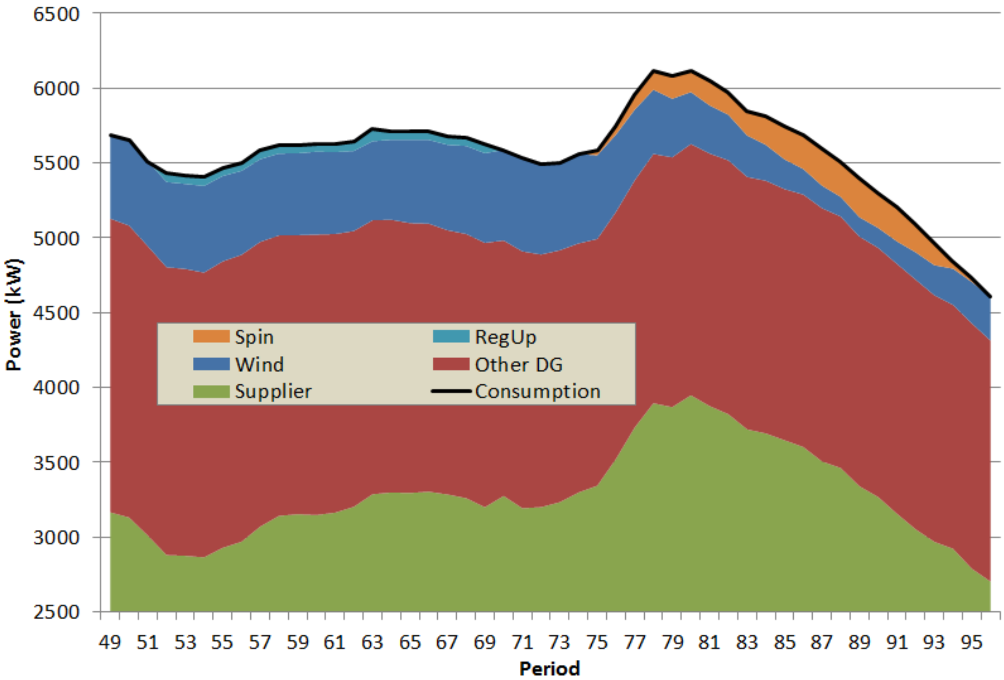

Fig. 10: Generation and demand results

The same price elasticity of demand was considered for the consumers of a certain type. However, since the initial consumption of each consumer is distinct, distinct demand increase is verified in each consumer.

5. Conclusions

The present exposed some facts concerning renewables, namely wind power and low wind power situations. Special focus is given to the Portuguese scenario. The work presented in the paper proposes a DR-based methodology to face situations of wind generation largely lower than the forecasted value. The energy resources use is optimized in order to minimize the operation costs.

The proposed model is especially useful when actual and day-ahead wind forecast differ significantly.

Acknowledgements

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912.

This work is also supported by FEDER Funds through the "Programa Operacional Factores de Competitividade – COMPETE" program and by National Funds through FCT "Fundação para a Ciência e a Tecnologia" under the projects FCOMP-01-0124-FEDER: PEst-OE/EEI/ UI0760/2011, PTDC/EEA-EEL/099832/2008, PTDC/ SEN-ENR/099844/2008, and PTDC/SEN-ENR/ 122174/2010; and SFRH/BD/80183/2011 (P. Faria PhD).

References

[1] C. Klessmann, A. Held, M. Rathmann, M. Ragwitz, "Status and perspectives of renewable energy policy and deployment in the European Union—What is needed to reach the 2020 targets?", Energy Policy, Vol. 39, no. 12, pp. 7637-7657, December 2011.

[2] DGEG, "Renováveis–Estatísticas rápidas", Jun.2013 (Portuguese).

[3] EWEA, "Pure Power – Wind energy targets for 2020 and 2030", 2011, web link: http://www.ewea.org/fileadmin/ewea_ documents /documents/publications/reports/Pure_Power_Full_Report.pdf

[4] P. Faria, Z. Vale, "Demand response in electrical energy supply: An optimal real time pricing approach", Energy, vol. 36, no. 8, pp. 5374-5384, August 2011

[5] G. K. Venayagamoorthy, "Dynamic, Stochastic, Computational, and Scalable Technologies for Smart Grids," IEEE Computational Intelligence Magazine, vol.6, no.3, pp.22-35, Aug. 2011

[6] H. Morais, T. Pinto, Z. Vale, I. Praça, "Multilevel Negotiation in Smart Grids for VPP Management of Distributed Resources", IEEE Intelligent Systems, vol. 27, no. 6, pp. 8-16, Nov- Dec. 2012.

[7] P. Faria, Z. Vale, J. Soares, J. Ferreira, "Demand Response Management in Power Systems Using a Particle Swarm Optimization Approach", IEEE Intelligent Systems, DOI: 10.1109/MIS.2011.35, 2011.

[8] M. D. Ilic, Xie Le, Joo, Jhi-Young, "Efficient Coordination of Wind Power and Price-Responsive Demand—Part I: Theoretical Foundations," Power Systems, IEEE Transactions on , vol.26, no.4, pp.1875-1884, Nov. 2011

[9] A. J. Conejo, J. M. Morales, L. Baringo, "Real-Time Demand Response Model," IEEE Transactions on Smart Grid, vol.1, no.3, pp.236-242, Dec. 2010

[10] Pedro Faria, Zita Vale, Hugo Morais, "A real time pricing approach to deal with excessive wind power situations", EWEA Annual event 2012, Copenhagen, Denmark, 16-19 April 2012.

[11] E. Karangelos, F. Bouffard, "Towards Full Integration of Demand-Side Resources in Joint Forward Energy/Reserve Electricity Markets," IEEE Transactions on Power Systems, vol.27, no.1, pp.280-289, Feb. 2012

[12] DGEG, "Renováveis – Estatísticas rápidas", web page, link: www.dgeg.pt.

[13] Conselho de reguladores do MIBEL, "Boletim mensal MIBEL – Outubro 2012", December 2012 (in Portuguese)

[14] Pedro Faria, Zita Vale, "Virtual Power Player Using Demand Response to Deal with Unexpected Low Wind Power Generation", EWEA Annual event 2013, Vienna, Austria, 4-7 February 2013.

[15] P. Faria, H. Morais, and Z. Vale, "Virtual power players demand response programs management based on locational marginal prices", IEEE PES T&D conference, Orlando, Florida, USA, 2012.

[16] REN, "Centro de informaçao", web page, link: http://www.centrodeinformacao.ren.pt/PT/InformacaoExploracao/Paginas/EstatisticaDiariaDiagrama.aspx

ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY
www.elecon.ipp.pt

Towards Efficient European and Brazilian Electricity Markets
First ELECON Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, September 24-25, 2013.

Smart Grid Communication Technologies in the Brazilian Electrical Sector

Philipp Kühne[a], Ines Hauer[a], Zbigniew A. Styczynski[a], Rubipiara Fernandes[b], Zita Vale[c]

[a]OVGU – Otto-von-Guericke-University Magdeburg 39106, Germany
[b]IFSC – Academic Depart. Of Electr., Florianópolis SC 88020-300, Brazil
[c]IPP - Instituto Politécnico do Porto, Portugal

Abstract

Intelligent electrical grids can be considered as the next generation of electrical energy transportation. The enormous potential leads to worldwide focus of research on the technology of smart grids. This paper aims to present a review of the Brazilian electricity sector in context with the integration of communication technologies for smart grids. The work gives an overview of the generation, transmission and distribution of electrical energy in the Brazil and a brief summary of the current electricity market. Smart grid technologies are introduced and the requirements for the Brazilian power system are pointed out. Various technologies for communication within an intelligent network are presented and their characteristics, advantages and disadvantages are compared to the Brazilian conditions. In addition, a summary is given of current pilot projects for Smart Grid technologies within Brazil, as well as a presentation of individual selected projects.

Keywords: smart grids, communication technologies, intelligent network, communication infrastructure

1. Introduction

With about 200 million inhabitants, Brazil is one of the most populous countries in the world. The total area is about 8.5 million km², making it almost as large as Europe. The country is rich in natural resources such as gold and bauxite and has one of the world's largest oil reserves. Brazil is considered as a global player since long time and has the sixth largest economy in the world. The great economic potential is mainly characterized by the progressive industrialization. Thus it is not surprising that the Brazilian electricity sector is

by far the largest in South America. However, the strong economic development is accompanied by an increasing requirement for energy. In recent years, the growth of demand for electricity was 4.6 % on average per year [*1*].

Brazil has enormous energy potential in the use of water power but this cannot be achieved without serious intervention in the nature environment. For this reason, the Brazilian government is very interested in a modernization of the traditional power sector. Alternative energy sources, such as solar and wind energy, in combination with smart grids can greatly contribute to relief and increasing effectiveness of the electrical network. Furthermore, the security of supply and the power quality can be increased, which is essential for a competitive global economic policy.

The potential of smart grid technology is worldwide considered as very large. All major economies of the world have already begun to shift their focus of research on smart grids. A particularly important point for the successful integration of a communication infrastructure in a major electricity network is the communication technology. Worldwide, many concepts are already available and are currently being tested in various pilot projects. Therefore, it should be the task of this work to give an overview of the Brazilian electricity sector in context with the integration of smart grids.

The paper is structured as follows: After the introduction, a summary of the Brazilian electricity sector is given. Emphasis is on the generation, transmission and distribution of electrical energy in Brazil and the electrical market. After a brief overview of the communications sector, there is an introduction in smart grids in Brazil. Afterwards, the current communication technologies and standards for smart grids will be presented in context with the Brazilian needs. Finally, there is an overview of current smart grid pilot projects in Brazil, a presentation of selected projects and the conclusion.

2. The Brazilian electrical sector

The history of the energy sector in Brazil is marked by major state reforms. The model of a completely state-dominated energy sector existed until the early 90s. Temporally, it proved to be a good system to prevent big crises. However, strong subsidy based policies led to strong revenue shortfalls and led the system into the 80s to the brink of a complete collapse. The main reasons were insufficient investment, corruption and big delays in the progress of large power plant projects. A great deal of uncertainty and skepticism also prevents larger investments of private capital in the energy sector. The growing energy demand of the population and industry could therefore not be sufficiently countered [*2*].

In 1996 there were great reforms in the conditions of the energy sector under the project RE-SEB (Reestruturação do Setor Elétrico Brasileiro). The slow expansion of power plants and transmission lines could not longer face the growing energy demand of the economy and the population. In the first step, opportunities were created to integrate the private sector into the system. This led to a higher privatization of some distribution companies and a large participation of private capital to the expansion of the transmission and the distribution system. However, the share of public transmission companies remained very high, while the distribution sector is today dominated by private companies. To create monitoring bodies, a number of governmental institutions were founded, which are supposed to control the

electricity sector [3]. Table 1 gives an overview of the main institutions and their role in the energy sector.

In 2004 under the government of Luiz Inácio Lula da Silva there were further fundamental reforms that shaped today's Brazilian energy market. A fully controlled environment was created to prevent competition within the markets. The privatization of the largest generator companies was stopped. The new system should primarily improve the prediction capability and reliability of the network, ensure price stability for consumers and also to attract long-therm investors. A comprehensive legal framework program controls the supply and the steady expansion of intrinsic sector activities of generation, transmission and distribution of electrical energy. These legal foundations form the basis of the Brazilian energy sector today [2], [3].

Table 1: Regulating institutions in the Brazilian energy sector

Name	**Abbreviation**	**Task**
Ministry of Mines and Energy	MME	Monitoring and following the energy policies in Brazil
Electric Sector Monitoring Committee	CMSE	Monitoring the supply continuity and security
Energy Research Company	EPE	Forecasting and long-term energy balance
National Energy Policy Council	CNPE	Advisory body to the presidency of the republic and has the objective of elaborating Policies and guidelines for energy planning; international energy policy
Brazilian Electricity Regulatory Agency	ANEEL	Economical and technical regulator and supervisor
Electric System National Operator	ONS	Operation, control and maintenance of the electrical grid
Chamber for the Commercialization of Electric Energy	CCEE	Commercialization of the electric market

2.1. Generation

The currently installed capacity of 123 GW is provided by nearly 3,000 power plants. Further 41.5 GW of power plants are approved or are under construction. Fig. 1 shows the energy mix of Brazil in the second quarter of 2013. With a share of 64% hydro power is the most important source of electrical energy in the Brazil making the country to the second largest producer of electric energy out of hydro power worldwide. It is estimated that the existing potential of untapped hydro power in Brazil is about 140 GW, i.e. far beyond the current electricity demand of the entire country. The share of electricity generation by thermal power plants is comparatively small. The main power fossil power sources are natural gas, oil and coal. Brazil has two nuclear power plants and plans to build a third one. All together, the generated electric energy in 2012 was 507 TWh. The major part of the

generated electric energy is consumed by the residential segment (40%). Only about a quarter is consumed in each industrial and commercial sector [*1*], [*4*], [*5*].

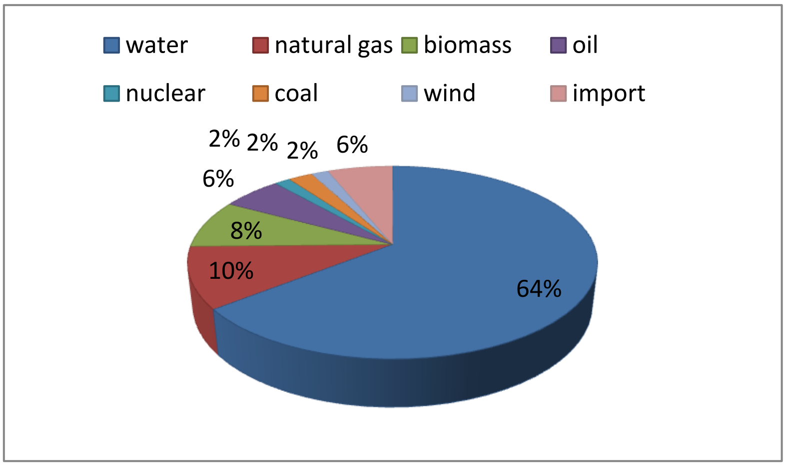

Fig. 1: Energy mix in Brazil 2013 [*4*]

The Brazilian power system is greatly dominated by the use of hydroelectric power plants. Currently, across the whole country there are about 1100 hydropower plants in operation with installed capacities from a few kW up to several GW. With an installed capacity of 14 GW the storage hydropower plant of Itaipu is the second largest power plant in the world. It is operated together with Paraguay at the river Paraná near the Iguacu waterfalls and has a 17 % share of the Brazilian electricity generation (share of Paraguay's electricity generation: 72 %). 78 other projects are under construction or being planned including another major project in Belo Monto with a planed installed capacity of 11 GW [*4*], [*6*].

Compared to conventional power generation by thermal power plants, barely any greenhouse gases are emitted by the use of hydropower. In contrast, there are also major environmental concerns, as the construction of a storage hydropower plant requires an enormous area for the formation of the water reservoir. During the creation of the water reservoir of Itaipu over 800 km² of agricultural land and 600 km² sub-tropical rainforest were flooded and destroyed. In addition to the questionable environmental aspects, the use of large-scale hydroelectric plants has a strong influence on the reliability of the entire power network. The reservoirs and rivers of hydropower plants are fed by an extensive network of streams, especially from the Amazon region. Regional dry periods and late rainfall seasons can cause the rivers and reservoirs to have not enough water. This seasonality dependence was responsible for major energy crisis in 2001. An unusually long dry period resulted in extremely low water levels in most the reservoirs and rivers, so that the supply of the electricity grid could not be guaranteed anymore. Only with the help of an extensive demand-cutting a total blackout of the power supply could be prevented [*2*].

To avoid this kind of scenario, the Brazilian government aims at increasing the use of thermal power plants, as well as alternative energy sources. Fig. 2 shows the evolution of the energy mix of 2001 until 2013. Although hydropower is still the main source of energy, an increase in conventional energy generation can be seen [*7*].

In addition to hydropower, the use of biomass for energy generation is the second most important source of renewable energy. Brazil is one of the world's largest producers of sugar

cane for ethanol synthesis. This process produces large quantities of biological waste and is responsible for a large share of electricity generation out of biomass [*4*].

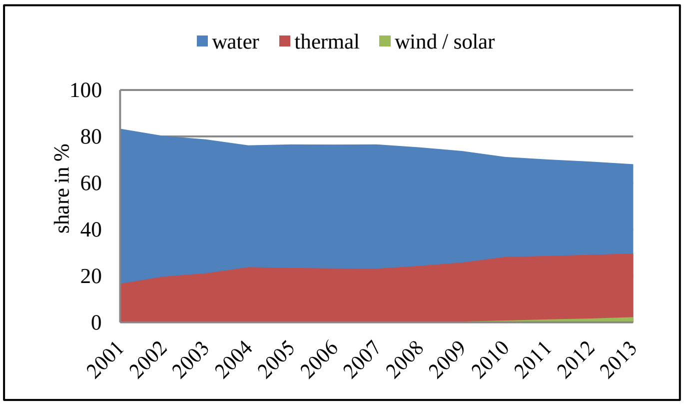

Fig. 2: Evolution of energy mix in Brazil [*4*]

The exploitation of wind and solar energy is still very low in Brazil. The installed capacity is only 2.1 GW in 2013 (1.6 % of total). Nevertheless, the existing potential is enormous. In the northeast of Brazil alone there is estimated untapped wind power equals to 140 GW. Furthermore, the amount of average sunlight intensity is about four times as high as in Europe [*8*]. As part of various projects and activities of the government, the expansion of wind energy, photovoltaic and biomass power plants should be increased. An example of the government's efforts is the PROINFA program to promote wind farms, small hydro and biomass power plants. As part of this program, 119 projects were implemented with a total installed capacity of 2650 MW [*9*].

2.2. Transmission

The transmission of electrical energy demand is particularly high in Brazil. Most hydropower plants are located near big rivers in the Amazon region. However, the main consumer centers can be found primarily in coastal areas. This uneven distribution of energy generation and consumption requires very long transportation distances and therefore transmission lines with partially over 1800 km. Different voltage levels and transmission paths are used. The standard method of energy transmission is high alternating current voltage up to 765 kV [*10*].

