INESC PORTO
LABORATÓRIO ASSOCIADO

INESC Porto – Instituto de Engenharia de Sistemas e Computadores do Porto, Portugal

Abridged presentation
of its Research and Development
Power Systems Unit
USE

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INESC Porto

1. THE INSTITUTION

INESC Porto is an independent private non-for-profit institution in Portugal.

As an interface institution between university and industry, it puts together the creative capacity and deep knowledge of academic researchers with a professional approach to projects and problems by its contracted engineer specialists.

Its associates are the University of Porto, INESC and the Faculty of Engineering of the University of Porto. The research teams of INESC Porto are mainly form the Faculty of Engineering and the Faculty of Sciences of the University of Porto, but other higher education schools also contribute to the humans resources in activity.

INESC Porto began as a branch of INESC, in 1985. INESC, with headquarters in Lisbon, Portugal, is an association between the most important Portuguese Universities and major players in the telecommunication business, namely Portugal Telecom. In 1998, from the restructuring of INESC, INESC Porto was formed as an independent institution. Its links with the Faculty of Engineering of the University of Porto (FEUP) were strengthened since then.

INESC Porto gathers together 20 of experience in fundamental and applied science and in technology transfer. During this period, it has accumulated a considerable expertise form its extensive participation in most of the European Union research programmes, being presently recognized as a reliable partner of excellence with a very specific know how in a number of areas.

Its technology transfer activity is intensive. It is based mainly on direct contracts with industry, service companies and government agencies. Its clients are mainly based in Europe and South America.

The INESC group has always devoted efforts to the incubation of business companies and at INESC Porto this activity proceeds at a steady pace. Spin-off and spin-out companies continue to emerge and constitute one of the distinctive characteristics of the profile of the institution.

INESC Porto conducts a solid post-graduation program of international amplitude; the MSc. and PhD. theses result from the research and contract work developed. A post-doc program is also in place, with the regular cooperation of scientists of outstanding international recognition. In total, INESC Porto counts with *circa* 250 persons among academics, grantees, contracted engineers and administrative staff.

INESC Porto is divided in five main research and development units:

- Power Systems
- Optoelectronics and Electronic Systems
- Telecommunications and Multimedia
- Information and Communication Systems
- Manufacturing Systems Engineering

INESC Porto has received from the National Science and Technology Foundation the status of Associate Laboratory of the State for the work in the field above, as recognition of its excellent performance and results achieved.

The following sections present an abridged description of the main activities and expertise of the Power Systems Unit.

Power Systems Unit

Experience and know-how in markets, regulation, network expansion and operation, distributed generation and renewables

2. THE POWER SYSTEMS UNIT

The **Power System Unit (USE)** is composed of about 30 researchers and has considerable expertise in the regulatory, planning and operation problem of networks with a high penetration of renewable energies, namely wind. This knowledge allowed USE researchers to play an important role in a number of European Union projects, namely in programmes like JOULE, THERMIE, ENERGY and NNE, SAVE, ALTENER and TEMPUS. It also opened the way for contracts with manufacturers, utilities, regulators, government agencies and investors both in Europe and South America.

The applied research developed in the Unit can be classified in three main areas:

- Markets and regulation
- Distributed generation and renewables
- Transient and steady state analysis, optimization and reliability

The following sections present a summary of the main projects and consultancy actions that were developed within the Power Systems Unit (USE) of INESC Porto, in recent years.

2.1. MARKETS AND REGULATION

2.1.1. CLIENT REFERENCES

- ERSE – Regulatory Authority for the Energy Services, Portugal
- ONS – Independent System Operator, Brazil
- EDP Energias de Portugal, S.A. – Group of power utilities in Portugal
- EDP Distribuição S.A. – Distribution Utility, Portugal
- MAE – Wholesale Electric Energy Market, Brazil
- EEM – Empresa de Electricidade da Madeira, S.A., Portugal
- USAID, United States

2.1.2. STUDY ON QUALITY OF SERVICE (AVAILABILITY, POWER QUALITY AND COMMERCIAL QUALITY) (1998 - ERSE)

In this project, a general conceptual approach to deal with the Quality of Service (QS), involving System Availability (interruption indices), Power Quality and Commercial Quality, was developed to serve as basis for the development a Quality of Service Regulation.

