INTEGRATION AND APPLICATION OF COMPUTER PROGRAMS IN POWER SYSTEMS PLANNING AND OPERATION - NEW PERSPECTIVES

João Carlos O. Mello, Eurico S. Sobrinho, Antônio R. C. D. Carvalho, Sérgio Granville
Nelson Martins, Hermínio J. C. P. Pinto, Ricardo D. Rangel, Albert C. G. Mello
Flávio R. M. Alves, Gerson C. Oliveira, Sérgio P. Romero, Marcos Roitman
Wo W. Ping, Dourival Carvalho

CEPEL
Centro de Pesquisas de Energia Elétrica
Brasil

João Carlos Luz, Roberto N. Fontoura

Eletrobrás
Centrais Elétricas Brasileiras
Brasil

Paulo Gomes

Universidade do Estado do Rio de Janeiro - UERJ
Brasil

ABSTRACT

The main purpose of a power transmission system is to satisfy the electrical and energetic demand of the consumers, at minimum costs, enhancing the reliability (consequently reducing the number and duration of interruptions) and maintaining a high quality supply (for example minimizing voltage variations).
The Brazilian electrical system has experienced complex scenarios in terms of operation, caused by several reasons which contributed to reduce the associated margins. The planning is also influenced by the expected significant growth in electrical energy consumption for the next years.
In order to accomplish that objective and considering these difficulties, several modern computer models are necessary to correctly evaluate the current system performance, and assure an adequate future planning regarding optimization of resources.
This paper presents an overview of CEPEL's available digital tools, in use by Brazilian utilities in order to help the power system planning and operation. Aspects related to the integration of these programs will also be presented, together with illustrative examples of practical applications and future perspectives for these tools, such as: possible utilization, necessary enhancements and potential customers, taking into account the changes in the Brazilian electrical system management model.

KEY WORDS

CEPEL Digital Tools - Computer Programs for Electrical Planning and Operation - Digital Simulation- ANAREDE - ANATEM - PACDYN - FLUPOT - NH2FPO - PLANVAR - ANAFAS - ANASIN - HARM - SLEP - MONDIN - Database

1. INTRODUCTION

CEPEL R&D activities in the electrical planning and operation started in the mid-seventies and have been carried out by multidisciplinary experts in the fields of optimization, statistics and power systems analysis. As a result, computational tools have been mainly produced in-house, with some cooperation of universities.
Projects have been developed under contract by ELETROBRÁS (the Brazilian electrical system holding) and its subsidiaries, and in close cooperation with the

other companies of the Brazilian power sector. The main objective is the development and application of computer programs, which constitute the technical basis for the expansion planning and operation of large electric energy systems.
Regarding this joint action with the Brazilian power sector companies, all computer programs have been developed based on the needs and requirements of the users, including significant contributions derived from practical applications.
CEPEL has also been using these tools for advanced studies in electrical planning and operation areas. The modeling and evaluation of new technologies to power transmission have been executed in CEPEL using these programs and therefore, also contributing to their improvement.
Some characteristics of the Brazilian power system induced the development of tailor-made programs in order to cater for all requirements. These characteristics include: high load growth rates, large scale transmission network, hydroelectric-based generation, long distance AC lines, high correlation between transmission and generation investments, voltage sensitive networks, subsystems with high different standards of reliability and operational procedures, high susceptibility to dynamic problems, need for special emergency controls, among others.
From some years ago, CEPEL has also been devoting considerable attention to incorporate user-friendly graphical interfaces to their tools and users' help desk, besides the training of utility personnel in order to consolidate the software usage. Finally, in order to enable the use of all computational programs from a single platform, an integrated data base project is being developed.

2. COMPUTER PROGRAMS DESCRIPTION

The computer programs were classified in accordance with the following topics: Steady State Analysis, Dynamic Behavior Evaluation, Probability Simulation, Transmission Systems Economical Evaluation - Expansion and Transport, Optimization, Artificial Intelligence. The integration of these knowledge areas will be performed through modern data base techniques, one of the projects in development. Figure 1 depicts the schematic interconnection among the different tools.
In the following sections, each computer program will be described in detail, in terms of their main characteristics and applications.

2.1 Power Flow Analysis Program (ANAREDE)

This package is a set of integrated computer programs for static analysis of electrical systems, comprising the following modules:
The Power Flow Program calculates the operating condition of a network for distinct generation, load and topological situations regarding previously established operating constraints such as the reactive power generation/absorption limits of the machines. Both the Fast Decoupled and Newton Raphson methods are available.
Active power area interchange control, static compensator, automatic transformer tap variation, DC links (including multiterminal schemes) and constant impedance or constant current load models are examples of available facilities.
Recently, an automatic increase of load and generation algorithm, associated with continuous load flow solutions, was incorporated to this program in order to perform voltage stability margin evaluations. PxV curves can be obtained.
The Network Equivalent Program determines a reduced power flow model which represents, with appropriate precision, the behavior or response of the external system (part of the whole network which may be represented as an equivalent in a study) when the internal system is subjected to given types of disturbance. The Extended Ward method is used for the determination of the reduced model, comprising equivalent series circuits, equivalent power injections and equivalent shunts.
The Contingency Analysis Program processes a set of contingency cases to detect severe operating conditions, comprising simple or multiple disturbances such as circuit removal, circuit opening at either end, shunt element outage, generation outage and load shedding. For each contingency case, a power flow solution is executed and the new operating point is monitored. Network monitoring is expressed in terms of severity indices for each case.
The Voltage Sensitivity Analysis Program calculates first order sensitivity factors, which express the behavior of selected electrical variables as a function of changes in a control variable, or a set of it. The system equations representing the network behavior is linearized around the operating point. The linear model is obtained by a Taylor series expansion of these equations, considering only the first order terms.
The Active Power Rescheduling Program determines an operating point for the electric network that satisfies the operating constraints and minimizes or maximizes an objective function. Violations of operating constraints are eliminated by modifying the active power generation value of given generators or the active power load of given buses, using linear programming techniques (Dual Simplex method).