As promising alternative for energy transfer via high voltage AC power lines, the high voltage direct current transmission is considered. Currently, there are only a few active DC transmission lines in Brazil. There is one connecting the bi-national operated hydroelectric power plant in Itaipu with the bulk consumer region of São Paulo. It is used to transfer the excess energy of the Paraguayan side to the Brazilian grid. The DC transmission can be considered particularly for this case, not only because of the large transmission range but also because of the indifferent power frequency standards between Paraguay (50 Hz) and Brazil (60 Hz). In connection with the major project Belo Monte, the world's first direct current transmission line is planned in the range of 800 kV to transport the energy in the south of the country [*11*].

Until 1999 there were two separate transmission subsystems in Brazil: the northeast and the south. Today a coherent transmission network, the National Interconnect System (SIN), with a total length of more than 100 000 km exists. There are 40 transmission concessions available in Brazil. The majority of the transmission companies are owned by the government. Nearly 56000 km belongs to the state-controlled company Eletrobras [*12*]. Fig. **3** shows the current transmission network in Brazil. A very high concentration of transmission lines can be found in coastal regions in the east and in the south of the country, because of the great number of consumers in this area. International connections of the transmission system are available with Paraguay at the bi-national hydroelectric power plant Itaipu and with Uruguay, Venezuela and Argentina. The installed capacity thus increases by about 8200 MW [*13*].

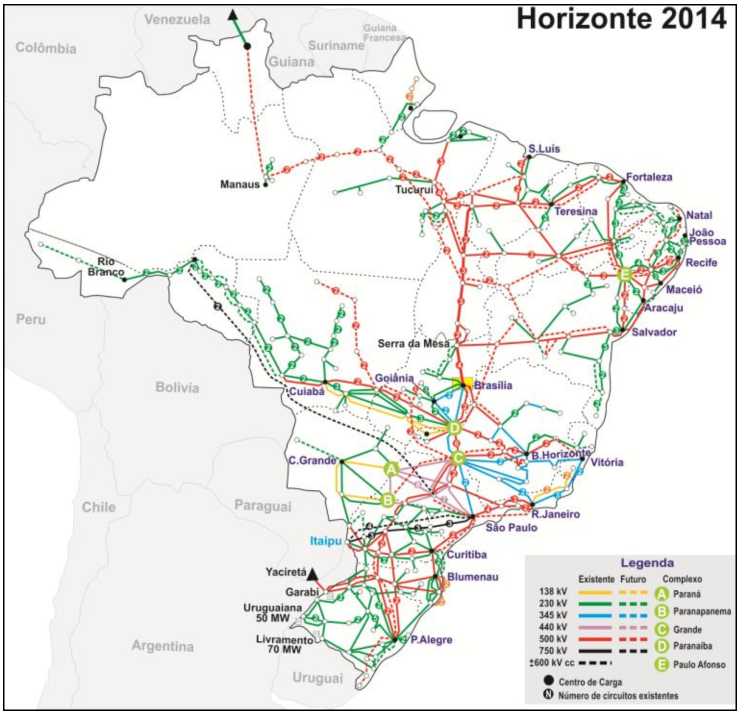

Fig. 3: Brazilian transmission system [*10*]

The natural and terrain characteristics in the Amazon region, requires special properties for constructing the transmission lines. For example there are widely flooded areas and particularly high rain forests. To overcome these areas and to minimize the environmental impact, the supporting structures must be built exceptionally high. One example is a section of a transmission line in northeastern Amazon, which bridges the rainforest with a 280 m high power pylon [*14*].

The extension of the power transmission network is performed by the EPE. This company together with the ONS is responsible for all design work and controlled by the Ministry of Mines and Energy. As well as in Europe, the N-1 criterion is the most important directive for planning new transmission lines. Once the new design plans are published, auctions for the construction and operation of the transmission line will be held under the direction of ANEEL. The successful bidder receives an operation concession which will be re-assigned by new auctions after 30 years. This auction model could achieve an increased participation

of private capital in the transmission sector. However, a majority of supplements still goes to state controlled companies such as Eletrobras [*5*].

2.3. Distribution

Until the end of the 90s, there was no clear separation of the generation, distribution and transmission by the legislation. In 2000, the independence of distributors in Brazil was decided. Under the supervision of ANEEL the distribution network was divided into regional concessions depending on individual local criteria. Today, these areas are operated by 63 distribution companies of which the majority is in private hands. The regulation of the distribution is followed by a policy document (PRODIST) that defines the responsibilities and requirements for the operation, expansion and planning for the distribution grid operator [*15*].

In Brazil, all power lines operated below 230 kV are considered as distribution lines. The standard voltage for residential consumers is usually 110 V or 220 V, depending on the region, with a frequency of 60 Hz. Altogether, there are almost 70 million connection points to end users, of which 85 % are residential customers. The common transportation constructions are overhead lines, especially in rural areas and small cities but there are also underground cable systems in big cities. The responsibility for connection, maintenance and service quality contributes to the competent regional distribution grid operators [*10*].

The average failure rate and downtime of the Brazilian power system has decreased since the reconstruction of the energy sector. When ANEEL was founded in 1996, there was an average of 21 interruptions with a total outage duration time of approximately 26 hours per year and users [*15*]. Fig. 4 shows the evolution of the System Average Interruption Index (SAIDI) in Brazil for the period from 2001 until 2012. It can be seen that the failure rate is generally lower but could not meet the specifications issued by ANEEL since 2009. With about 18 hours of downtime the SAIDI of Brazil is much higher than the SAIDI of Europe (e.g. Germany 2011: 15.31 min [*16*]).

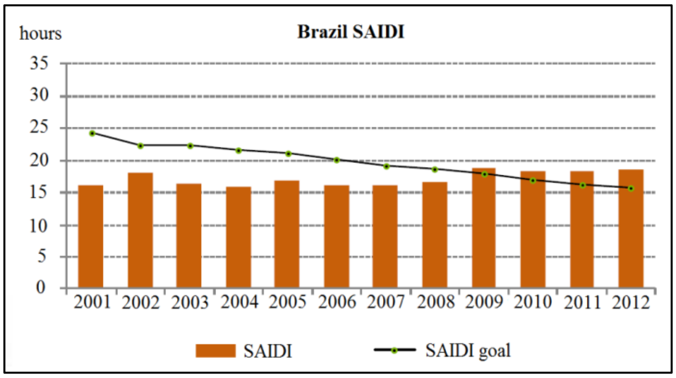

Fig. 4: System Average Interruption Index of Brazil [*12*]

Another problem in the distribution sector is the unusually high loss of energy. With a percentage of about 14 %, the loss rate is almost twice as high as in Central Europe. This value is not only related to the technical losses. The large divergence and poverty in the population leads to a disproportionate high share of non-technical losses due to theft and crime. While in some distribution networks there are virtually no non-technical losses in large cities with extensive slums the loss values can be reported up to 30 % [*3*]. Fig. 5 shows an example of electrical energy theft in a slum of Rio de Janeiro.

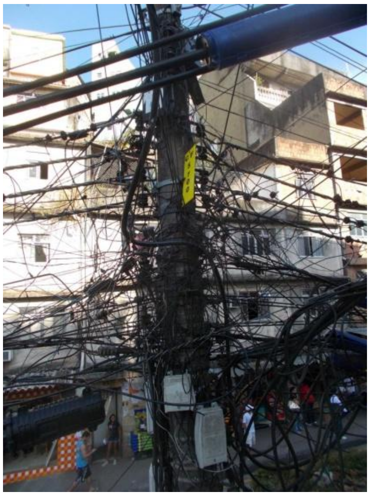

Fig. 5: Energy theft in a slum of Rio de Janeiro

2.4. Market

The electricity market in Brazil is the largest in Latin America. Nearly 99 % of the population has access to electricity which corresponds to almost 200 million people. The market model to ensure the supply in Brazil is based on long-term contracts between agents on generation and consumer side. The basis of this model was laid in 2004. It specifies that the utility companies need to ensure the complete supply of the customers through contracts with generation companies. For this purpose, two platforms, the Regulated Contracting Environment (ACR) and the Free Contracting Environment (ACL), were created on which the agents may conclude contracts between the producers and provider.

Within the concept of the free market, the participants have the opportunity to act under their own conditions. They can set their own prices and quantities of exchanged electrical energy. These bilateral contracts are concluded directly between producer and provider. Free consumers and energy intensive industries are allowed to trade freely as well. The consumer is obliged to prove that the contractually exchanged amount of electricity is able to cover 100 % of the demand. If it turns out that the power demand cannot be covered, the consumer must expect substantial fines. The Electric Energy Commercialization Chamber (CCEE, acronym in Portuguese) is responsible for maintaining the security of supply and takes care of the compliance of the contracts. The CCEE is also in charge, if there should be disputes and disagreements between suppliers and buyers [*17*].

Within the concept of the regulated market the electrical energy from the generator is passed to the consumer via energy auctions which are led by ANEEL and CCEE. The goal of this auction model is to ensure that the lowest possible price reaches the end-consumer. To

optimize the overall system of generation, transmission and distribution, the EPE tries to determine the optimal composition between source of generation and consumer. The next step is the auction phase, in which the company that offers the required amount of energy for the lowest price gets the bid. The legal basis for the energy delivery to the end customer is provided by bi-lateral contracts called the Contracts for Commercialization of Electricity in the Regulated Environment (CCEAR, acronym in Portuguese) [*17*].

Besides the two market models, the distribution network operators have more options to purchase electricity. By Distributed Generation (DG) it is possible for small producers (less than 30 MW) to feed electrical energy directly in the distribution grid. This energy can be generated from different sources such as small hydro power plants, wind or solar farms and biogas power plants. The energy that is fed into the distribution grid may be up to 10% of the total load and is contractually sold directly to the distribution network operator. An advantage of DG is that the cost of transmission is reduced, as well as losses in the distribution since the decentralized small power plants can be built close to the consumer. Several projects have already been funded by the government to increase the share of alternative energy sources in the electrical grid [*2*], [*18*].

The two presented market models can be of interest for different participants. The free market model has the advantage that the contracts conducted by producers and consumers can be adapted to make sure that the agreement has favorable condition for both parties. However, only consumers with an annual energy load of 500 GWh are allowed to participate in the free market. If the consumed energy exceeds this value, the company must acquire the electrical energy in the regulated market. In contrast, the generators can always choose the environment for their energy transactions [*19*].

The tariffs paid by the consumer consist of the sum of production costs and a fixed value for transmission, distribution and commercialization of the electrical energy. Depending on the kind of consumer there is a variable pricing system in Brazil. The end users are thereby divided into two groups. All consumers with voltages between 2.3 kV and 69 kV or power consumption greater than 75 kW pay variable tariffs depending on time of day and peak load situations. The price may be several times higher in peak load periods than in off-peak situations. All consumers with voltage less than 2.3 kV, i.e. residents or communities in rural areas, are bound by a constant tariff rate to the owner of the local distribution concession. In addition, because of the hydro-electric characteristic of the Brazilian Electric System, there is a seasonal pricing model. Depending on the level of the water reservoirs of hydro power plants there are additional fees for the consumer [*20*].

3. The Brazilian communication sector

The history of the communications sector in Brazil can be divided into different stages of development. From the early 80s to the early 90s the ICT market in Brazil was subject to strong governmental control. By high inflation, low demand and high import duties on foreign electronic products only a few specialized companies could be established. In the mid of the 90s there was an increased demand, especially in personal computers. By the liberalization of the ICT market and the removal of import duties a lot of foreign companies such as Compaq and IBM established in Brazil. They were able to offer the required electronic hardware much cheaper and made joint ventures with local private and state-owned enterprises. The ICT market developed very fast over the following years. In 2010 the market grew by more than 21 % to a size of $166 billion [*21*].

The mobile phone market in Brazil is the fourth largest in the world. About 220 million mobile phone contracts are concluded. Nearly 17.33 % of these contracts include mobile Internet via 3G. Even the standard 2G and 2.5G is still widespread, especially among the poorer population. In consideration of major events such as the FIFA World Cup 2014 and the Olympics in 2016 the 4G standard will be introduced very soon. In contrast to the mobile Internet, only 40 % of Brazilian households have a fixed internet connection. The main reason can be found in the high cost of internet access. Therefore especially low-income earners cannot afford to buy access to the internet. In 2010 the Brazilian government launched a national broadband program. The goal is to provide up to 2014 at least 40 million households with broadband connections [*21*]. For this purpose large area routers have been installed in slums of major cities such as Rio de Janeiro to provide free wireless internet for poor people (Fig. 6).

The ICT market shows a very high potential in Brazil. However, there is a number of reasons that slow the development down. One problem is the complex fiscal politics. High taxes to each step of the value chain leads to multiple taxation for the same product. Furthermore, high interest rates have a negative effect of new investments and there are very complex regulations to establish new companies which curbs down high technology spin-offs from universities. Nevertheless, Brazil has the basic requirements to become a global player within the ICT market [*22*].

Fig. 6: Free internet access point in a slum of Rio de Janeiro

4. Smart grids in Brazil

With the liberation of the distribution market by the legislation in 2004, the first step has been taken away from the traditional centralized power generation towards decentralized power plants. By these new terms, the use of small generators of electrical energy is playing an increasingly important role. Due the possibility to operate in a location near to the consumers, DG contributes to cost reduction of the energy transfer by reducing transmission losses and relieving the transmission networks. In addition, the integration of alternative

energy sources from wind and solar energy is promoted and thus an important step towards reducing carbon dioxide emissions is taken.

The integration of this new distribution system in the Brazilian energy sector requires not only political regulatory steps as subventions and new pricing models. Especially a technological revolution of the traditional distribution system has to be carried out. Due to the growing number of small generators in the distribution network, the energy flow can no longer be considered as an one-way flow. To ensure the stability and the correct balance between power generation and consumption the distribution network needs the capability to be monitored and controlled. The network has to become more intelligent.

Brazil is one of the pioneer countries in Latin America, which deals with the development and research of smart grids since recent years. In contrast to Germany, where a high share of fluctuating renewable energy like wind and photovoltaic demands a fully controlled electrical grid to balance the power flow, the main reasons for the introduction of smart grids in Brazil are [*23*]:

- The reduction of technical and non-technical losses in transmission and distribution of electrical energy
- The improvement of system security, system reliability and power quality
- The integration and control of micro-generation and micro-grids to compensate peak load situations
- Creation of a new energy market through the integration of new flexible pricing models
- Preparation for the integration of electric mobility sector

An intelligent network or smart grid allows a full automatic control and management of the electrical distribution system. The communication between the main hub, generators and consumers creates new possibilities for the stabilization of the entire electrical network by: Advanced Metering Infrastructure (AMI), Advanced Distribution Operation (ADO), Advanced Transmission Operation (ATO) and Advanced Asset Management (AAM). By using the AMI, a bi-directional communication link can be established to the end user via smart meters and thus useful information can be exchanged. The ADO uses this information to optimize the energy flow and collects information about the condition of the distribution system. The ATO uses the information of the ADO to optimize the transmission operation. By using the AMI and the ADO the consumer can have direct access to the market. The AAM is the controlling instance, which uses all the information gathered from the AMI, ADO and ATO to optimize the whole network, enhance the reliability and minimize the failure rate [*24*].

To support the modernization of the energy sector, all owners of public concessions in distribution and transmission sectors and involved companies are forced according the Brazilian law to invest approximately 0,5 % of their income to R & D. The goal is to create a constant urge to improvement, which cannot arise naturally because of the lack of competitive pressure in a monopoly economy. Due these measures there is great number of researches on smart grids in almost all engineering institutes and universities in Brazil. The government plans to equip more than 65 million consumers with smart meters until 2020. Today, over 1 million smart meters in Brazil are already installed. It is expected that the policy framework for smart metering and integration of micro generation, which was

recently published by ANEEL, will cause the market for smart grid technology to grow extremely fast [*25*].

4.1. Communication in smart grids

In order to guarantee smart grids can work reliable, fast and effective, there is a great requirement on information and communication technology. Fig. 7 shows a schematic representation of a typical measurement system presented in a smart grid.

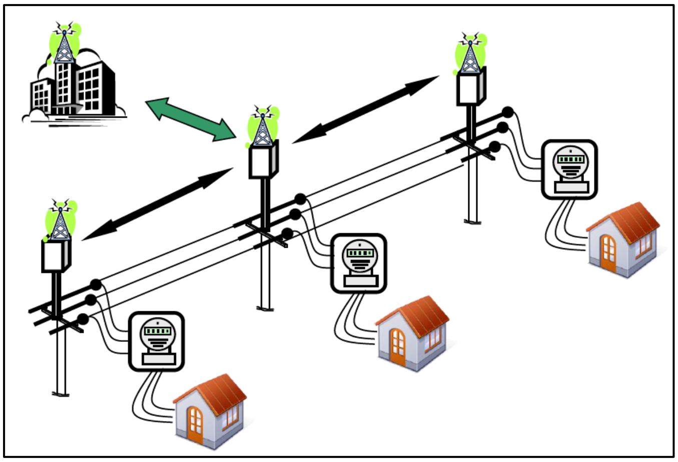

Fig. 7: Basic communication structure in smart grids [*23*]

The basic elements are the measuring center, the smart meter and an intervening communications infrastructure. Particularly important is the point of data concentration that collects consumer measurement data and sends them to the centralized control center. The concentrator also represents the nodal point for the distribution of information to the consumer. The bi-directional communication offers many new opportunities for the electrical grid. Due continuous information flow about the grid condition high power quality can be ensured. In addition, rapid fault detection and automatic recovery are greatly improved. The control ability can perform a quick load flow regulation and consumers can be integrated in the distribution system with their own small generators. The integration of a new flexible electricity price system also provides a great opportunity to influence the consumer behavior [*26*].

4.2. Communication technologies

It is therefore very important to discuss the optimal conditions in the field of hardware and software for communication. There already exist several methods that can be used for smart grids. The most important technologies, which play a role in Brazilian smart grid sector, will now be presented:

Powerline Communication

Power Line Communication (PLC) is one of the oldest known methods for communication in electrical networks. This technique uses data transmission frequencies which are fed into the existing power grids. Depending on the frequency band, transmission rates up to several Mbit per second can be achieved. This technique is used in load control of energy transfer for many years. The particular advantage of this method is that no new communication lines are needed; resulting in a strong cost reduction. Especially in rural sector PLC can be used to easily connect important data nodes and smart meters. It has already been shown that the signal transmission from low voltage into a higher voltage level by a transformer is possible [*27*]. Disadvantages in the use of PLC are mainly the environmental signal conditions, which have a high noise level. Furthermore, the signal quality may be affected by: the number of devices communicating on the same line, the length of the line and the network topology. For this reason, the PLC is not considered as the ultimate solution. The security question to protect the user data is not yet clear as well. In addition undesirable interference between different PLC data transmission standards can occur. A possible solution to this problem would be the introduction of coexisting standards, which are specialized and optimized for respective applications [*28*], [*29*].