The approach adopted in the project involved the following stages:

I – Characterization of the initial situation of the system regarding quality of service;

II – Definition of QS Reference Levels, taking into account the present situation of the companies, available standards, quality of service indices verified in other countries and recommendations from international bodies;

III - Definition of *implementation stages*, namely a transition period where companies should: a) install hardware and dedicated software for collecting and analyzing data regarding interruptions and claims from consumers and b) implement corrective measures for the worst cases detected;

IV – Suggestions for the implementation of a regulatory scheme and a permanent control procedure.

2.1.3. STUDIES ON THE IMPACT OF (SMALL) INDEPENDENT GENERATION IN THE PORTUGUESE TRANSMISSION AND DISTRIBUTION PUBLIC NETWORKS (2000 - ERSE)

This project addressed the characterization of the problem and the evaluation of the international situation regarding the degree of penetration of dispersed generation (DG) in the electrical network. Several studies were performed in several types of distribution grids considering different levels of DG penetration regarding steady state, reliability and dynamic impacts in system operation. A similar analysis was conducted on the Portuguese transmission grid, assuming different levels of DG penetration in order to identify congestion problems or other technical impacts. Recommendations were derived from these studies regarding the degrees of acceptability of DG for the networks and an identification of bottlenecks in the network was obtained in order to identify requirements of system reinforcements.

2.1.4. DEFINITION OF METHODOLOGIES TO INCENTIVE THE QUALITY OF SERVICE IN DISTRIBUTION AND TRANSMISSION NETWORKS (2002/2003 - ERSE)

In this project it was performed an identification of technical and economical parameters for an incentive mechanism (penalties and prizes) defined initially by the Regulator to be included in the distribution activity remuneration formulas, based on a price cap scheme. This was performed by analyzing the historical behavior of quality of service in transmission and considering the needs to force the improvement of quality of service.

A similar mechanism was developed to promote the quality of service in the transmission activity, considering the specificities of the accepted costs remuneration scheme adopted in Portugal for the transmission activity. This included also the identification of the technical and economical parameters to be adopted for this new scheme. Such a study was performed by analyzing the historical behavior of quality of service in transmission activity.

The project included a characterization of the international situation regarding incentive mechanisms used in the distribution and transmission activities.

2.1.5. COLLABORATION IN THE DEVELOPMENT OF THE IBERIAN ELECTRICITY MARKET MODEL (2002 – ERSE)

Personal consultancy of a member of the unit, regarding the development of the model of the Iberian Electricity Market, working as a consultant of the Portuguese regulator. This involved the study and comparison of the Portuguese and Spanish trading aspects as well as technical and operational issues followed in two areas of control. The development of the market model included tackling several issues like: stranded costs absorption, definition the different agents operating in the market, definition of the models of the negotiation platforms for daily, balancing, ancillary services and short term bilateral negotiation markets. Aspects related with technical and trading issues of the integration of small dispersed generation and large renewable generation were also treated. The treatment of the guarantee of supply in the Iberian system was also discussed, involving the development of financial derivatives market.

2.1.6. STUDY ON THE COMMERCIAL RULES OF ACCESS AND CONNECTION TO THE PUBLIC SYSTEM (2001 - ERSE)

This project included a preliminary analysis of the regulation under use in Portugal regarding commercial connection rules for consumers and generating facilities and a characterization of the international situation on this subject.

Recommendations were made to change the existing situation in order to obtain more equity, transparency and a more fair treatment when dealing with connection of new agents to the networks.

2.1.7. STUDY ON RULES AND PROCEDURES FOR INDEPENDENT GENERATION CONNECTION IN THE ELECTRICAL GRIDS OF BRAZIL (2003 - ONS)

This project was developed for the Transmission System Operator of Brazil (ONS) and involved the analysis of the actual operation procedures and rules in use in Brazil and the definition of new rules for the acceptance of the connection of Wind Generation and other small independent generation units either at the distribution or transmission grids. It included the specification of impact studies to be performed, data to be required, protections to be used, variables to be monitored and controlled (if necessary) and suggestion on the administrative flux of information to be adopted in the different stages of the connection of these units to the grids.

2.1.8. DESIGN OF TARIFFS OF THE USE OF TRANSMISSION NETWORKS (1998/2000 – ERSE)

This project aimed at identifying the tariff approaches available in the literature to allocate the costs of transmission companies to the users of networks and to analyze a set of generation/demand scenarios of the 400 kV / 220 kV / 150 kV national transmission grid in order to compute those tariffs using different methods. In the project they were analyzed the advantages and drawbacks of embedded average cost methods of incremental methods and of short term marginal approaches. The simulations used the MW.mile Method, the Modulus Method, the Zero Counter Flow Method as well as the use of short-term nodal marginal prices. The most relevant conclusion is related to the fact that a short-term marginal based tariff term would only allow to recover about 10% of the regulated remuneration for the year 1998. This meant that another tariff terms would have to be used to obtain revenue reconciliation and that, in 1998, the national transmission grid had no significant congestion problems.

2.1.9. COEFFICIENTS TO SIGNAL THE INTEREST TO CONNECT NEW AGENTS TO NODES OF THE TRANSMISSION GRID (2002/03 – ERSE)

The Portuguese Regulations include a mechanism designed to signal the interest in connecting a new agent to the nodes of the 400 kV / 220 kV / 150 kV. This mechanism was included in the regulations in view of the fact that the Tariffs for the Use of Networks are currently set according to a postage stamp approach inside each voltage level. In this project, the procedures available in the literature to allocate transmission losses were identified, as well as mechanisms in force in the regulation of several countries. In a second step, several scenarios of operation of the generation/demand system were analyzed, in order to compute nodal marginal coefficients reflecting losses and congestion problems. In a third phase and for each voltage level, the nodes were clustered according to their geographic location and to the values obtained for the referred coefficients. The final results correspond for each voltage level to sets of nodes and the corresponding nodal coefficients.

2.1.10. METHODOLOGIES TO PLAN THE EXPANSION OF THE NATIONAL TRANSMISSION NETWORK (2001-03 – ERSE)

According to the current regulations, the Portuguese Energy Regulatory Board is responsible for the analysis and approval of the long-term expansion plan submitted by the Transmission System Operator of Portugal. In view of this responsibility, in a first step this projected aimed at identifying the practices in use in several transmission companies, computational models commercially available to perform expansion planning studies, reliability evaluations and integration of uncertainty. Secondly, it included the identification criteria and constraints to include in expansion planning problem of transmission networks, the description of models available in the literature addressing this problem

and the preparation of a road map of tasks to be completed by the Regulatory Board once an exercise of analysis of such a long term plan in initiated.

2.1.11. ANALYSIS OF THE INVESTMENT PLAN FOR NATIONAL TRANSMISSION NETWORK (2001 – ERSE)

Consultancy services to the regulatory authority, relative to the analysis of the Investment Plan for 2002-2007 presented by the Transmission System Operator of Portugal (REN).

2.1.12. METHODOLOGIES TO PLAN THE EXPANSION OF THE DISTRIBUTION NETWORKS (2001-03 – ERSE)

Project similar to 2.1.10, but oriented to the distribution network, with all the intrinsic specificities, like a different kind of regulation (price caps).

2.1.13. LOAD PROFILING AND DISTRIBUTION NETWORK CHARACTERIZATION (2002/04 – EDP)

In the framework of the new Iberian Electricity Market (MIBEL), the distribution company of the EDP group felt the need to characterize the consumers and networks regarding load profiles, contribution to losses and network use. The main objectives of the project are the following:

a) Characterization of LV, MV and HV consumers, based on load diagram measurement campaigns and questionnaires about electricity use. Typical profiles will be constructed for all the types of consumers.

b) Estimation of the contribution to the network losses by the different types of consumers.

c) Studies about network use, leading to recommendations about tariffs.