The use of PLC as a part of a hybrid solution for communication has already been carried out in China, France and Italy. There, the PLC was used as a communication tool to connect existing smart meters in households with a data collector. From this data collector then the GPRS standard is used for data transmission to the control center [*30*].

Cellular Network Communication

Other technologies for communication in a smart grid are Cellular Networks. Similar to the PLC, one of the biggest advantages is that these networks are already in place. Thus no major investments need to be made and costs are minimized. The available communication technologies are: 2G, 2.5G, 3G, WiMAX and LTE. A further advantage is that strong security standards have already been developed by the spread of mobile cell phone data transmission. A major task for the deployment of mobile networks in smart grids is the large amount of data obtained while operating. This can be a problem especially in rural areas where only slow transmission standards are available. But there are also new standards such as WiMAX and LTE with very high data transmission rates. However, the mobile networks share the environment with the large number of private user. This can sometimes lead to unpredictable peak loads on the networks and thus jeopardize the system stability. In general the low investment costs, high availability, high security and low maintenance costs make the use of mobile networks one of the most promising candidates in the data transmission of smart grids [*30*].

Wireless Mesh

The mesh network is built up of individual nodes that have the ability to communicate with each other. They operate with standardized IEEE 802.11 protocols and can have many benefits. Since all the routers are able to communicate with each other, the network has a high self-healing potential. If a single node fails, the connection can be reestablished via another active router so that the network is complete again. This signal transmission method is very effective and adaptable, particularly in urban areas, where a network of many routers can be available. Especially for domestic applications such as metering and energy management, this technology is well suited. Disadvantage for Wireless Mesh Networks are the limited capacity and the susceptibility. If the density of the routers is too low, the stability

and capacity of the network suffers considerably. Accordingly, a sufficient number of routers always must be available, which can cause significant costs. Since the information packets passing through each router, a strong security encryption is necessary. Furthermore, a frequent change of the connection path can cause faster network utilization [*30*], [*31*].

ZigBee

ZigBee is based on IEEE 802.15.4 industrial radio standard with a maximum range of 100 m. The technology is considered as the most promising candidate for communications technology in the Home Area Network (HAN) to connect smart devices and smart meters with each other. Thus it is possible to build up a comprehensive energy management system. The advantages of using the ZigBee standard are mainly: low power consumption, fast response and response time, high reliability, self-organizing network topology, high cross linking ability (65,000 nodes) and high safety standards. In China ZigBee networks are used for monitoring of ultra-high voltage power lines. With their help environmental parameters such as temperature, humidity and wind speed are collected. The biggest advantage in such rural areas is the very low energy consumption. However, in practice there are various problems in the use of ZigBee as a communication standard. By the use of license free IEEE 802.15.4 standard there are possible complications with other networks such as WiFi, Bluetooth and microwaves. Under these noisy conditions, the system stability of the network could be vulnerable, e.g. by interferences with 802.11/b/g standards. A further disadvantage is the limited amount of memory related to a low processing capacity [*30*], [*32*].

Digital Subscriber Lines

The use of Digital Subscriber Lines (DSL) in the communications sector is very common. The digital connection reaches very high transmission rates by the use of a wide frequency band. The copper-based wired infrastructure already exists in many parts of Brazil. This allows avoiding greater investment costs. Because of the high availability and transfer rate DSL communication is of great interest for transmitting data in a smart grid. However, some disadvantage need to be mentioned. There is an occasional non-availability which might be sufficient for private internet users but not acceptable for live monitoring in a smart grid. High maintenance costs of the cable-linked system, as well as unavailability in rural areas are more disadvantages of the system [*30*].

In summary it can be considered that the available communication technologies have different advantages and disadvantages for the use in a smart grid. There is nothing like a general solution and therefore the choice of technology must always be adapted to the given conditions.

Table 2 shows the mentioned communication technologies and their characteristics. The choice of the optimal technology always dependents on the field of application. For example, control and automation processes require only very low data rates of a few 100 kbit / s. In contrast, network monitoring needs very large amounts of data that must be transmitted almost in real time. For these applications networks are used, which have transfer rates over 1 Mbit / s and a maximum response time of 20 ms. The availability is also a major point of interest. While some less critical applications like demand management stand a reliability of 99 % per year need (3.65 d downtime per year) other applications such as synchronization between the elements need a much higher reliability of 99.9999 % (31 s of downtime per year) [*30*].

Table 2: Smart grid communication technologies [*30*]

Technology	Spectrum	Data Rate	Coverage Range	Application	Limitations
GSM	900-1800 MHz	Up to 14.4 kBit / s	1-10 km	AMI, Demand Response, HAN	Low date rates
GPRS	900-1800 MHz	Up to 170 kBit / s	1-10 km	AMI, Demand Response, HAN	Low data rates
3G	1.92-1.98 GHz 2.11-2.17 GHz	384 kBit / s- 2 MBit / s	1-10 km	AMI, Demand Response, HAN	Costly spectrum fees
WiMAX	2.5 GHz; 3.5 GHz; 5.8 GHz	Up to 75 Mbit / s	10-50 km (LOS) 1-5 km (NLOS)	AMI, Demand Response	Not widespread
PLC	1 - 30 MHz	2-3 Mbit / s	1-3 km	AMI, Fraud Detection	Harsh, noisy channel enviroment
ZigBee	2.4 GHz-868-915 MHz	250 kBit / s	30-100 m	AMI, HAN	Low data rates, short range

An example of how the technology hierarchy may look like in a Brazilian Smart Grid can be found in a report on smart grid structures in Brazil called "Relatório smart grid" published by ANEEL. The following solutions are proposed for the different tasks:

- Data reception and data delivery from electronic measuring points in the distribution network via PLC to the data concentrators
- Data concentrators connected via RF mesh radio technology with the central control center
- Data transmission to consumers metering devices via PLC
- Control of smart devices in HAN with the help of ZigBee networks
- Measuring systems in distribution system for comprehensive energy management; communication via DSL or WiMAX

When choosing the optimal communication technology the local conditions must always be considered, too. These include the existing communications infrastructure, geographical conditions, potential markets, the density of necessary control elements in the distribution network and the number of consumers. Since in Brazil local conditions show strong differences in the social sector as well as in the field of geography and economics, various approaches have to be investigated [*23*], [*33*].

4.3. Communication standard protocols

Furthermore, uniform communication standards must be found for the technologies and fields of application in a smart grid. The various standardization bodies such as ANSI (American Standards Institute) and IEC (International Electrotechnical Commission), IEEE (Institute of Electrical and Electronics Engineering) and ISO (International Organization for Standardization) have already published a set of standards for smart grid applications. Table **3** shows the most important standards and their applications.

Table 3: Smart grid communication protocol standards [*30*]

Type/Name of standard	Details	Application
IEC 61970/61969	Providing Common Information Model (CIM) in transmission and distribution domain	Energy Management System
IEC 61850	Flexible, future proofing, open standard for communication	Substation Automation
IEC 60870-6/TASE.2	Data exchange between utility control centers, utilities, power pools and regional centers	Inter-control Center Communications
IEC 62351 Parts 1-8	Defining cyber security for the communication protocols	Information Security Systems
IEEE P2030	A Guide for smart grid inter-operability of energy technology and IT operation with the electric power system	Customer side applications
IEEE P1901	High speed power line communication	In-home multimedia, utility and smart grid application
ITU-T G.9995/G9956	Contains the physical layer specification and the data link layer specification	Distribution Automation, AMI
Open ADR	Dynamic pricing, demand response	Price Responsive and Load Control
BACnet	Scalable system communications at customer side	Building automation
HomePlug	Powerline technology to connect the smart appliances to HAN	HAN
U-SNAP	Provides many communication protocols to connect HAN devices to smart meters	HAN
SAE J2293	Standard for the electrical energy transfer from electric utility to EV	Electric Vehicle Supply
ANSI C12.19	Flexible metering model for common data structure and meter communication	AMI
M-Bus	European standard and providing the requirements for remotely reading all kinds of utility meters	AMI
PRIME	Open, global standard for multi-vendor interoperability	AMI

Different communication protocols and standards have progressed far in Brazil partially. The main focus for the optimal standard protocol in Brazil is on choosing open standards to avoid legal problems and not be dependent on a single manufacturer for communications technologies. In particular, the IEC 61850 standard is already used in a wide range of applications. Especially in the area of monitoring transformer stations these free protocols are already frequently used. Other tasks are automatic load balancing, fault detection and circuit breaker control. For communication between the control centers IEC 60870-6 protocol (ICCP) is already used by large companies such as Eletrobras and Eletrosul. The operation of a Common Information Model (CIM) for an independent integration of IT systems is defined by the standards IEC 61968 and IEC 61970. In addition, the CIM requires an appropriate level of safety. In Brazil the IEC 62351 catches on, even if it is not very widespread yet. These standard protocols have been proposed in the U.S. Nation Institute of Standards and Technology. In Brazil, these proposals will be adopted so far [*23*].

5. Smart grid pilot projects in Brazil

Given the large market potential and anticipated regulatory foundations several companies and cities initiated pilot projects for integration of smart grids in the power distribution system. The range of these projects starts from various simulations to entire cities with an integrated smart grid. Table 4 gives an overview of the major projects Brazil, which are currently performed by some holders of distribution concessions.

Table 4: Smart grid pilot projects in Brazil [*26*]

Name	Location	Company
Buzios Cidade Inteligente	Armação dos Búzios - Rio de Janeiro	Ampla/Endesa
Projeto Smart Grid	Rio de Janeiro	Light
Cidades do Futuro	Sete Lagoas – Minas Gerais	Cemig
Projeto Parintins	Rio de Janeiro	Eletrobras Amazonas Energia
Projeto de Smart Grid	Barueri - São Paulo	AES Eletropaulo
InovCity	Aparecida - São Paulo	EDP Bandeirante
Aquiraz Smart City	Aquiraz - Ceará	Coelce/Endesa
Fazenda Rio Grande	Fazenda Rio Grande - Paraná	Copel

In this section, three other pilot projects are presented, which deal with the integration of different communication methods for smart grids in Brazil. The project in Curitiba and Niterói shows the experimental urban implementation and the project of Fernando de Norohna shows the experimental rural implementation. Thus the two main Brazilian applications will be investigated. In addition, a project dealing with the integration of micro grids and distributed generation is presented.

5.1. Fernando de Norohna – CELPE

The project is part of the R & D plan of ANEEL which is supposed to represent the feasibility of smart grid in Brazil. It was initiated on the Brazilian island of Fernando de Noronha by the distribution network operator CELPE (Companhia Energetica de Pernambuco). The main objectives of the project are:

- Building a smart grid infrastructure (smart metering, network automation, telecommunications, integration of micro-generation and power measurement)
- Establishment of a network of electric cars as electric buffer
- Assessment of the feasibility (reducing losses, increasing system stability, dynamic pricing, demand side management)
- Assessment of the ecological sustainability of Smart Grids

Particularly the use of communication technology plays an important role in this project. The results must fulfill technical, commercial and environmental requirements. The high temperatures and high salinity require high reliability of the used technology. Especially the GPRS antennas can be subject to performance degradation due corrosion on the surface. The dense vegetation also makes it necessary to use very high radio antennas to prevent a reduction of the signal strength.

Based on a comprehensive requirement analysis, a plan for the installation of the communication network was created. The architecture shown in Table 5 includes three levels that use various communication technologies for operation. The backbone network, which is characterized by a high data transfer rate, is provided by fiber optic cables and WiMax connections. The backhaul system, which is the minor connection to the central system, is implemented by different technologies depending on the field of application. The access level uses ZigBee, GPRS and PLC as communication technology.

Table 5: Communication technologies in smart grid project of Fernando de Norohna [*34*]

Level	Technology
Backbone	Fiber optic cables, WiMAX
Backhaul	Fiber optic cables, WiMAX, WiFi, GPRS
Access	ZigBee, GPRS, PLC

In order to compare the technologies, different scenarios were created. In scenario 1, the communication system is completely based on fiber optic cables. Scenario 2 relies on a total commitment of radio technology. Scenario 3 represents a hybrid solution between fiber optic cable and radio systems. It was shown that Scenario 3 achieved the best cost/benefit solution. However, the project must continue to investigate the ecological impacts. The results can be used to define requirements for future scenarios. The project is currently in the initial phase [*34*].

5.2. Niterói and Curitiba – Ampla Energia

This project is created with the assistance of ANEEL to investigate a feasibility study for the integration of smart grids in the urban sector. As reference cities Niterói and Curitiba were chosen. In Niterói the distribution system was equipped with intelligent network technology for measuring and monitoring the condition of the grid and in Curitiba a comprehensive street lighting monitoring network was built. The focuses of the project are on increasing the power quality, improving grid stability, proving the installation feasibility in an existing overhead line distribution system and reducing the maintenance costs. The selection of communication methods and technologies aims on open standards to prevent high costs spreads by licensed products.

A meshed network with a very low energy consumption, which communicates on the free IEEE 802.11 standard, was chosen as the communication method. Due the ability of the routers to communicate with each other, the network can work without having a coordination server. It is appropriate to use these networks in the urban sector, as a high cross-linking density can be expected. This also leads to high system stability, since in case of failure of single nodes the communication can be reestablished through alternative nodes. Fig. 8 shows an example of communication within a distribution system using meshed networks.

The network provides monitoring applications, switches, voltage regulators, monitoring lights or transformers and power quality measurement. To allow simultaneous control of applications, multiple protocol layers have to be used in the network. For this task, the ZigBee standard is considered as a good solution and added to the MAC layer of the IEEE 802.15.4 standard. For communication between the smart meters ABNT (NBR 14522), which is a standard published by the Associação Brasileira de Normas Técnicas was chosen. The controlling and monitoring devices use the widespread standard DNP 3.0. At the choice

of hardware it was taken into consideration to guarantee full compatibility with the IEEE 802.15.4 standard and implementation ability of additional protocol layers. All routers also have super capacitors that provide the electronics with electrical energy up to 8 hours after a power failure. Special attention was given to the selection of small price hardware with open source integrated circuits.

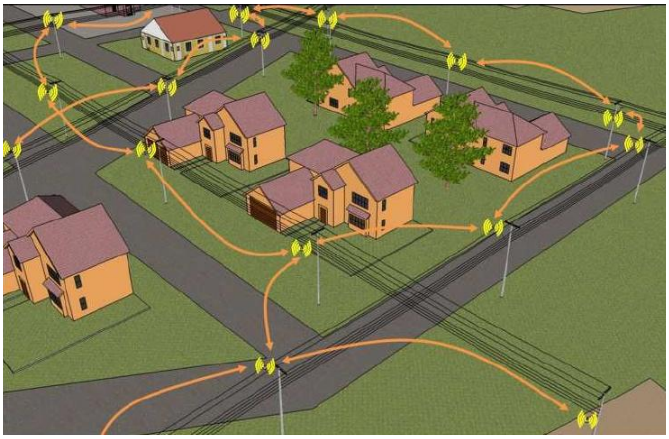

Fig. 8: Example for a meshed network [35]

Various field test measurements were carried out. For coordination of the router network a management system was developed and integrated, which verifies the availability and the response time for every node. Fig. 9 shows the voltage measurement of a router in a region with a high proportion of the tertiary sector of the city of Niterói.

Another field test experiment was investigated in Curitiba. The street light network in a residential area was automated and measurements of current and voltage were performed at each point.

In this project the feasibility of a communication network using mesh networks could be shown. It is planned to increase the number of installed routers up to 400 units. In addition, a further project is being considered, which would be located in rural areas [35].

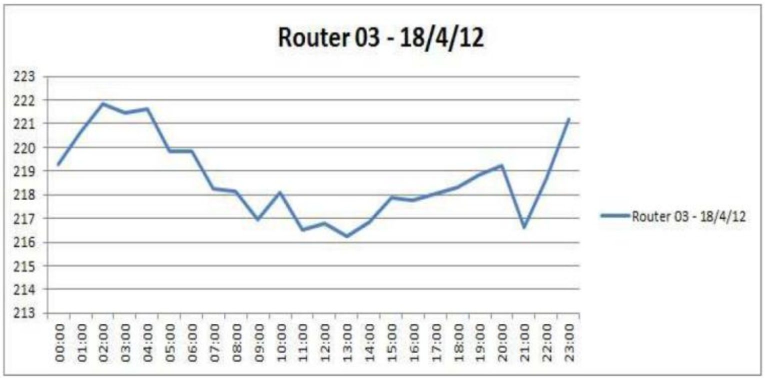

Fig. 9: Voltage measuring in a commercial area of Niterói [35]

5.3. Micro Grid of Sustainable Energy – CELESC

Under the direction of the distribution network operator CELESC another project for the integration of smart grids in Brazil is currently carried out in Florianópolis and Blumenau in the state of Santa Catarina. The focus in Florianópolis is on the implementation of micro grids and distributed generation into the existing distribution network, as well as researches in demand response. As a result, the share of regenerative energy in the electrical grid can be increased and peak loads can be balanced especially in the summer.

More than 10 000 control devices and over 7000 smart meters and measurement units were installed in Florianópolis and Blumenau. The goal is to increase the power quality and reduce the losses with the use auf an effective demand management system. The communication between the measuring points and the central control station is done with the help of power line communication using the existing distribution grid. The measurement devices are connected via transponders with the control center. Then, the transmitted data is sent to a central data collection station where they will be evaluated. The system performance includes the possibilities of smart meter reading, remote connection/disconnection, automatic restart after cutoff, grid monitoring and automatic restart after power failure.

Furthermore, there is a comprehensive test area currently being built in Sapiens Park in Florianópolis, which investigates the design and feasibility of micro grid networks using renewable energy sources and their integration into the existing distribution network. The goal is to show that micro grids consisting of decentralized micro power generators can make a major contribution to the stability of the electrical network [*36*].

6. Conclusion

The present paper is a structured presentation of the Brazilian energy and communication sectors, as well as the current state of development of smart grid in Brazil with focus on the communication technology. The integration of a comprehensive intelligent infrastructure will be an important goal of the Brazilian government. Brazil has the potential to be key market for smart grid technologies. The role of individual communication technologies in the context of a future smart energy network is still open. For this instance the Brazilian government is trying to adapt the experience made by the USA in smart grid technology. The social, topographical and economic diversities, which may take different proportions in all of Brazil, pose a great challenge for the optimal integration of a communication infrastructure in the electric network. The communication methods presented in this paper must be optimally selected for an effective use based on local indicators. Focus should be on reliability, availability, performance as well as on aspect of economics and data security. There is no doubt that this can’t be done by just one single solution. The integration of smart grids will require different technologies, which are adapted to their suitable operating conditions and work as hybrid solutions. The projects, which are currently investigated in selected regions of Brazil, will give further information on the feasibility of different approaches in the near future.