2.1.14. DETERMINATION OF LOSS FACTORS TO BE APPLIED TO THE BRAZILIAN WHOLESALE ELECTRIC ENERGY MARKET (2001-03 – MAE)

Under the past vertically integrated structure, losses were usually treated as an extra load in the system. In the present competitive model, however, its cost must be shared in a transparent and non-discriminatory manner. Some loss allocation schemes have been proposed in the literature. According to the assumptions and approximations adopted, the available methodologies may be divided into the following schemes: *pro rata*¸ proportional sharing, incremental transmission loss (ITL), loss formula and circuit-theory. Following the trends in Brazil, this work presents a new methodology for transmission loss allocation based on the ITL concept. A fictitious bus (*Center of Losses*) is defined where all transactions are carried out taking into account transmission losses. Two models – *Basic* and *Extended* are developed and the advantages in terms of accuracy and transparency for the participants of a single energy market are discussed. The extension of this work to interconnected energy markets was also implemented.

NB: This work was developed by Armando Leite da Silva (now with INESC Porto) while he was with the Federal University, Itajubá (Brazil). Other Companies Involved: Brazilian Electricity Regulatory Agency (ANEEL); Brazilian Independent System Operator (ONS); Brazilian Research Center for Electric Energy Systems (CEPEL)

2.1.15. TRAINING OF THE BULGARIAN REGULATOR STAFF ON DEVELOPING AND IMPLEMENTING NEW REGULATION FOR AN ENERGY MARKET ENVIRONMENT (2004 – USAID WORLD LEARNING, WASHINGTON)

The Bulgarian Regulator Authority required high level training and INESC Porto was selected by the American agency USAID to provide such service. Seven persons from the high staff of the Bulgarian Regulator entered a training program organized and supervised by INESC Porto, having as objectives, among others, to study the regulator's functions, its role and responsibilities by law, in particular with respect to the promotion of competitive markets and the regulation of energy exports and imports; to understand the regulator's information flow and its communication among divisions and management of relationships with licensees, applicants, consumers and advocacy groups; to study conceptual issues related with quality of service and levels of investment; to study indices used to evaluate

quality of service in the 3 components: commercial quality, power quality and availability; to study planning approaches to the regulation function.

2.2. DISTRIBUTED GENERATION AND RENEWABLES

2.2.1. CLIENT REFERENCES

- European Commission
- ONS – Independent System Operator, Brazil
- EDA – Electricidade dos Açores, S.A.
- ENERVENTO, S.A.
- EEM – Empresa de Electricidade da Madeira, S.A., Portugal
- FCT – Foundation for Science and Technology, Portugal
- University of La Rioja, Spain

2.2.2. MICROGRIDS (2003-2005 – EUROPEAN COMMISSION, NNE 5TH FP)

Large scale integration of MICRO-generation to low voltage GRIDS - Research project financed by the EU 5th Framework program related with the integration of micro-generation technologies in LV distribution networks. It tackles several technical issues, namely protection coordination, management and control, communication using power wires, market integration, dynamic behavior analysis, islanding operation and contribution for black start. This one of the big projects financed by EU in this research domain and INESC Porto has in this project the largest participation among all partners

2.2.3. RESPIRE (2003-2004)

Renewable Energy Sources: Promotion and Integration for the Sustainable Development of Insular Regions. A EU project of the NNE program. The overall objective of RESPIRE is to set up tools for guiding the action os insular territories targeting one hundred percent RES, to validate these methodological tolls by setting up a significant number of RES plants on island territories and to develop innovative system for ensuring the grid stability in context of variations of power output from the RE power plants.

2.2.4. MORECARE-EDA (2002-2003)

Development and Supply of a system GOS (Optimized and Secure Management of an electro-generation system). This project is a contractual activity for Electricity of Azores (EDA). It aimed at the installation in the island of Flores of an advanced control system to help managing, in the most optimum way, the operation of the local electrical grid. A concern on the maximization of the integration of hydro and wind power generation is behind the development of the project.