Acknowledgements

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912.

The author gratefully acknowledges the support and efforts of Daniel Tenfen as well as all colleagues from Labplan (UFSC Florianópolis). Furthermore the author would also like to convey thanks to Ines Hauer (OvGU Magdeburg) and the staff around the ELECON project for giving the opportunity to visit Brazil and gain a lot of new experiences.

References

[1] Roberto Venhochea, "Brazil: The Smart Grid Network," Zpryme Research & Consulting, Sao Paulo, 2011.

[2] Gary Stuggins Venkataraman Krishnaswamy, "Closing the Electricity Supply-Demand Gap," Energy and Mining Sector Board, Worldbank, Washington, Paper No. 20, 2007.

[3] Leonardo Mendonça Oliveira de Queiroz, "Assessing the Overall Performance of Brazilian Electric Distribution Companies," George Washington University, Washington D.C., 2012.

[4] ANEEL Brazil, "Inforações Geração," Agência Nacional de Energia Elétrica, 2013.

[5] Empresa de Pesquisa Energética. (2013, september) [Online]. www.epe.de

[6] Brazilian government. (2013, september) Itaipu Binacional. [Online]. www.itaipu.gov.br

[7] Empresa de Pesquisa Energética, "Balanço Energético Nacional," EPE, 2012. [Online]. www.epe.gov.br

[8] Fernando Ramos Martins, Samuel Luna de Abreu, Ricardo Rüther Enio Bueno Pereira, *Atlas Brasileiro de Energia Solar*, INPE, Ed. São José dos Campos, Brasil, 2006.

[9] Eletrobras. (2013, august) www.eletrobras.com. [Online]. http://www.eletrobras.com/elb/data/Pages/LUMISABB61D26PTBRIE.htm

[10] Operador Nacional do Sistema Elétrico. (2013, September) www.ons.org.br. [Online]. http://www.ons.org.br/conheca_sistema/mapas_sin.aspx

[11] J.W. Feltes, B.S. Fernandes, P.M.M. Portugal, and A.P. Leite, "Transmission expansion in Brazil for renewables ," in *Power and Energy Society General Meeting, 2012 IEEE* , San Diego, California, USA, 2012, p. 7.

[12] Eletrobras, "Annual and Sustainability Report," 2013.

[13] L.A. Barroso et al., "Transmission structure in Brazil: organization, evaluation and trends," in *Power Engineering Society General Meeting, 2004. IEEE*, 2004, p. 6.

[14] J. H. A. Monteiro, A. J. G. Pinto, S. Kurokawa, J. L. Franco, J. Pissolato E. C. M. Costa, "A First Approach on the new Transmission System in Northern Brazil," in

Reliability of Transmission and Distribution Networks (RTDN 2011), IET Conference on , 2011, p. 5.

[15] Portal Brazil. (2013, august) http://www.brasil.gov.br. [Online]. http://www.brasil.gov.br/energia-en/power-sector/distribution

[16] Bundesnetzargentur. (2013, february) http://www.bundesnetzagentur.de. [Online]. http://www.bundesnetzagentur.de/cln_1912/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Versorgungssicherheit/Stromnetze/Versorgungsqualit%C3%A4t/Versorgungsqualit%C3%A4t.html

[17] Câmara de Comercialização de Energia Elétrica. (2013, september) [Online]. http://www.ccee.org.br

[18] Fabio Cavaliere de Souza, "Brazilian Electricity Market Structure and Risk Management Tools," in *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century*, Pittsburgh, 2008, p. 8.

[19] ANEEL. (2013, august) www.aneel.gox.br. [Online]. http://www.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm

[20] Erlon C. Finardi, Ildemar Cassana Decker, Rubipiara Fernandes, Flávio Lemos Daniel Tenfen, "Microgrids and Microgeneration in Brazilian Energy Market: a Discussion of Regulatory and Commercial Aspects," *[unpublished paper]*, September 2013.

[21] Alejandro Germán Frank, and Rogério Feroldi Miorando Marcelo Nogueira Cortimiglia, "ICT Trends in Brazil," Federal University of Rio Grande do Sul, Rio Grande do Sul, 2012.

[22] Andrew Nusca. (2012, octobre) Brasscom. [Online]. http://www.brasscom.com.br/brasscom/Ingles/detNoticia.php?codArea=2&codCategoria=45&codNoticia=341

[23] Grupo de Trabalho de Redes Elétricas Inteligentes, "Relatório: Smart Grid," Ministério de Minas e Energia, Brasilia, 2010.

[24] Nation Energy Technology Laboratory. (2008, february) http://www.netl.doe.gov. [Online]. http://www.netl.doe.gov/smartgrid/referenceshelf/whitepapers/AMI%20White%20paper%20final%20021108%20%282%29%20APPROVED_2008_02_12.pdf

[25] LLC Northeast Group. (2012, august) http://www.northeast-group.com. [Online]. http://www.northeast-group.com/reports/Brazil_Smart_Grid_Market_Forecast_2012-2022_Brochure_Northeast_Group_LLC.pdf

[26] Djalma M. Falcão, "Redes Elétricas Inteligentes - Smart Grid," in *Inserção de Novas Fontes Renováveis e Redes Inteligentes no Planejamento Energético Nacional*, 2012, p. 20.

[27] Cosentino, Dario Di Cara, Giovanni Tinè Antonio Cataliotti, "On the use of Narrow Band Power Line as Communication Technology for Medium and Low Voltage Smart Grids," in *Instrumentation and Measurement Technology Conference*, Graz, 2012, p. 4.

[28] Stefano Galli, "For the Grid and Through the Grid: The Role of Power Line Communications in the Smart Grid," *Proceedings of the IEEE*, vol. 99, no. 6, pp. 998 - 1027, june 2011.

[29] Anna Scaglione, Zhifang Wang Stefano Galli, "Power Line Communications and the Smart Grid," in *Smart Grid Communications*, Vancouver, 2010, p. 6.

[30] Dilan Sahin, Taskin Kocak, Salih Ergüt, Concettina Buccella, Carlo Cecati, Gerhard P. Hancke Vehbi C. Güngör, "Smart Grid Technologies: Communication

Technologies and Standards," *Transactions on Industrial Informatics*, vol. 7, no. 4, pp. 529-540, november 2011.

[31] Dabin Kim, Keun-Woo Lim, Young-Bae Ko, and Sang-Youm Lee Jaebeom Kim, "Improving the Reliability of IEEE 802.11s Based Wireless Mesh Networks for Smard Grid Systems," *Journal of Communications and Networks*, vol. 14, no. 6, pp. 629-639, december 2012.

[32] Qiang Zhang, Yugeng Sun, and Zhenhui Cui, "Application and Analysis of ZigBee Technology for Smart Grid," in *International Conference on Computer and Information Application (ICCIA)*, Tianjin, China, 2010, pp. 171-174.

[33] Luciano de Errico, Wallace do Couto Boaventura Leonardo Henrique de Melo Leite, "Criteria for the Selection of Communication Infrastructure Applied to Power Distribution Automation," in *IEEE PES Conference On Innovative Smart Grid Technologies Latin America*, São Paulo, 2013, p. 8.

[34] Luciano Zanatta, José Aderaldo Lopes, Maurício Lôbo Nelson Mincov, "Communication Technologies for Differentiated Smart Grid Environments," in *IEEE Conference On Innovative Smart Grid Technologies Latin America*, São Paulo, 2013, p. 4.

[35] J. D. Gabriel, R. Wagner, G. C. Heck, L. Lippmann Jr., A. Soletti, D. F. de Araújo, F. A. Salles, O. A. C. Macedo V. C. Zambenedetti, "Communication Solution for Implementing Smart Grid Environment in the Distribution Network," in *IEEE Conference On Innovative Smart Grid Technologies Latin America*, São Paulo, 2013, p. 5.

[36] Daniella Vieira, Gabriel Dettogni Cesare Quinteiro Pica, "An Overview of Smart Grids in Brazil," in *ENERGY 2011 : The First International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies*, Florianopolis-SC, 2011, p. 5.

ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY
www.elecon.ipp.pt

Towards Efficient European and Brazilian Electricity Markets
First ELECON Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, September 24-25, 2013.

Status of Non-Technical Losses of Electricity in Brazil

Danilo Gastaldello[a], André Nunes de Souza[b], Haroldo Amaral[b], Zita Vale[c], Filipe Fernandes[c]

[a]*University os São Paulo (USP), São Paulo, Brazil*
[b]*São Paulo State University (UNESP),São Paulo, Brazil*
[c]*Polytechnic Institute of Porto (ISEP/IPP),Porto, Portugal*

Abstract

The electricity demand in Brazil has been growing. Some studies estimate that through 2035 the energy consumption (the power consumption) should increase 78%. Two distinct actions are necessary to meet this growth: the construction of new generating plants and to reduce electrical losses in the country. As the construction of power plants have a high price, coupled with the growth of (current) environmental concern, electric utilities are investing in reducing losses, both technical and non-technical. In this context, this paper aims to present an overview of non-technical losses in Brazil and to raise a discussion on the reasons that contribute to energy fraud.

Keywords: Non-technical losses, energy consumption, energy status

1. Introduction

The main concern in the distribution sector, the electricity losses, as inferred by the name, refer to the electrical energy that although inserted in the interconnected system and network of the distribution companies, does not arrive to be sold, either for technical reasons or commercial reasons.

Technical losses can occur by a number of reasons, one of the main, however, occurs by heating of electricity conductors, due to flow of electric current (*electricity*), called the "Joule effect". In this aspect, therefore, the extension of networks and the greatness territorial of Brazil make its level of technical losses suffer impact.

Already losses known as commercial losses generally have two main modalities: energy theft and fraud. The theft is characterized by direct diversion of energy by the consumer, what makes the used energy illegal and not registered, such as, leading to losses [1], for example:

- Illegal connection;
- Bypass.

In the case of fraud, however, the consumer is recorded by the distributor, but the consumer makes tampering the electrical installations of residence, commerce or industry, so that, although consuming a quantity of energy, effectively will pay only for a small part of consumption due to fraud [2]. The examples of fraud are listed below:

- Change in the measurement connections that make the disc turn back;
- Sectioning or opening the potential of meters (open test leads);
- Locking of disc meter;
- Handling of the register;
- Change the gears of logger;
- Potential coil violated;
- Wires of the secondary of currents transformers (CTs) bare, forming a bridge for contact between drivers, reducing the current flow by the meter;
- Key blade of verification open;
- Enlargement of the poles of the key benchmarks, interrupting electrical contact;
- Insulating varnish on the poles of the switch of measurement.

Research conducted on commercial losses estimate that 10% of the generated energy in Central America is stolen, in Asia this percentage is in the range of 20%, reaching 45% in India. Even in countries like the United States, Canada, England, Australia and New Zealand electricity thefts occur. Today in Brazil, 16% of all energy produced is lost [3].

The reduction of these non-technical losses has been a priority in the energy concessionaires in Brazil, as well as regulatory agencies, both for its growth in recent years as by their current size. The thefts of electrical energy performed by active consumers in the residential, commercial and industrial are the major amount of commercial losses.

The existence of this problem is due to several factors that go beyond the scope of management of distribution, such as socioeconomic status, education level and cultural level of the population and degree of urbanization of the areas served. Therefore, the state must create institutional and socioeconomic conditions that favor the reduction of losses and defaults and the regulatory mechanisms that encourage energy concessionaires to act efficiently in the same direction.

In this context, the paper presents a discussion of the reasons that lead to consumer default, besides measured values of the national view on the problem.

2. National Panorama of Energy losses

The generation of electricity in Brazil on public utilities and auto producers has reached 552.5 TWh in 2012, 3.9% higher than the result of 2011. The net imports of 40.3 TWh, added to internal generation, allowed a domestic supply of 592.8 TWh of electricity, an amount 4.4% higher to 2011. The final consumption was 498.4 TWh, an increase of 3.8% compared to 2011. About 16% of the total offered was lost through technical losses and non-technical, i.e., about 9,472 TWh [4]. Fig. 1 presents an overview of energy consumption by sector from 2003 to 2012.

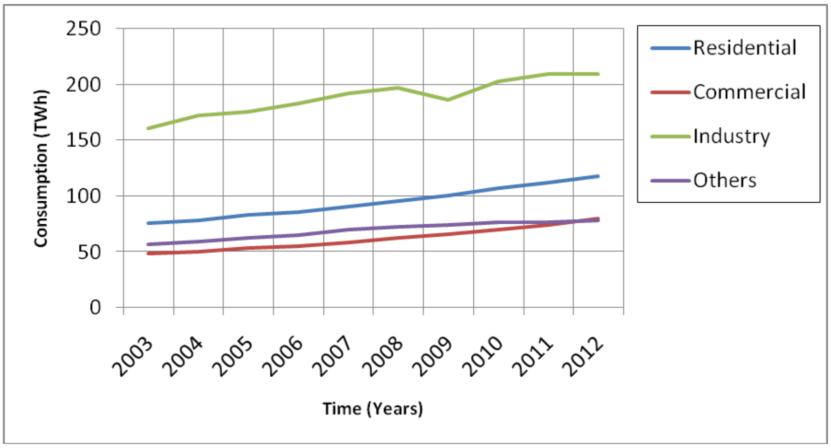

Fig. 1. Energy Consumption by Sector in the last 10 years in Brazil

It can be observed that the electricity consumption grew in all sectors over the past 10 years due to increase per capita income and the development of the country in the past years. In the Fig. 2 is shown the percentage of non-technical losses over recent years in relation to the total energy generated and imported.

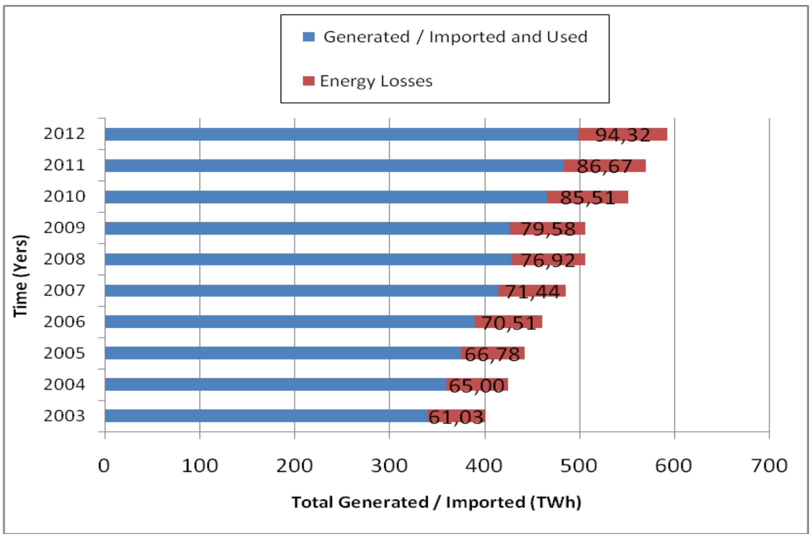

Fig. 2. Total energy lost in last 10 years on Brazil

Although energy losses present increasing numbers in the past years, as shown in the previous figure, the percentage in front of the total remained basically constant at 15%, as can be seen in Fig. 3. This means that the non-technical losses are growing along with the growth in demand. If we consider that the losses by Joule effect increases due to higher current flow in the existing system and that concessionaires are finding some defaulters, means that new customers may be stealing, or that have not been discovered are stealing even more.

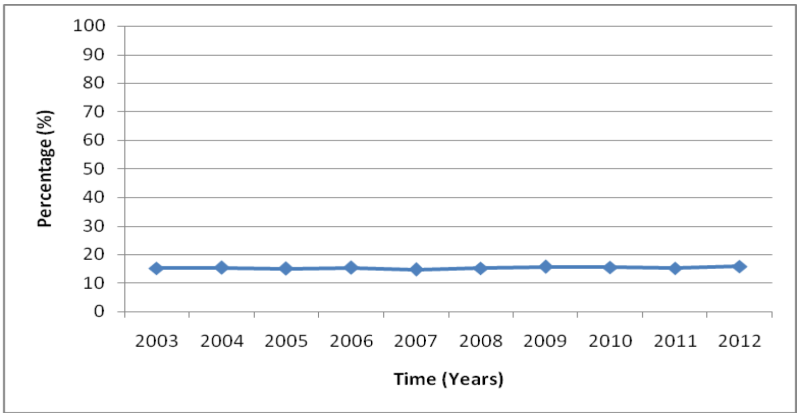

Fig. 3. Percentage of losses in relation to total production in the last 10 years in Brazil

Fig. 4 shows the percentage of each portion of the technical and non-technical losses.

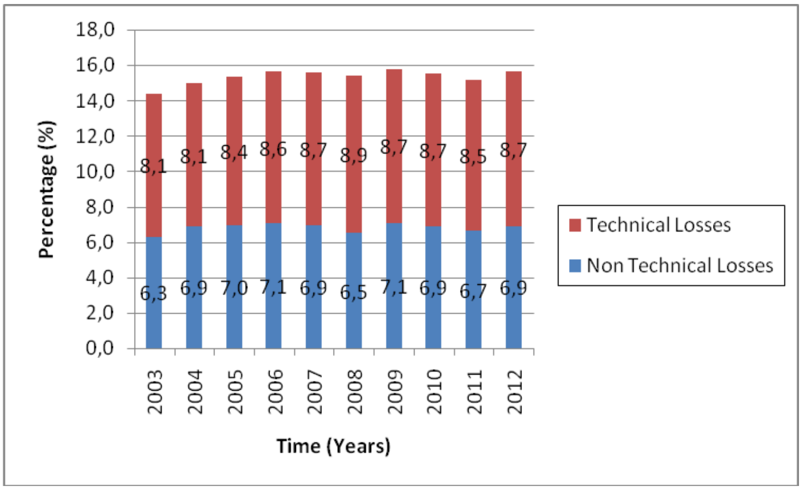

Fig. 4. Percentage of technical losses and non-technical in the last 10 years in Brazil

It can be observed by previous figure that non-technical losses or commercial losses remained constant in the past years, with around 7%, which represents approximately 45% of the energy lost in the country.