2.2.5. DIPTUNE (2001-2005)

Analysis of Distributed Power Production Capacity Ancillary Services. This project, financed by FCT, has the main goal to analyze how distributed generators (DG) can contribute to system security and optimum management of the networks by delivering ancillary services. It also includes the development and adaptation of EMS/DMS software applications to include the participation of DG units in the Automatic Generation Control and reactive power supply and voltage control. Studies about additional remuneration policies of such ancillary services, exploiting namely market concepts, are also developed.

2.2.6. EXPANSION PLANNING OF GENERATION/TRANSMISSION SYSTEM OF MADEIRA ISLAND ELECTRICITY COMPANY (2003 – EEM)

Madeira Island Electricity Company has to submit an expansion plan for the generation / transmission system to the Portuguese Energy Regulatory Board. This plan has an horizon of 5 years and the corresponding costs, when approved, will be integrated in the regulated remuneration that finally lead to the tariffs for the use of networks. In view of this task, this project involves collaboration,

consultancy actions and performing of studies in the areas of load forecasting, temporal location of new generation capacities involving the decision regarding technologies to be used, scenarios of development of renewables, list of works to be eventually done on the grid, organization of these works in plans, technical validation of plans, reliability analysis, cost evaluation, bi-criteria analysis of the plan and preparation of the final report including the expansion plan.

2.2.7. ENERGIS (2000-2002)

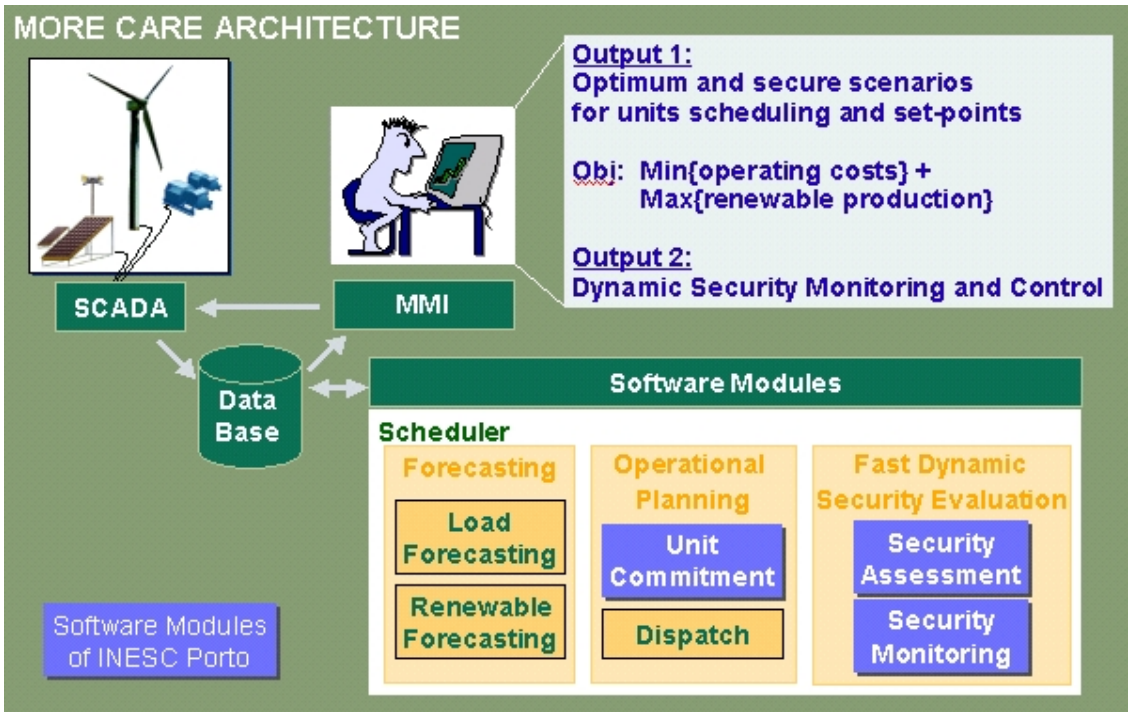
Regional Energy Planning With GIS. Project developed under a contract with the University of La Rioja, aiming at the development of a software tool, with GIS support (Geographic Information System), that allows to accomplish studies for regional energy resources planning (wind, solar radiation, biomass, hydro), selection of technologies and energy infrastructures. An application in the La Rioja region (Spain) was included, financed by European Union FEDER.