3. Relationship of Non-Technical Losses with Income Per Capita

In Brazil, commercial losses are high by several factors of socioeconomic and cultural nature such as: unemployment, low income, poor housing, inadequate infrastructure, high energy prices and connection accessories and also impunity relative to corruption and fraud.

In his context, we have the bad distribution of income and information, leading the people who live off the South-Southeast to feel a certain way discriminated. Given this, the Fig. 5 and Fig. 6 respectively, show the distribution of income by region of the country and the percentage of non-technical losses by energy company.

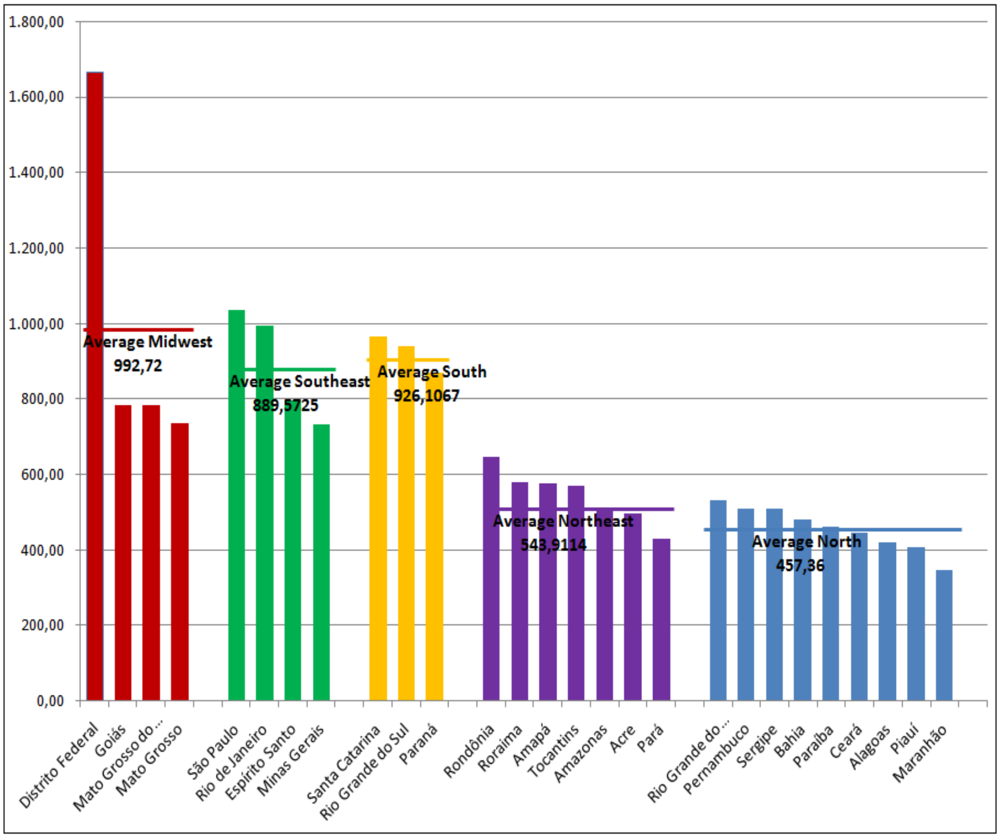

Fig. 5. Per Capita Income in R$ by Region in Brazil

In Fig. 5 it is observed that the Midwest has the highest per capita income in the country, followed by the South, Southeast, North and Northeast. This was due to the high value of income of the Federal District and also due to population density. The large center *Rio-São Paulo* despite possessing great richness also has a very high population density, coupled with slightly lower rates of other states (*Minas Gerais and Espírito Santo*) makes the region stay behind the South who have three states with good levels of income distribution and also education. The northern region is ahead of the Northeast region mainly due to population density, and the Northeast also has the hinterland (*Sertão*) regions, where the living conditions are precarious.

Stands out in Fig. 6 that the three concessionaries with higher commercial losses are located in the North and Northeast, where structural investment is lower, which makes it difficult to supervision and inspection by the companies. On the other hand, the three concessionaries with the lowest rates are located in the South and Southeast, where industrial development is greater, and public education is slightly higher.

However it should be emphasized that this relationship is not directly proportional, given the fact that the company that provides power to the Federal District (which is what has better per capita index) CEB is in twelfth place, in the total of thirty one concessionaries analyzed, with approximately 11.4% of losses; Light, serving the *Rio de Janeiro*, mainly in the Southeast is the twenty-seventh place, with a loss ratio of 23.9%. Another highlight is the company *Energisa SE* serving the states of the Northeast and Southeast who is in seventh with an index of 9.8% of commercial losses.

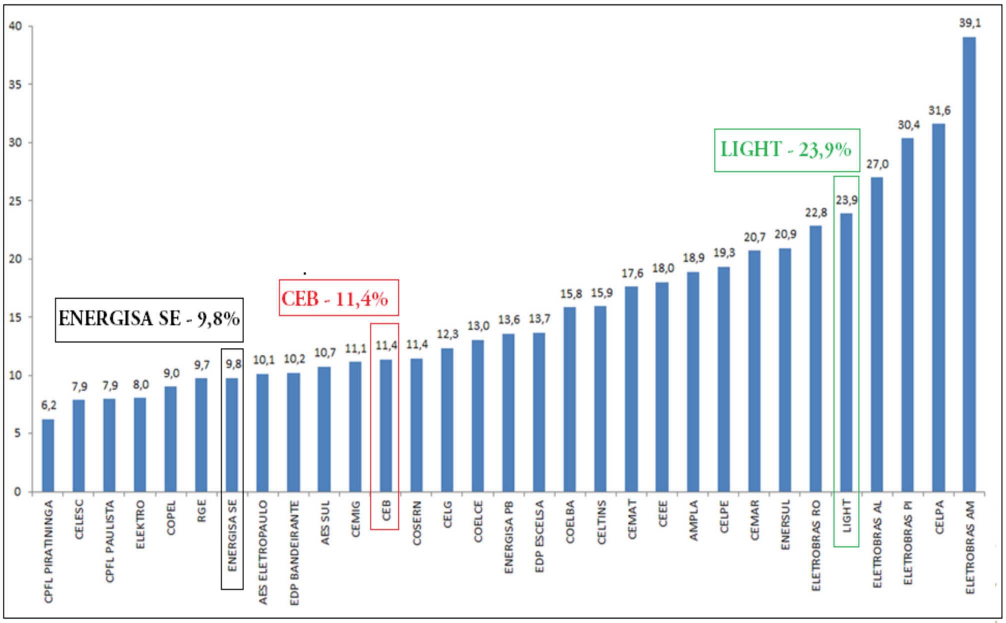

Fig. 6. Percentage of Losses by Commercial Carrier

4. Impacts of Commercial Losses in Billing Rate

A high level of commercial losses means higher tariffs for consumers, who pay for the generation and transmission of electricity stolen. In Brazil this problem corresponds to about 5% of Total Energy Required by distributors, representing an annual bonus of R$ 5 billion and tariff impact of 4% to 17%, according to each concessionaire. Fig. 7 shows the variation of the energy tariff of four power utilities in the country.

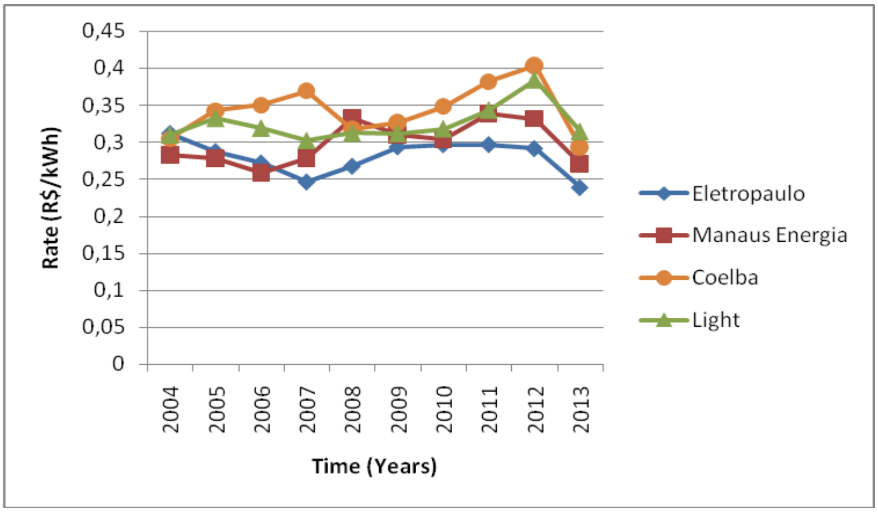

Fig. 7. Change in Residential Billing Rate by Concessionaire

Despite the variation in the residential billing of the four concessionaries analyzed are very similar, with a decrease in the last period, it is important to highlight that both *Coelba (Bahia)*, as *Light (Rio de Janeiro)* and *Energy Manaus (Amazonas)* have longer periods of elevation that decrease their tariffs, which brings us to the figure above that these companies have a high level of commercial losses.

5. Proposals of Some Initiatives to Contain Losses

Find consumers fraudsters is not a simple task since, although companies in Brazil invest millions to develop new methodologies, default continues to grow in recent years. In this context, there should be greater involvement of the state in punishing the identified consumers more rigorously, as well, new fraudsters will not commit this crime. Presented below is a sequence of proposed actions to reduce the losses, both by concessionaires, as by the state:

a) Distribution Companies

- Regular inspections searching for robbery;
- Cutting off the supply of energy customers fraudsters;
- Externalization of meters and remote metering of energy;
- Shielding of networks to prevent theft;
- Notice of court and court of defaulting customers;
- Recoveries and extrajudicial documents;
- Installment payment of defaulted consumer debt, and
- Education and awareness of the communities served.

b) State

- Regulatory incentives to encourage distributors to reduce losses and debt;

- Additional resources to deepen the actions of the distributors when the benefits don´t outweigh the incurred costs on fight;
- Social action programs and awareness campaigns;
- Improving the quality of social least favored areas of each concession.

6. Conclusion

In this work we presented a view of the non-technical losses situations in Brazil, presenting possible reasons that encourage the practice of this situation that should be considered a crime. It was verified the possible contribution of the income distribution, as well as the infrastructure of each of the five regions of the country, was presented some numbers of concessionaries, confronting the expectation that only the poorest states conduct frauds, and was listed some actions that can be taken to reduce bad debt.

Many studies are being done to decrease the rate of technical losses and non-technical studies that create new methodologies, new computational tools for classification and pattern recognition of consumers defaulted, but only these measures are not sufficient. There must be a greater awareness of population through social action programs in all areas of service concession power distribution.

Acknowledgements

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912.

To the ELECON project which allows the exchange of experience among students of IPP and UNESP, specifically research groups of GECAD and LSISPOTI.

References

[1] D. Suriyamongkol, "Non-Technical Losses In Electrical Power Systems", M.Sc. thesis, Fritz J. and Dolores H. Russ College of Engineering and Technology, Ohio University, 2002.

[2] Associação Brasileira de Distribuidores de Energia Elétrica. “Procedimentos para Prevenção e Combate ao Furto de Energia”, Documento Técnico ABRADEE, 2012.

[3] M. Silveira, P. Bastos, I. Micheli, M. A. de Almeida, P. R. Dantas, “Metodologia para Identificação de Perdas Não-Técnicas - Matriz de Perdas”, CIDEL, Buenos Aires, 2006.

[4] EPE - Empresa de Pesquisa Energética, “Balanço Energético Nacional 2013 - Ano Base 2012”, Rio de Janeiro, EPE, 2013.

ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY

www.elecon.ipp.pt

Towards Efficient European and Brazilian Electricity Markets

First ELECON Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, September 24-25, 2013.

Study of Proposed Identification of Non-Technical Losses of Electricity in Brazil

Danilo Gastaldello[a], André Nunes de Souza[b], Tiago Forti[b], Zita Vale[c], Pedro Faria[c]

[a]*University os São Paulo (USP), São Paulo, Brazil*
[b]*São Paulo State University (UNESP),São Paulo, Brazil*
[c]*Polytechnic Institute of Porto (ISEP/IPP),Porto, Portugal*

Abstract

The electric utilities have large revenue losses annually due to commercial losses, which are caused mainly by fraud on the part of consumers and faulty meters. Automatic detection of such losses where there is a complex problem, given the large number of consumers and the high cost of each inspection, not to mention the wear of the relationship between company and consumer. Given the above, this paper aims to briefly present some methodologies applied by utilities to identify consumer frauds.

Keywords: Non-technical losses, identification and classification, electrical energy consumer

1. Introduction

In the last years, the Brazilian system had many changes, passed the period of the privatization of the generation companies, transmission and distribution of electric energy, this results in the creation of a competitive market in the national scenario. The investments made by the private companies have with main aim a great improvement of theirs technical and financial performance, through more productivity, efficiency and profitability [1].

Commercial losses or non-techniques are those associated with marketing of the energy supplied to the user and refer to the energy delivered but not billed, generating a loss in the revenue. Are also defined as the difference between total losses and technical losses, and are mainly related to illegal connections in distribution system [2].

Although advances in this area have been observed in recent years, particularly with regard to the different measurement techniques of electrical energy, it becomes increasingly necessary to research alternative methods with great flexibility and easy to adaptation to the context of the problem, as computational techniques models with intelligent algorithms [3].

Among the computational intelligence techniques commonly used for the detection of commercial losses are Artificial Neural Networks, Support Vector Machines, Nearest neighbors, Fuzzy Logic, among many others. The applications of these intelligent algorithms enable the development of computational tools used for the estimation and identification of fraud (commercial losses) in several companies, analyzing the data of a particular customer and their transactions, and you can check if there is any suspicious transaction occurrence of irregularity.

The intelligent techniques help to identify the potential fraudsters by analyzing data of each consumer, but the company still needs to invest in other procedures to assist in the correct identification of delinquency, as well as consumer awareness of the problem. With the aim to reduce the value of the non-technical losses, the electric energy companies usually work in:

- Inspection programs: consists in verifying the integrity of the measurement system, detecting equipment failures, fraud and theft of energy, connection errors and other problems that may compromise electrical energy measurement [4];
- Replacement of meters: the assessment consisting of lots of meters through field sampling, laboratory testing and analysis of the meters removed in the field. In addition, the replacement of meters with service life expired or possible technical failures;
- Regularization of sites with high probability of illegal connections, such as slums, through a program of regulatory nature, consequently reducing commercial losses;
- Implementation of trade policies: consists of visits to the community about explanations, talks and trainings on the consumption of electricity;
- Shares of energy efficiency with a focus on reducing electric bills and effective use of energy, serving as an incentive for consumers to not defrauding.

One of the most traditional types of detect and reduce the commercial losses is conducting inspections on consumers. The selection of which consumers should be inspected is an arduous task for the experts, and then the need for the use of intelligent computational systems to help in the treatment of thousands data from millions of consumers registered.

Many actions have been taken in the search for technological solutions and methodological effective to solve the problem of trading losses. However, the experience has demonstrated the impossibility of applying unique solutions for their economic agents, even within the concession area of the business, which is due not only physical factors but mainly to the enormous cultural, social and economic Brazilian society. This scenario suggests the need to construct creative solutions differentiated by the distributors.

In this context, this paper presents a survey of some actions taken by the Brazilian utilities to detect and reduce non-technical losses. These actions are used to improve the database of knowledge of each consumer profile, which assists in the development of computational tools for identifying and classification of consumers.

2. Shares Applied for Distributors to Detect and Reduce Commercial Losses

The high damage caused by fraud energy, made the distributors takes some actions that help to detect and reduce commercial losses, such as:

- Identification of critical areas: a clear identification of areas with the highest concentration of commercial losses inside the concession area of distribution is essential to solve the problem;
- Energy balance: the difference between the amount of energy measured in distribution transformers and the sum of individual consumption of customers served in that region can be a good indicator of commercial losses;
- Billing systems: important action to detect and reduce non-technical losses is the insertion in their billing systems, of tools that allow obtaining and maintaining accurate information pertaining to sharp variations in energy consumption units, for example, may be carried out using neural networks or data mining;
- Development and/or use of new technologies: several innovative technologies have been developed and/or implemented in the search for more effective solutions to detect and reduce commercial losses, with emphasis, among others, the use of external measurement and electronic meters, shielding cables and the development of new types of meters and software that employ artificial intelligence to increase the effectiveness of inspections;
- Actions of institutional marketing: distributors have used institutional marketing, usually with the development of educational campaigns with the underserved communities, in order to provide information on the proper and efficient use of electricity;
- Motivating employees: for an effective fight against non-technical losses, it is essential to engage all employees in the company;
- Establishment of specialized teams: it is necessary to set up specialized teams to detect and reduce commercial losses, which receive constant training and remuneration consistent.

3. Techniques and Methodologies Used to Identify Fraud

Many techniques are used to detect and reduce commercial losses such as neural networks, support vector machines, k-nearest neighbors, genetic algorithms, fuzzy logic, among others. Each technique has its advantages and disadvantages, and sometimes is more or less efficient for a particular profile of customer than to another, according to the focus of the search, the region of operation, etc., making it very difficult to establish a technique like the best for all possible scenarios.

In this paper we will detail three different techniques that have been widely used in the literature in recent years, which are neural networks, the support vector machines and technique of near neighbors.

1.1. Artificial Neural Networks

The Artificial Neural Networks (ANN) consist of a method of solving problems related to engineering and science through simple circuits that mimic the human brain, including their behavior, learning, making mistakes and making discoveries. In a technical view, it is a

computational model that use inherently parallel processing techniques and adaptive through a large number of processing simple units [5].

An ANN is formed by small modules which simulate the operation of a neuron, working like the elements that were inspired, receiving and transmitting information. A simple artificial neuron model has the main features of a biological neural network, parallelism and high connectivity, a neuron is composed of a linear combination and a transfer function.

The transfer function is responsible for processing the information received and is also responsible for the output of the neuron and it can assume values of type Binary (0 or 1), Bipolar (-1 or 1) or Real [6]. Fig. 1 presents the model of an artificial neuron.