2.2.8. ENERVENTO (2000-2001)

Research project in cooperation with the industry, aiming at the development of a prototype of a doubly fed induction wind generator, financed by the Portuguese ICPME program and developed with ISR and Enervento SA. INESC Porto has participated in the development of the theoretical model of the generator and their control system, with the purpose of evaluating impacts in the electrical network as a result of its operation.

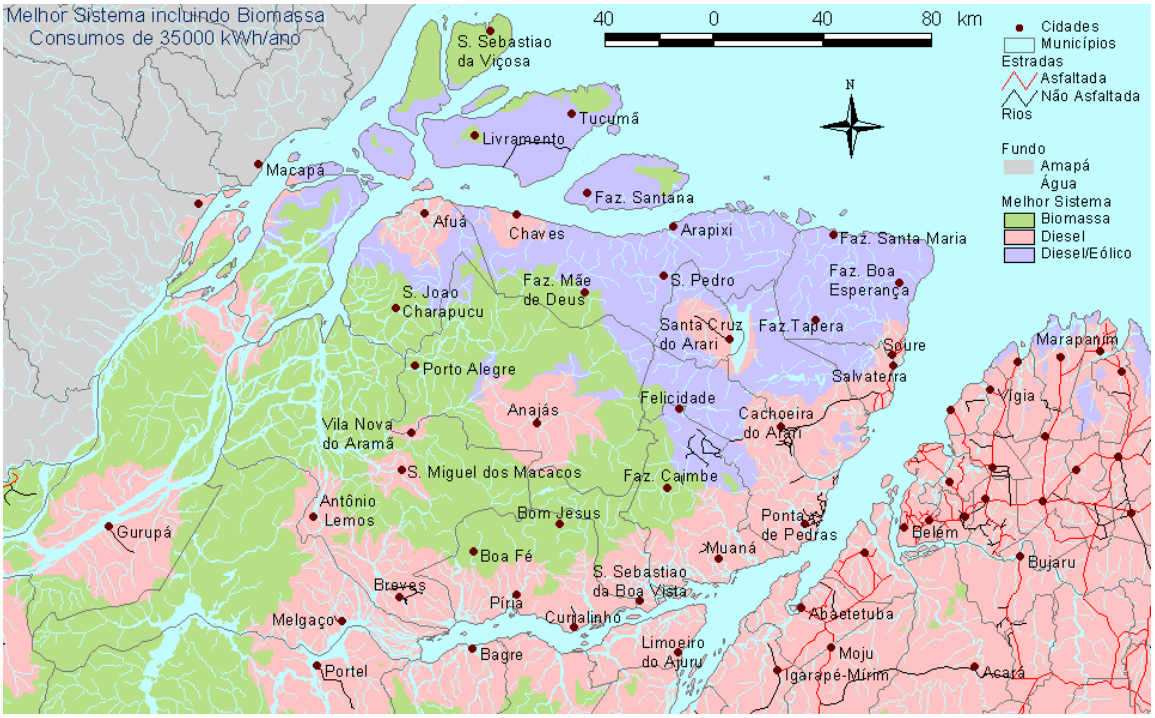
2.2.9. MORECARE (2000-2003)

More Advanced Control Advice for Secure Operation of Isolated Power Systems with Increased Renewable Energy Penetration and Storage. An EU project of the NNE programme. This project has as main objective the development of MORE CARE, an advanced control software system aiming to optimize the overall performance of isolated and weakly interconnected systems in liberalized market environments by increasing the share of wind energy and other renewable forms, taking into account pumped hydro storage facilities and providing advanced on-line security functions, namely by providing preventive control measures. It resulted in implementing an advanced control system at Crete, Greece, the development of wind prediction tools namely for ESB (Ireland) and the launching of implementation projects for control centers in other companies.