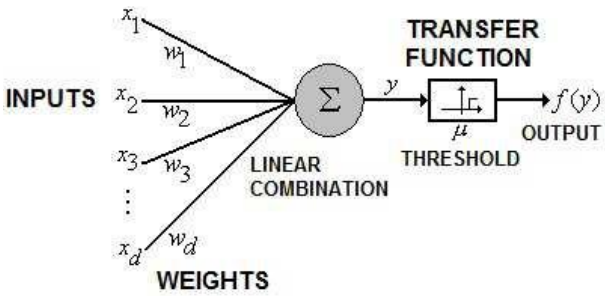

Fig. 1. Simple artificial neuron

In the training phase the weights of the network are adjusted to make the ANN able to identify a pattern input and process a correct answer with respect to this pattern. The training time is influenced by several factors, but one should always use a stopping criterion, such as error rate, maximum number of cycles or periods of training. The most common training is the algorithm "*Backpropagation*".

The idea of the "*Backpropagation*" is use pairs of inputs and outputs, previously known, to adjust the synaptic weights of the network through an error correction mechanism and during the training process, the output value is generated and compared with the known value. The error obtained is used to adjust the synaptic weights in order to gradually reduce this error. This error is propagated from the output layer to the input layer. Therefore, the synaptic weights of the inner layers will be corrected according to the error when it is done the *"backpropagation"*.

When the training wad finished, occurs the testing phase, when the patterns which have not yet been presented to the network are tested and the answers of the network will be evaluate. If the number of write answers was satisfactory, the network is ready to be implemented otherwise, one can repeat the training choosing a new topology for the network, like the number of layers or the number of neurons per layer.

1.2. Support Vector Machines:

The Support Vector Machines (SVMs) is an application of statistical learning theory. This is a research area that offers many options to work, most of them being more conceptual than

merely technical, and his its scope has increased significantly in terms of new algorithms and a further theoretical understanding with great speed [7], [8].

In recent years, many successful applications of SVMs have shown that this technique not only has a more solid substantiation as ANN but are also able to replace them with similar or better performance [8].

According to the issues highlighted to control the effectiveness of learning algorithms, it is necessary that the capacity of the class of functions can be calculated. In the early days of his study, Vapnik [7] considered a class of *hyperplanes* in the space H dot product,

$$\langle w, x \rangle + b = 0 \quad (1)$$

where $w \in H, b \in \mathbb{R}$ correspond to decision functions

$$f(x) = sgn(\langle w, x \rangle + b) \quad (2)$$

Then he proposed the learning algorithm called Portrait Generalized for *hyperplane* separable problems. His idea is based in that among all *hyperplanes* separating the data, there is only one optimal *hyperplane* distinguished by the maximum margin of separation between any training point and this *hyperplane*. This *hyperplane* is calculated like the solution of

$$\max_{w \in \mathrm{H}, \mathrm{b} \in \mathbb{R}} \min \{\|x - x_i\| x \in H, \langle w, x \rangle + b = 0\} \quad (3)$$

Other important point is that the over fitting of the separating *hyperplanes* decreases with increasing margin. To construct the optimal hyperplane, it is necessary to solve

$$max_{w \in H, b \in \mathbb{R}}\, \tau(w) = {}^1\!/_2 \, \|w\|^2 \quad (4)$$

subject to

$$y_i(\langle w, x_i \rangle + b) \geq 1 \qquad i = 1, \dots, m \quad (5)$$

with the constraint (5) ensuring that $f(x_i)$ will be +1 for $y_i = -1\ e - 1$ for $y_i = -1$ and also fixing the scale of *w*. The function τ in (4) is called the objective function, while (5) are the inequality constraints.

1.3. k-Nearest Neighbor

The k-Nearest Neighbor (k-NN) classifier is based on analogy to the distances between the neighbors. It is very used in applications that involve classification tasks, and is easy to understand and implement. [9].

The k-NN has no processing during the training phase, it only make for each test sample a simple measurement of the distance between him and all samples of the training set. After this measurement, the class of the most part of the neighborhood will be the class of the tested sample [9].

If the parameter *k* was equal 1, the class of the tested sample will be the class of the most near neighbor, if *k* was greater than 1, for example 3, is checked the three nearest neighbors considering all the samples of the training set. In the Fig. 2 is showed a *k-NN* parameterized with *k=3*, when the green sample is be testing to discovery if it is from the red class or the blue class. We can see in the picture that two neighbors are from the red class and only one from blue class, so in this case the tested sample will be classified like a red sample.

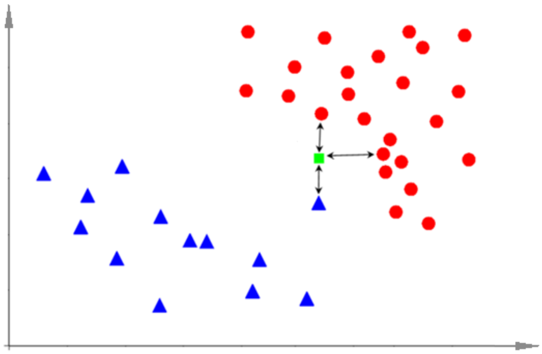

Fig. 2. A parameterized example for a *k-NN*

The only restriction is that must be careful in choosing the parameter *k* to be an odd number, because an even number could cause a conflict when a point has the same number of neighbors of each class, for example in the case of the Fig. 2, if the parameter *k* was set like 2, the *k-NN* will can't choose a class to the green sample, because the two most near neighbors was one red and one blue.

The classification rule of *k-NN* is based normally in Euclidean distance, but in specific problems may be necessary use other types of distances such as Manhattan and Minkowski [10].

If $p=(p_1,p_2,...,p_n)$ and $q=(q_1, q_2,...,q_n)$ was two points in $\Re^n$:

- Euclidian's distance between p and qis calculated by:

$$d(p,q) = \sqrt[2]{(p_1 - q_1)^2 + (p_2 - q_2)^2 + \cdots + (p_n - q_n)^2} \qquad (6)$$

- Manhattan's distance between p and q is calculated by:

$$d(p,q) = |p_1 - q_1| + |p_2 - q_2| + \cdots + |p_n - q_n| \qquad (7)$$

- Minkowski's distance between p and q is calculated by:

$$d(p,q) = (|p_1 - q_1|^j + |p_2 - q_2|^j + \cdots + |p_n - q_n|^j)^{\left(1/_j\right)} \qquad (7)$$

where $j \in \aleph$.

The Minkowski distance is a generalization of the two previous distances. It becomes the Manhattan distance when $j=1$ and it becomes the Euclidean distance when $j=2$.

4. Conclusion

Commercial losses are a big problem in Brazil, generating high annual losses of power distribution companies. To detect and reduce fraud are used several techniques such as neural networks, the support vector machines and k-nearest neighbors. Each technique has its advantages and disadvantages, and sometimes is more or less efficient for a particular profile of customer than to another, according to the focus of the search, the region of operation, etc., making it very difficult to establish a technique like the best for all possible scenarios.

This work presented a review of the main techniques to detect and reduce fraud in Brazil as well as an introduction to some of the most widely used techniques for the detection of fraud.

Acknowledgements

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912.

To the ELECON project, that enables the exchange of experience among students of IPP and UNESP, specifically the research groups GECAD and LSISPOTI.

References

[1] R. F. Calili, “Desenvolvimento de Sistema para Detecção de Perdas Comerciais em Redes de distribuição de energia elétrica”, Dissertação de Mestrado, Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro-RJ, Julho, 2005.

[2] A. C. M. de Araújo, “Perdas e Inadimplência na Atividade de Distribuição de Energia Elétrica no Brasil”, Dissertação de Doutorado, Universidade Federal do Rio de Janeiro, Rio de Janeiro-RJ, Abril, 2007.

[3] R. Alves, P. Casanova, E. Quirogas, O. Ravelo, W. Gimenez, “Reduction of Non-Technical Losses by Modernization and Updating of Measurement Systems”, Transmission & Distribution Conference and Exposition: Latin America - IEEE/PES, August, 2006.

[4] R. M. Queiroga, “Uso de Técnicas de Data Mining para Detecção de Fraudes em Energia Elétrica”, Dissertação de Mestrado, Universidade Federal do Espírito Santo, Vitória-ES, 2005.

[5] S. Haykin, “Neural Networks: A comprehensive foundation”, Prentice-Hall, 1998.

[6] C. Bishop, “Neural networks for pattern recognition”, Oxford University Press, 1995.

[7] V. N. Vapnik, “An overview of statistical learning theory”, in IEEE Transactions on Neural Networks, vol. 10, pp. 988–999, 1999.

[8] B. Schlkopf, A. J. Smola, “Learning with Kernels”, MIT Press, 2002.

[9] T. M. Mitchell, “Machine Learning”, WCB/McGraw-Hill, 1997.

[10] J. Pan, Y. Qiao, and S. Sun, “A fast k nearest neighbors classification algorithm,” in IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences, vol. E87-A, 2004.

ELECON
ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY
www.elecon.ipp.pt

Towards Efficient European and Brazilian Electricity Markets
First ELECON Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, September 24-25, 2013.

Voltage Magnitude Analysis Considering Load Curtailment Minimization in Sub-Transmission Networks with Distributed Generators

Adriana Cruz[a], Bruno Canizes[b*], Grimoni J. A. B.[a],

Zita Vale[a] Senior member IEEE

[a]*Electric Energy and Automation Engineering Department,*
University of São Paulo,
Av. Prof. Luciano Gualberto, Travessa 3, nº 380, Butantã São Paulo, Brazil

[b]*Polytechnic of Porto (ISEP/IPP),*
Rua Dr. António Almeida, 431, 4200-072, Porto, Portugal

Abstract

Most of distribution generation and smart grid research works are dedicated to the study of network operation parameters, reliability among others. However, many of this research works usually uses traditional test systems such as IEEE test systems. This work proposes a voltage magnitude study in presence of fault conditions considering the realistic specifications found in countries like Brazil. The methodology considers a hybrid method of fuzzy set and Monte Carlo simulation based on the fuzzy-probabilistic models and a remedial action algorithm which is based on optimal power flow. To illustrate the application of the proposed method, the paper includes a case study that considers a real 12 bus sub-transmission network.

Keywords: Distribution generation, Optimal power flow, Reliability, Sub-transmission network.

1. Introduction

Minimizing the unserved power by minimization of load curtailment leads to a reliability maximization in electrical systems. Thus, an important monetary loss due to undelivered power, economic damage and inconvenience to the power system user is avoided. The reliability criteria used to support decision making in electrical power system can be deterministic or probabilistic. In both cases, it is necessary to make use of a consistent database and to undertake an exhaustive statistical analysis of all the available information, such as failure rates (λ) and average repair times (r) of each distribution system component.

The new structure of the electrical network, after the implementation of concepts such as distributed generation (GD) and smart grid, consists of various subsystems or networks of different levels which belong to the same power system. In reality, the structure of such networks varies; it depends on the area and on the policy that guide the energy planning.

The IEEE test systems are used to analyze and simulate methodologies. However, depending on the network characteristic, such circuits sometimes don't give a reasonable description of reality. Taking Brazil as an example, the huge size of the power system as well as the territory makes it possible to exploit several levels of voltage where it is suitable to use high voltage in distribution or sub-transmission networks (69 kV) through the extensive usage of distributed generation [1, 2]. Thus, it is necessary to characterize and analyze the sub-transmission networks.

The present work proposes a voltage magnitude study in presence of fault conditions considering the realistic specifications found in countries like Brazil. The methodology proposed is based on statistical failure and repair data of the sub-transmission power system components and uses fuzzy-probabilistic modeling for system component outage parameters. To catch both randomness and fuzziness of component outage parameters, a hybrid method of fuzzy set and Monte Carlo simulation based on the fuzzy-probabilistic models is presented. A remedial action algorithm, based on optimal power flow is used to minimize the total load curtailment [3, 4].

This paper is organized as follows: Section 2 explains the proposed methodology. Section 3 presents the case study and the discussion of the obtained results. Finally, in section 4 the most relevant conclusions are presented.

2. Methodology

Figure 1 presents the idea of the proposed methodology. This methodology is intended only for independent forced outages and has five main aspects: database creation, network characterization, fuzzy models for repair time, failure rate and unavailability, selection of system states and remedial actions.

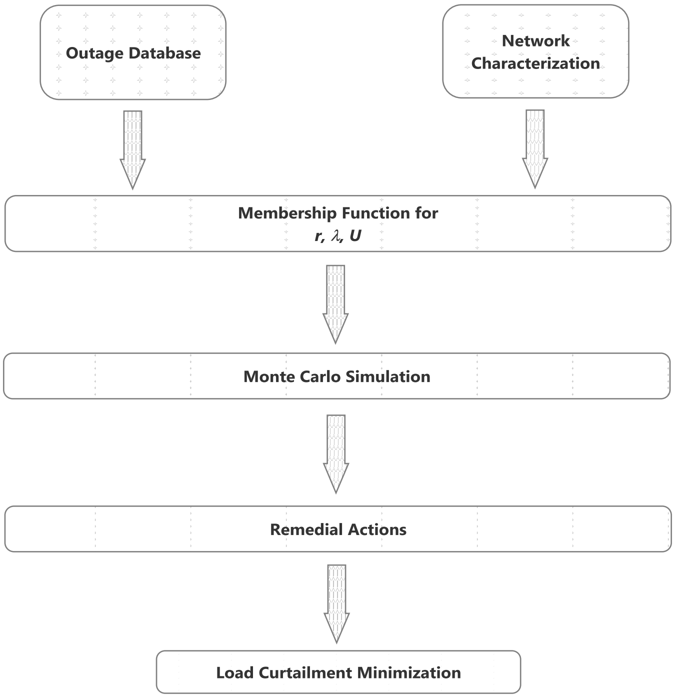

Fig. 1. Proposed methodology scheme

2.1. Outage database

A creation of a consistent database an exhaustive statistical analysis of all available information are the main basis for the proposed methodology.

2.2. Network characterization

The test network with intensive usage of distributed generators take into account with electrical characteristics, such as topology, load level, generation power, voltage magnitude and angle, etc.

2.3. Fuzzy membership functions for repair time, failure rate and unavailability

It is extremely difficult to distinguish precisely the effects of the weather conditions, and environment and operational conditions on the outage data of individual components using a probability model. The failure frequency or probability of sub-distribution power systems are directly impacted by these conditions. It is also very common that a large number of utilities do not have sufficient statistical records of outage parameters. Thus, the fuzzy model is an appropriated method to represent the uncertainty. Fuzzy models for repair time, failure rate and unavailability can be found in [3, 4].

2.4. Monte Carlo simulation

In general, sub-transmission components are represented using the two-state (up and down) model. The two-state models for generating units and transmission components are created by Nonsequential Monte Carlo Simulation [3] in order to obtain a sample of all possible transmission power system states:

$$S_i = \begin{cases} (success) & if \quad R_i > Q_i \\ (failure) & if \quad 0 \leq R_i \leq Q_i \end{cases} \tag{1}$$

The system state containing N components is depicted by vector S:

$$S = (S_1, \dots, S_i, \dots, S_N) \tag{2}$$

where S_i denotes the state of the ith component and Q_i its failure probability (unavailability) for the ith component. R_i is a random number uniformly distributed between [0, 1] for the ith component.

2.5. Remedial actions

A remedial action algorithm, based on optimal power flow (OPF) (see equations (3–14)) is used to reschedule generation and alleviate constraint violations and, at the same time, to avoid any load curtailment, if possible, or, otherwise, to minimize the load curtailment. The objective function of the OPF model minimizes the total load curtailment.

$$min \sum_{i \in LG} Scut_i \tag{3}$$

$$PGEN_i^{min} \leq PGEN_i \leq PGEN_i^{max} \quad i \in GN \tag{4}$$

$$QGEN_i^{min} \leq QGEN_i \leq QGEN_i^{max} \quad i \in GN \tag{5}$$

$$Pcut_i \leq Lp_i \quad i \in LG \tag{6}$$

$$Qcut_i \leq Lq_i \quad i \in LG \tag{7}$$

$$PGEN_i - Lp_i - P_i(v, \delta) + Pcut_i = 0 \quad i \in GN \tag{8}$$

$$QGEN_i - Lq_i - Q_i(v, \delta) + Qcut_i = 0 \quad i \in GN \tag{9}$$

$$P_i(v, \delta) + Lp_i - Pcut_i = 0 \quad i \in LN \tag{10}$$

$$Q_i(v, \delta) + Lq_i - Qcut_i = 0 \quad i \in LN \tag{11}$$

$$V_i^{min} \leq V_i \leq V_i^{max} \quad i \in N \tag{12}$$

$$\delta_i^{min} \leq \delta_i \leq \delta_i^{max} \quad i \in N \tag{13}$$

$$S_k(v, \delta) \leq S_k^{max} \tag{14}$$

3. Case study

A Brazilian 12 bus sub-transmission network (Figure 2) with 69kV, 1 substation and 11 load points is used for the application of the proposed methodology. In this case study were considered three load levels referred as light, moderate and heavy load. Eight capacitor banks are located in buses 2, 5, 6, 7, 9, 10, 11 and 12. The MVA base is 100.

Simulations were carried out in order to determine the response of the Brazilian 12 bus sub-transmission network with addition of distributed generators (DG) (they can be located at buses 2, 5, 6, 7, 9, 10, 11, 12) considering steady state and fault state in the network. The data network are presented in tables 1 and 2.

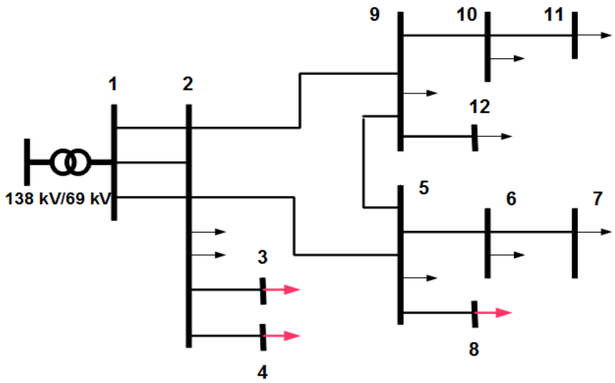

Fig. 2. Sub-Transmission network topology

The DG characteristics are:

- Size - 1, 3, 5, 7, 10 for steady state and additional 20, 30 MVA in failure analysis;
- Power factor - 0.9.

Table 1. Line data

Bus Out	Bus In	R (pu)	X (pu)	Thermal Limit (MVA)
1	2	0.0644	0.1527	71
1	2	0.0146	0.0617	106
1	2	0.0265	0.1164	106
2	3	0.0099	0.0417	34
2	4	0.0024	0.0058	71
2	5	0.0128	0.0544	106
5	6	0.1481	0.3593	72
6	7	0.1346	0.3264	72
5	8	0.0038	0.0089	72
2	9	0.0561	0.2460	106
9	10	0.1996	0.4842	72
10	11	0.2472	0.5995	72
9	12	0.6579	0.5562	34
5	9	0.0449	0.1972	106

Table 2. Load data

Bus	Heavy Active Load [pu]	Moderate Active Load [pu]	Light Active Load [pu]	Heavy Reactive Load [pu]	Moderate Reactive Load [pu]	Light Reactive Load [pu]	Capacitor [pu]
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.3045	0.2284	0.1218	0.1544	0.1003	0.0463	0.1836
3	0.1150	0.0863	0.0460	0.0378	0.0246	0.0113	0.0000
4	0.2320	0.1740	0.0928	0.0763	0.0496	0.0229	0.0000
5	0.3099	0.2324	0.1240	0.1494	0.0971	0.0448	0.0918
6	0.0751	0.0563	0.0300	0.0426	0.0277	0.0128	0.0406
7	0.0708	0.0531	0.0283	0.0322	0.0210	0.0097	0.0204
8	0.0310	0.0233	0.0124	0.0102	0.0066	0.0031	0.0000
9	0.1210	0.0908	0.0484	0.0353	0.0230	0.0106	0.0714
10	0.0771	0.0578	0.0309	0.0329	0.0214	0.0099	0.0306
11	0.0343	0.0257	0.0137	0.0131	0.0085	0.0039	0.0204
12	0.0166	0.0125	0.0066	0.0107	0.0070	0.0032	0.0306

3.1. Voltage analysis for steady state

As an example figures 3 and 4 presents the voltage results for steady and fault state in each bus considering the DG in bus 6.

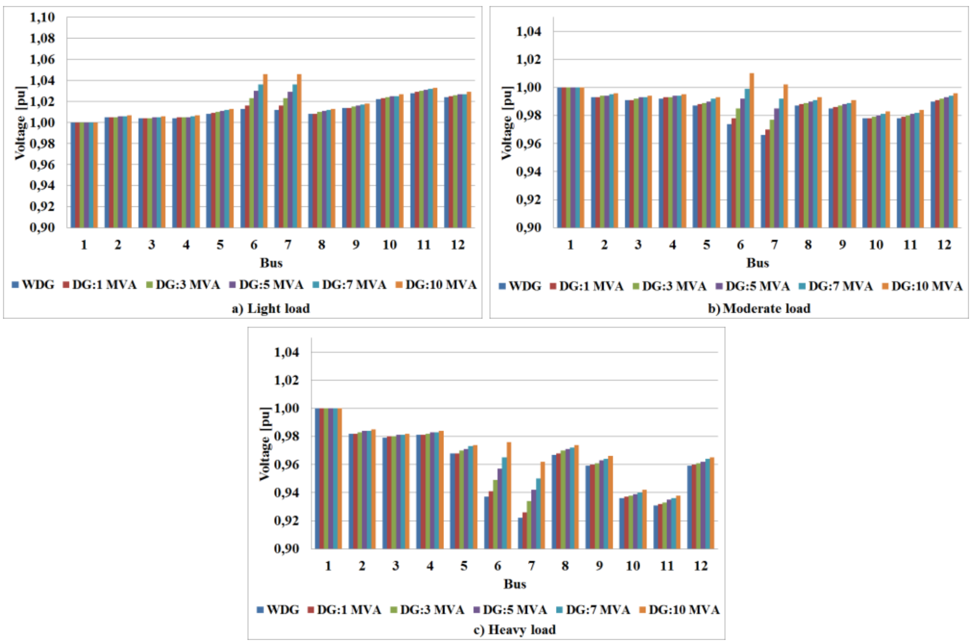

Fig. 3. Bus voltage in steady state: DG in bus 6

As can be seen in Figure 3 a strong impact in voltage magnitude occurs when heavy load is considered, mainly in buses 6, 7, 10, and 11. These four buses belongs to radial structure in the network and are very sensible to load growth.

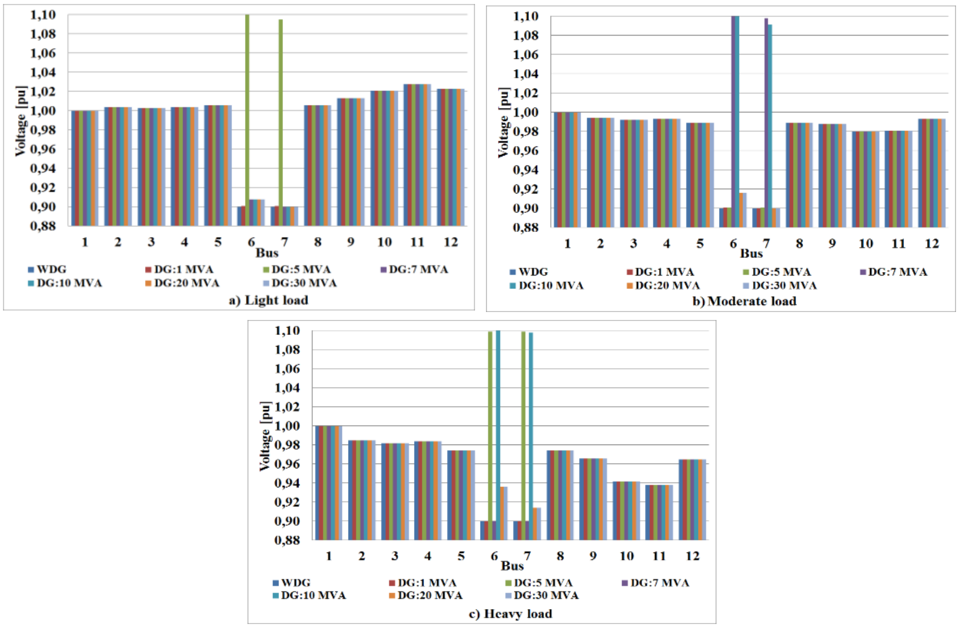

Fig. 4. Bus voltage in fault state: DG in bus 6

Monte Carlo simulation shows that line 5-6 presents the highest fault probability (0.17%). Thus, the simulation in fault condition considers line 5-6 in down sate. It is possible to seen through Figure 4 that buses 6 and 7 are the most affected. There are two reasons for this situation; these two buses are close to the fault and are in radial lines. Buses 10 and 11 are also strongly affected with the load increasing (heavy load).

Table 3 presents the active load curtailment for a fault in line 5-6 considering three load levels and six different DG capacities in bus 6.

Table 3 Total load curtailment for a fault in line 5-6

DG (MW)	Light Load Curtailment		Moderate Load Curtailment		Heavy Load Curtailment	
	(p.u.)	(%)	(p.u.)	(%)	(p.u.)	(%)
1	0.036	6.49	0.1	9.61	0.137	9.88
5	0.013	2.34	0.064	6.15	0.101	7.28
7	0	0	0.046	4.42	0.083	5.98
10	0	0	0.02	1.92	0.056	4.04
20	0	0	0	0	0	0
30	0	0	0	0	0	0

Through table 1 it is possible to see that load curtailment doesn't exceed 10% of total system load and can be observed that the DG contributes to the reliability increasing.

4. Conclusions

This paper presents a voltage magnitude study in presence of fault conditions considering the realistic specifications found in countries like Brazil. As can be seen, the load influence and network topology are essential factors in sub-transmissions network studies. Fault conditions in radial lines, like 5-6 leads to a considerable variation in voltage magnitude in buses that proceeds that line (buses 6 and 7). It was verified a strong contribution in reliability increasing in fault condition when DG is present on the network.

Nomenclature

$Scut_i$	Load curtailment at bus i in p.u.
$PGEN_i$	Generated active power at bus i in p.u.
$PGEN_i^{max}$	Upper limit of generated active power at bus i in p.u.
$PGEN_i^{min}$	Lower limit of generated active power at bus i in p.u.
$QGEN_i$	Generated reactive power at bus i in p.u.
$QGEN_i^{max}$	Upper limit of generated reactive power at bus i in p.u.
$QGEN_i^{min}$	Lower limit of generated reactive power at bus i in p.u.
$Scut_i$	Apparent load curtailment at bus i in p.u.
Lp_i	Active load at bus i in p.u.
Lq_i	Reactive load at bus i in p.u.
$P_i(v,\delta)$	Active power injections at bus i in p.u.
$Q_i(v,\delta)$	Reactive power injections at bus i in p.u.
V_i	voltage magnitude at bus i in p.u.
V_i^{max}	Upper limit of voltage magnitude at bus i in p.u.
V_i^{min}	Lower limit of voltage magnitude at bus i in p.u.
δ_i	Voltage angle at bus i in p.u.
δ_i^{max}	Upper limit of voltage angle at bus i in p.u.
δ_i^{min}	Lower limit of voltage angle at bus i in p.u.
$S_k(v,\delta)$	Apparent power flow on line k in p.u.
S_k^{max}	Rating power limit of line k in p.u.
LG	Set of buses with loads (generator bus and load bus that contain loads)
GN	Set of generator buses
LN	Set of load buses
N	Total number of buses

Acknowledgements

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912.

This work is also supported by FEDER Funds through COMPETE program and by National Funds through FCT under the projects FCOMP-01-0124-FEDER: PEstOE/EEI/UI0760/2011, PTDC/EEA-EEL/099832/2008, PTDC/SEN-ENR/099844/2008, and PTDC/SEN-ENR/122174/2010

References

[1] Plano Decenal de Expansão de Energia 2019 - PDE, Ministério de Minas e Energia do Brasil, 2010

[2] Plano Nacional de Energia 2030 - PNE, Ministério de Minas e Energia do Brasil. Empresa de Pesquisas Energéticas, Brasil, 2012

[3] B. Canizes, Z. A. Vale, J. P. Soares, and H. M. Khodr, "Fuzzy Monte Carlo Mathematical Model for Load Curtailment Minimization in Transmission Power Systems," presented at the 17th Power Systems Computation Conference (PSCC'11), Stockholm, Sweden, 2011

[4] B. Canizes, J. Soares, Z. Vale, and H. Khodr, "Hybrid Fuzzy Monte Carlo Technique for Reliability Assessment in Transmission Power Systems," Energy, 2012

ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY
www.elecon.ipp.pt

Towards Efficient European and Brazilian Electricity Markets
First ELECON Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, September 24-25, 2013.

Residential appliance identification and consumption prediction for better distribution grid management

Kasutav Basu[a], Vincent Debusschere[a], Seddik Bacha[a]

[a]G2ELab, 11 rues des Mathématiques, 38402 Saint Martin d'Hères, France

---

Abstract

A better distribution grid management is based on more local information on consumption patterns. Focusing on buildings (residential or tertiary), two main steps are to be considered. First, identify the particular electrical appliance usage(s) from the meter panel energy reading without being too intrusive in the inhabitant's day-to-day life. Second, predict the future consumption of specific appliances (especially the ones that can be remotely controlled) in order to adapt the (local) production accordingly. Therefore, appliance usage(s) identification and prediction from the meter panel energy reading has become an area of study in its own right and will be assessed in this work.
Unlike many other existing approaches based on signal processing at a high sampling rate, (1 second typically) the proposed approach tries to identify the usage of high power consuming appliance(s) by using the aggregate energy consumption at 10 minutes interval from the meter panel. The proposed approach is then both practical and affordable, without causing any privacy issue. The novelty of the approach lies in using a time series windowing approach which gives additional information about an aggregate energy state. The usage of specific inputs for the algorithms allows taking into account the temporal behavior of residential users. The usage of Multi label classification approach for identification is also new for this domain. The identification and prediction algorithms are tested over a data set of 100 houses monitored over one year.

Keywords: Smart Grids ; Distribution Networks ; Non-intrusive load monitoring, Multi-label classifier, Appliance usage prediction, Energy Management, Data-mining, Smart Homes.

Buildings (residential and tertiary) represent the first energy consumer and the second greenhouse emission source in France. Passive house and positive energy houses are being accepted as a standard for new buildings where the electrical part of energy consumed will be predominant. In order to achieve this goal, energy management have to be set including energy use, meteorology, inhabitant's comportment, etc. But these optimizations of energy savings can contradict an optimal comfort of the habitants. Load management allows

inhabitants to adjust power consumption according to expected comfort, and allows DSO to work on energy price variation in order to reduce economical (or environmental) costs, to increase local renewable integration, etc. It is then of great interest to be able to identify the usage of each appliance because, regarding dynamic demand side management, it is
important to evaluate how much energy can be saved thanks to requests to customers like unbalancing requests or energy price variations. The energy savings depend on appliances: some can be postponed and some cannot be shaded. From a smart grid point of view, the task requires the identification of the total load into its constituent components and then future usage prediction of the appliances.
The primary approach of load separation is based on identification of state transitions which in most cases is done by the ON/OFF transition identification. Prediction of appliance usage is based on appliance consumption data (received after identification), time of the event and meteorological information.

1. Problem definition

The identification model tries to formalize appliance identification by using a temporal windowing approach where the only input after the training phase is the time stamped aggregate power from the power meter. The time is represented as hour of the day. In figure 1 the identification architecture is shown.
The classifier system both for load identification and future usage prediction is based on temporal classification of standard propositional machine learning algorithms. In order to model the time dependency it creates copies of the target field that are shifted in time and generate the sub-sequences. Instances containing these sub-sequences and the current target value are presented as standard propositional instances to the underlying classifying algorithm. This process effectively removes the time dependency in the original target since this is captured by the shifted attributes which is essentially a sliding window.
The work presented in this paper is based on a problem representation in a way that it can be understood by propositional concept learners. Meat-features are defined in order to increase the precision of the identification and the prediction. The definition of these meta-features is one of the key of the algorithm efficiency. Figure 2 proposes different meta-features definition in a sliding time window.

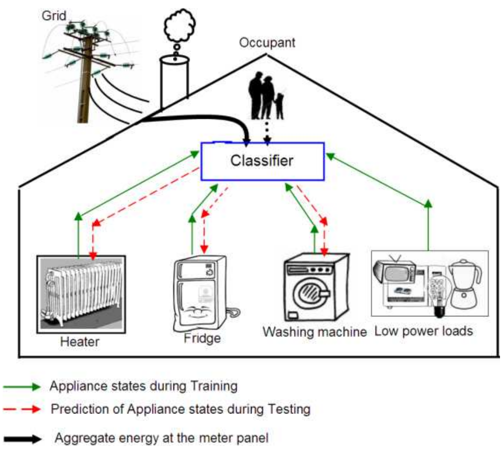

Fig. 1. Classifier architecture

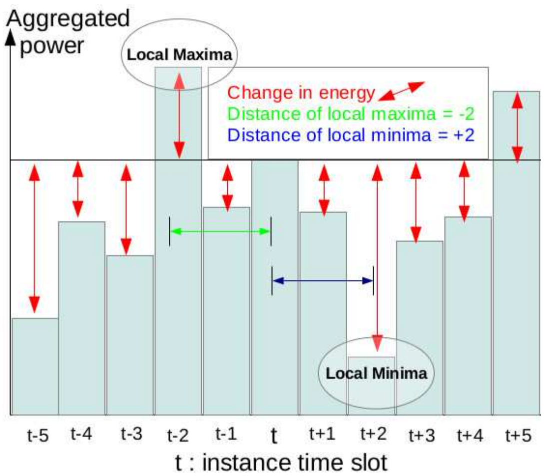

Fig. 2. Different meta-features concerning the aggregated power measurements in a sliding window

2. Load identification and appliance usage prediction

The future usage prediction based on iterative learning approach is proposed taking into account consumption data, time of the event and meteorological information. Figure 3 shows the prediction architecture.

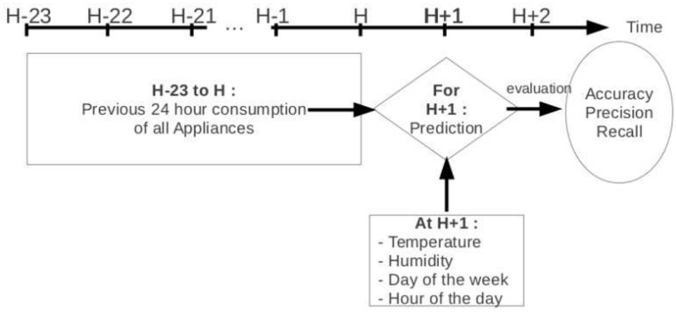

Fig. 3. Proposed Model at a given time instance

The future usage prediction based on iterative learning approach is proposed taking into account identified state, time of event and meteorological information. In this work, the future appliance usage when the individual consumption load is known is compared with the appliance usage after it has been identified at the smart-meter, i.e. based on the previous identification. Results using Label Powerset (LP) algorithm which takes inter-appliance co-relation and Binary Relevance (BR) algorithm are shown in Table 1.

Table.1. Results of appliance usage prediction, based on not on previous identification

Appliance	Algorithm	Based on identification (Smart Meter)			no previous identification (direct connection)		
		Accuracy	Precision	Recall	Accuracy	Precision	Recall
Washing Machine	LP	95.11	66.66	18.66	96.58	90.74	64.42
	BR	95.13	60.51	28.22	96.61	90.00	65.57
Microwave Oven	LP	88.22	13.33	1.41	90.47	32.83	2.75
	BR	88.27	0	0	90.40	35.92	4.62
Water Heater	LP	95.71	83.42	81.68	98.73	96.29	93.29
	BR	95.96	86.16	80.33	98.73	96.29	93.29
Dish Washer	LP	95.94	0	0	98.96	83.67	33.60
	BR	95.94	0	0	99.00	86.00	35.24

The results in Table 1 indicate the appliances which can be identified with high accuracy and precision can also be better predicted for future usage consumption. In our case the water heater can be predicted with higher accuracy because it was identified with high precision. As only high energy consuming appliances are used for prediction, the inter-appliance dependence is not reflected in these results. So both the algorithms give similar performances. But previous results show strong indication of inter-appliance dependence. The fact that some appliances have high accuracy but low precision and recall (sometimes zero) is due to the dataset being highly sparse and it being representative of only the ON class. Indeed, most of the high energy appliances are OFF most of the time.

References

1. Kaustav Basu, Vincent Debusschere, Seddik Bacha, "Appliance Usage Prediction Using a Time Series Based Classification Approach", IECON Montreal, Canada, 2012.
2. Kaustav Basu, Vincent Debusschere, Seddik Bacha, "Load identification from Power Recordings at Meter Panel in Residential Households", ICEM Marseille, France, 2012

3. Acknowledgement

This work is part of the project SUPERBAT which is sponsored by the National Research Agency (ANR), France. The results are implemented in Java using open-source packages from Mulan and Weka.
The future travel of researchers and the research following these results will received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912 (PIRSES-GA-2012-318912).

www.elecon.ipp.pt

Towards Efficient European and Brazilian Electricity Markets
First ELECON Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, September 24-25, 2013.