2.2.10. MEAPA (1998-1999)

Integrated methodologies for renewable energy assessment on Amazonian region, Brazil. This project consisted in the development of methods and software tools, based on Geographic Information Systems, to support Energy Planning and Renewable Energy integration for powering stand alone consumers.



2.2.11. SOLARGIS (1994-1996)

Integration of renewable energies for decentralized electricity production. A European Union project of the JOULE programme. The main objective of the SOLARGIS project is to demonstrate how a methodology based on the use of Geographical Information Systems (GIS) may provide an efficient help for people in charge of developing the use of Renewable Energy for decentralized electrification. This methodology is applied in six selected regions of Europe and developing countries. INESC Porto was in charge of developing integrated solar and wind energy geographical modules and apply them to islands in the Republic of Cape Verde, Africa, bith for isolated systems and for interconnection of wind generation with the grid.

2.3. TRANSIENT AND STEADY STATE ANALYSIS, OPTIMIZATION, RELIABILITY OF POWER SYSTEMS

2.3.1. CLIENT REFERENCES

- ERSE – Regulatory Authority for the Energy Services, Portugal
- EDP Energias de Portugal, S.A. – Group of power utilities in Portugal
- REN – Rede Eléctrica Nacional, S.A., Portugal
- EDP Distribuição S.A. – Distribution Utility, Portugal
- EFACEC Sistemas de Electrónica, S.A., Portugal
- ELECTRA, S.A. – Power utility in Cabo Verde (Africa)

2.3.2. EDA-CAP (2004)

Studies for the definition of loss coefficients in transmission and distribution networks for Electricidade dos Açores, SA

2.3.3. INTERLIG-CV (2003-2004)

Studies for the submarine interconnection of islands in Cape Verde Republic (Africa) and optimization of renewable energy resource use (in cooperation with IST)

2.3.4. RPC (2001-2002)

Consultancy for REN and EDP-Distribution to evaluate the impacts of adopting different limit values, from the ones presently under use, for the reactive power accepted to be consumed without penalties. These impact studies were developed over the transmission grid and in several distribution networks. It included steady state analysis, in the transmission and distribution grids, transient stability (through time domain simulation for several disturbances) and evaluation of system robustness regarding distance to voltage collapse in the transmission grid. An economical impact evaluation quantifying the benefits and costs (corresponding to necessary investments) that would result from the implementation of the new reactive compensation strategies in all the Portuguese electric power system was provided

2.3.5. PSS (2000-2001)

Tuning of Power System Stabilizers in the Portuguese System. Contract with REN (Portuguese National Grid Company) to perform stability and dynamic behavior studies associated with tuning of PSS for generating units of the public power system (SEP). This project included the identification of the models of the existing generators and regulators included (AVR, frequency regulators and stabilizers), considering the available models in PSS/E software library. A study of a very large system, representing the Portuguese - Spanish and French interconnected systems, was performed, involving namely calculation and investigation of system oscillation modes, by frequency domain analysis, before and after PSS tuning. Performance evaluation of dynamic behavior analysis through time domain simulations, for several disturbances, was also included.

2.3.6. DMS/EFACEC (1997-1999)

Development of Advanced Modules for DMS (Distribution Management Systems). Development of several advanced scientific modules to be integrated in a DMS (Distribution Management System) of a Portuguese industrial vendor company (EFACEC SA) that acts in the international market. It includes conventional software modules like topology processor, load flow and short-circuit analysis, as well as new software application modules like load and feeder current forecasting, optimum network configuration finder, state estimation in distribution networks using fuzzy concepts, load allocation, fault detection, optimum voltage and reactive power control and also contingency analysis. This project included also advanced consultancy and staff training.

2.3.7. MDC (1996-1998)

Load Diagrams Estimation Using Artificial Neural Networks. Development and testing of new models, based on Artificial Neural Networks, to infer load diagrams from commercial data in MV distribution networks. Contractual activity with distribution companies from EDP Group.

2.4. RESEARCHERS

The following are a few of the internationally acknowledged researchers whose work has been associated with USE in recent years:

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