An automatic tool to Extract, Transform and Load data from real electricity markets

Ivo F. Pereira, Isabel Praça*, Tiago Pinto, Tiago M. Sousa, Ana Freitas, and Zita Vale

Polytechnic of Porto
Rua Dr. António Bernardino de Almeida, 431
4200-072 Porto

Abstract

The study of Electricity Markets operation has been gaining an increasing importance in the last years, as result of the new challenges that the restructuring produced. Currently, lots of information concerning Electricity Markets is available, as market operators provide, after a period of confidentiality, data regarding market proposals and transactions. These data can be used as source of knowledge, to define realistic scenarios, essential for understanding and forecast Electricity Markets behaviour. The development of tools able to extract, transform, store and dynamically update data, is of great importance to go a step further into the comprehension of Electricity Markets and the behaviour of the involved entities. In this paper we present an adaptable tool capable of downloading, parsing and storing data from market operators' websites, assuring actualization and reliability of stored data.

Keywords: Databases; Electricity Markets; Machine Learning; Multi-Agent Simulators; Real Electricity Markets Data

1. Introduction

Electricity markets are complex environments with very particular characteristics. A

* Corresponding author.
E-mail address: icp@isep.ipp.pt

critical issue regarding these specific characteristics concerns the constant changes they are subject to. This is a result of the electricity markets' restructuring, which was performed so that the competitiveness could be increased, but it also had exponential implications in the increase of the complexity and unpredictability in those markets scope [1]. Electricity markets, as competitive environments, require good decision-support tools to assist players in their decisions. Relevant research is being undertaken in this field, namely in what concerns player modelling and simulation, strategic bidding and decision-support.

The functioning of liberalized markets over the last years provides valuable information most of the times available to the community. Lessons can be learnt from these last years to improve knowledge about markets, to define adequate players' profiles and behaviours, but also to test and validate existing simulation tools, such as MASCEM (Multi-Agent System for Competitive Electricity Markets) [2, 3], making them suitable to represent reality and provide the means for a coherent and realistic analysis of its evolution (or possible alternative pathways for the future of the Electricity Markets sector).

The realistic modelling of electricity markets, which provides the means for a suitable knowledge extraction from the study of advantageous simulations, requires an extensive search and organization of as much information as possible concerning these markets characteristics, particularities and constraints. Automatic tools, able to gather, store, update and organize data from distinct real electricity markets will be a key issue to improve markets simulators and the modelling of the participating entities, enabling researchers and professionals to extract knowledge and really learn from this last years' experience.

This paper presents a tool that was developed with the purpose of automatically searching for new electricity market data, extracting it from various websites, parsing the information, and storing it in the appropriate database, so that it can be used by the electricity market simulators to model realistic scenarios. This tool is adaptive to the data availability timings; it is capable of dealing with different data formats, and it includes parallel processing capabilities, in order to deal with multiple data sources processing.

This paper is organized in 5 sections. In section 2 we present an insight on the electricity markets data requirements, both in what concerns the distinct nature of different countries' electricity markets, and the requirements from the currently most important electricity market simulators, namely MASCEM, which we are developing since 2003 [2]. Section 3 presents the system capable of downloading, analysing and saving information from real electricity markets to provide a database with real historical data. In section 4 we illustrate, by means of simple example, the processing of some of the data available at the EPEX Market operator homepage [4]. Finally, section 5 presents the most relevant conclusions and future implications of the presented work.

2. Electricity Markets Data

The liberalization of the electricity sector provides new market rules, the emergence of new market players and new forms of interactions among them [5, 6].

The functioning of liberalized markets over the last years provides valuable information most of the times available to the community trough market operators websites. Indeed, market operators such as the Iberian Market Operator [7], NordPool [8], EPEXSPOT (European Power Exchange) [4], MISO [9] and GME (*Gestore Mercati Energetici* – Italian Energy Market Operator) [10] provide on their web sites information regarding market proposals and transactions, usually after a period of confidentiality. The available information depends on each different market operator, however, essential information such as market proposals, with quantity and price; accepted proposals and established market

prices is usually always available. This information grows up in a very dynamic way, as it is put available in the various websites.

The Iberian Market Operator [7], which includes the electricity markets of Portugal and Spain, started on July 2006 with the futures market. One year later, in July 2007, both the day-ahead and the intraday markets started operating.

NordPool [8] is currently the largest energy market in Europe and includes the northern countries of this Continent, namely Norway, Denmark, Sweden, Finland, Estonia and Lithuania. There are two different markets in the NordPool: the ELSpot (day-ahead market) and the ELbas (intraday negotiations).

The EPEXSPOT [4], covers all the central area of Europe, including countries such as France, Germany, Belgium, Netherlands, Austria and Switzerland. The EPEX includes the day-ahead and intraday markets and an established deal with Czech Republic, Slovakia and Hungary to create a trilateral market between these countries.

The MISO [9] includes 15 U.S. states and the Canadian province of Manitoba and includes the day-ahead market.

GME [10], the Italian market operator, includes the day-ahead market (MGP), the intraday market (MI), ancillary services market (MSD) and The Forward Electricity Market.

With the information taken from the operation of different markets, lessons can be learnt from these last years to improve knowledge about markets, to define adequate players' profiles and behaviours, and realistic scenarios.

The need for understanding these market mechanisms and how the involved players' interaction affects the outcomes of the markets, contributed to the growth of usage of simulation tools, with the purpose of taking the best possible results out of each market context for each participating entity. Multi-agent based software is particularly well fitted to analyse dynamic and adaptive systems with complex interactions among its constituents, such as the electricity market. Several modelling tools directed to the study of restructured wholesale power markets have emerged. Some of the most relevant tools in this domain are:

- Electricity Market Complex Adaptive System (EMCAS) [11]: software agents with negotiation competence use strategies based on machine-learning and adaptation to simulate Electricity Markets;
- Agent-based Modelling of Electricity Systems (AMES) [12]: open-source computational laboratory for studying wholesale power markets, restructured in accordance with U.S. Federal Energy Regulatory Commission (FERC);
- Multi-Agent Simulator for Competitive Markets (MASCEM) [2, 3] : a platform based on multi-agent simulation firstly proposed in 2003 [2] that evolved into a complete tool acting in forward, day-ahead, and balancing markets, considering both simple and complex bids, and players strategic behaviour, based on ALBidS (Adaptive Learning strategic Bidding System) [13].

These simulators are very good examples of tools able to represent market mechanisms and players' interactions, but for them to be valuable decision support tools in foreseeing market behaviour, they need to be used in testing adequate and realistic scenarios. Real data analysis by means of a knowledge discovery process will be a crucial forward step to assure that MASCEM agents exhibit adequate profiles and strategies, namely by improving ALBidS strategies.

3. Automatic tool for real markets information extraction

After a careful analysis of the available data, since different operators make available different types of information, some of them providing even entities technical characteristics

and localization, a database model was defined. Figure 1 illustrates the Domain Model. As can be seen, the websites provide several files. Each file is related to a day, and may also include a session. The files have lines and those lines have: an agent, a proposal and the date. The proposals include the volume of traded energy, its price and whether it was a selling or buying proposal.

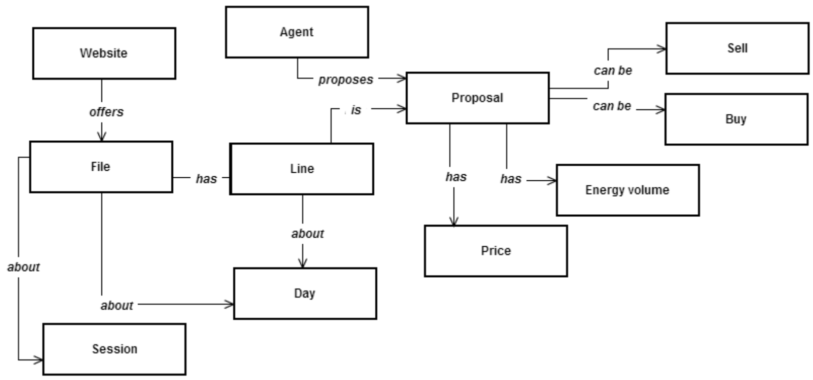

Fig. 1. Domain Model

Some requirements for the application are: the needs to assure the treatment of different file types, reliability in storing all the gathered data, as well as the needs to update the extracted data whenever it is available. Another relevant issue is efficiency regarding the treatment of great amounts of files, which, indeed in the initial use of the application may imply an enormous amount of files to assure gathering historic relevant data.

So that the files management can be performed in the best possible way, the adapter software standard is used for each file format. The adapter standard is used in circumstances in which a system needs to connect to an external service. In these cases the user should not need to allow such action, as it is intrinsic to the program. For this, it is necessary to create a class that provides the interface expected by the user and that uses the interface of the service provider. This means that it is necessary to create an interface with the signatures of the necessary methods for each adapter, and build each adapter in an independent fashion. The global class FileAdapter was built to provide the required abstraction that enables the system's ability to deal with new and different file formats.

The developed automatic tool includes four major steps:

- Download data - the download of several files containing the new data. The download depends on the website from which the data is being extracted, and it is performed accordingly to the data type of each file;
- Parse data - the extraction of the stored data from the downloaded files. The parsing of the data includes the analysis of the data fields of each file, from which the information and its associated value are taken;
- Store data - the storage of collected data in the database. The storage of the parsed data takes into account the necessary connections between different sets of data. This enables the data to be stored appropriately, respecting the interconnectivity and dependencies between all data;

- Mechanism for automatic data updates – machine learning techniques to automatically define downloads periodicity. The availability timings of type of file are analyzed so that the developed tool can process all available data the sooner as possible.

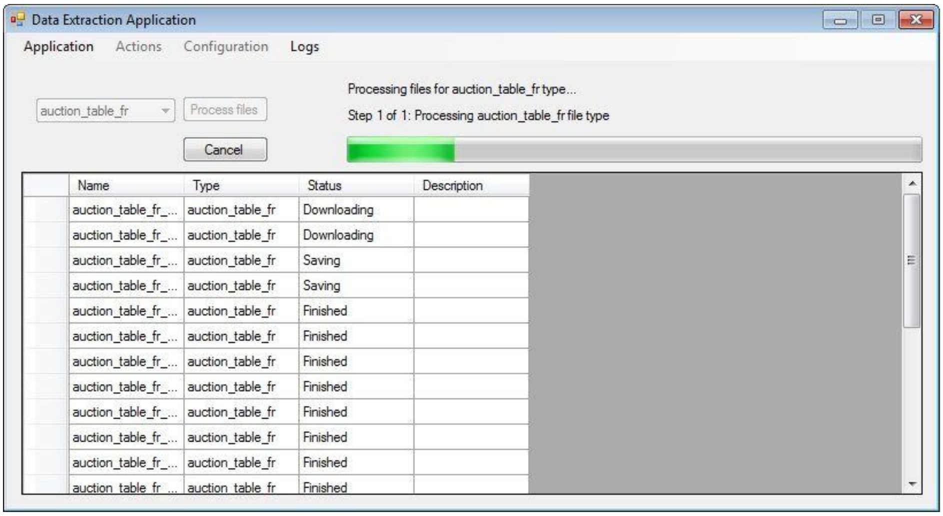

Fig. 2. Data extraction from the EPEX website

From figure 2 it is possible to see the interface of the developed tool, showing the treatment of different files in parallel, while displaying the status of each of the processed files.

4. EPEXSPOT Test-Case

The EPEX SPOT webpage [4] provides several information regarding the France, Germany, Austria and Switzerland market transactions. The existing information starts on 2006, and it is put available daily. This is a very complete website, easy to access and navigate, however, the information is not that easy to manipulate. The EPEX includes the day-ahead and intraday markets in separated webpages and both files considered by the data extraction tool. The "Auction" page provides information about the period, price and volume for each day. The "Intraday" page considers for each period the lowest, highest, last, weighted average and index prices (€/MWh) and also the buy and sell volumes (MW).

The example that is shown in this section refers to the file "Auction". This information can be accessed via browser on the EPEX website [4].

In this case, the presented information is shown on the webpage, and the page link has the following format: *http://www.epexspot.com/en/market-data/auction/auction-table/2013-09-10/FR,* where "*auction/auction-table*" corresponds to the market type, in this case the day-ahead market, "*2013-09-10*" corresponds to the date (in the format: yyyy-mm-dd) and indicating the country is "*FR*", which, in this case, corresponds to France.

In the first phase of the whole process - *Download Data*, the file to be analysed needs to be downloaded. Since the information shown on the webpage concerns several days, only the information of the day we are analysing is copied to a text file and then stored. The files are placed in a temporary folder, so that at the end of the process are removed since they are no longer required.

In the second phase - *Parse Data*, it is necessary to parse each extracted file. As the files to be read come in plain-text form it is very easy to open them. To execute the parsing of the files, the file structure was studied, bringing to attention that the format is similar to an HTML table, in which each line is a period of the day, and each of these lines are subdivided on other two lines, one for the price (€/MWh) and the other for the volume transacted (MWh). The data type of each field is shown in table 1.

Table 1. Field Types for the considered file

Field	Data Type
Period	Integer value indicating the period
Price (€/MWh)	Numeric Value
Volume (MWh)	Numeric Value

Finally, each line of the file will result in a database record being further included in a database corresponding to the *StorageData* phase of the process. This way, the information of all files is centred on the same database, in order to be used by other systems such as market simulators.

5. Conclusions

Electricity markets worldwide suffered profound transformations. The privatization of previously nationally owned systems; the deregulation of privately owned systems that were regulated; and the internationalization of national systems, are some examples of such transformations. With the increase of the competitiveness and consequent decrease of electricity price in sight, the restructuring of electricity markets brought a significant enlargement of the complexity in this sector.

Data regarding electricity market players of very distinct nature, with enormous differences in their characteristics; data regarding the market mechanisms of different types from country to country; data regarding the interactions and negotiations between players in different market environments; data regarding the decision support and strategic behaviour of such players; are only a few examples of what is required for electricity market simulators to adequately model the electricity market environment, so that realistic scenarios can be built and an advantageous decision support can be provided.

Even though most of the referred data is available, it is of very difficult access, for diverse reasons; therefore it is not used in the way and extent it should. In order to overcome the problem of the data access and treatment, making it available in an useful way for electricity market studies, in this paper we present our work regarding the development of a tool that provides a database with available information from real electricity markets.

The presented tool has the capacity of collecting, analysing, processing and storing real electricity markets data available on-line. Additionally, this tool is built in a way that it can deal with different file formats and types, some of them inserted by the user, resulting from information obtained not on-line but based on the possible collaboration with market entities.

This tool includes the capability of managing files using parallel processing, allowing the system to deal with multiple data sources at the same time. The different data files are accessed through a machine learning approach for automatic downloads of new information available on-line. All procedures are secured by a reliability mechanism that prevents from the storage of incomplete or unviable information.

The final result from the continuous execution of the presented tool is the definition and

implementation of a database that gathers information from different market sources, even including different market types.

This is a crucial tool to go a step forward in electricity markets simulation, since the integration of this database with a scenarios generation tool, based on knowledge discovery techniques, will provide a framework to study real market scenarios allowing simulators improvement and validation.

The possibility of using electricity market simulators capable of providing scenarios based on real data is an enormous asset for the study of electricity markets. Market operators and regulators are able to experiment and test new market rules and mechanisms, and obtain valuable insights regarding the consequences of such changes, both in what affects the market itself, and also in what way it influences the market players. In what concerns the advantages for market players, scenarios based on real data provide the means for testing different strategic behaviours, and analysing their results. Real market players are also able to thoroughly studying competitor players' actions, coming to understand how they behave, act and react in different circumstances and contexts, meaning an invaluable tool for adapting their own behaviours to the expected actions from behalf of competitors.

Acknowledgements

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912.

This work is also supported by FEDER Funds through COMPETE program and by National Funds through FCT under the projects FCOMP-01-0124-FEDER: PEstOE/EEI/UI0760/2011, PTDC/EEA-EEL/099832/2008, PTDC/SEN-ENR/099844/2008, and PTDC/SEN-ENR/122174/2010

References

[1] G. Rothwell and T. Goméz, "Electricity Economics: Regulation and Deregulation", IEEE Series on Power Engineering, 2003, pp.15-42

[2] I. Praça, C. Ramos, Z. Vale, M. Cordeiro, "MASCEM: A Multi-Agent System that Simulates Competitive Electricity Markets", IEEE Intelligent Systems, vol. 18, No. 6, pp. 54-60, Special Issue on Agents and Markets, 2003

[3] Z. Vale, T. Pinto, I. Praça, H. Morais, "MASCEM - Electricity markets simulation with strategically acting players", IEEE Intelligent Systems, vol. 26, n. 2, Special Issue on AI in Power Systems and Energy Markets, 2011

[4] EPEX – European Power Exchange – homepage, http://www.epexspot.com, accessed on April 2013

[5] L. Meeus, et al., "Development of the Internal Electricity Market in Europe", The Electricity Journal, vol. 18, no.6, pp. 25-35, 2005

[6] M. Shahidehpour, et al., "Market Operations in Electric Power Systems: Forecasting, Scheduling, and Risk Management", Wiley-IEEE Press, pp. 233-274, 2002

[7] OMIE - Operador del Mercado Ibérico de Energia – Iberian Electricity Market Operator, homepage, http://www.omie.es, accessed on April 2013

[8] Nord Pool – homepage, http:// www.nordpoolspot.com, accessed on April 2013

[9] MISO energy – homepage, http:// www.misoenergy.org, accessed on April 2013

[10] GME - Gestore Mercati Energetici – Italian Energy Market Operator, homepage, http://www.mercatoelettrico.org, accessed on April 2013

[11] V. Koritarov, "Real-World Market Representation with Agents: Modeling the Electricity Market as a Complex Adaptive System with an Agent-Based Approach", IEEE Power & Energy magazine, pp. 39-46, 2004

[12] J. Sun and L. Tesfatsion, "Dynamic Testing of Wholesale Power Market Designs: An Open-Source Agent-Based Framework", Computational Economics, vol. 30, nr. 3, 2007, pp.291-327

[13] T. Pinto, et al., "Strategic Bidding Methodology for Electricity Markets using Adaptive Learning", Modern Approaches in Applied Intelligence, vol. 6704, pp. 490-500, 2011