2.2 Time-Domain Stability Evaluation Program (ANATEM)

The main purpose of this computer software is the study of electric power systems dynamic performance, regarding the aspects associated to electromechanical stability.
Two contexts for use are available. The *ANATEM* one establishes an environment for stability simulations considering the network and all control models. The *ANACDU* is a standalone context, where user-defined control systems may be separately analyzed without the need to incorporate the remaining elements.
The controllers may be represented using built-in or User Defined (UDC) models. This last alternative uses a description language based on frequency domain block diagrams.
Some of the main features of the program are listed below:

- The program pre-defines three types of Generator Models (Classical, Salient pole and Round rotor models). The data are supplied on the machine base. It also provides 24 built-in AVR models, 7 built-in Governor models and 12 built-in PSS models. All these controllers may be modeled through the UDC.

- A voltage-dependent Load Model is available, as well as network frequency dependence.
- Induction Motors can be represented by two built-in models.

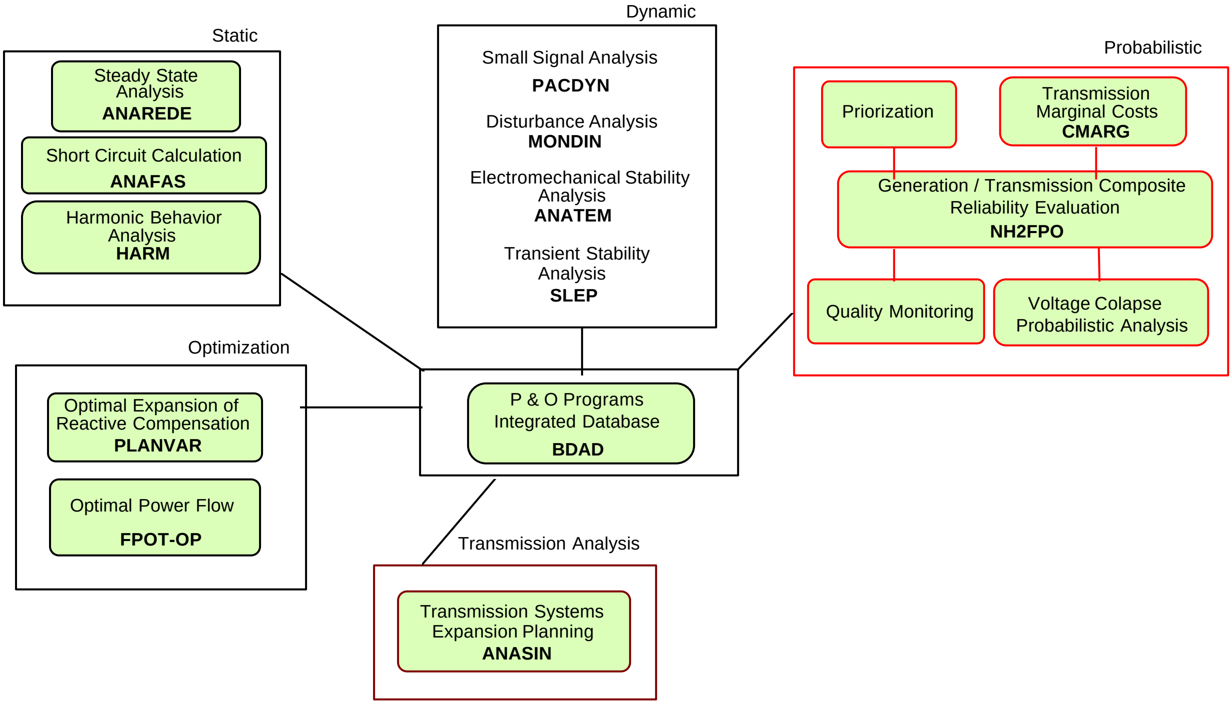

Figure 1 - Schematic Interconnection among the different tools.

- Thyristor Controlled Devices Models are available: one built-in model for the SVC (Static VAR compensator) and another for the TCSC (Thyristor Controlled Series Capacitor). The UDC may be used if desired.
- HVDC Link Model is available, also including the multiterminal configuration. The control system model allows user-defined controllers to incorporate power or current modulation signals.
- In order to help the user simulate the variation of load consumption and power generation during a certain period of time, the program allows the automatic linear variation of these quantities.
- The program provides user defined control and one built-in model for the representation of transformers' on-load tap changers. The representation of this type of equipment is important for mid-term studies.

2.3 Small-Signal Stability Analysis Program (PACDYN)

The program PacDyn is a comprehensive package for the analysis of small-signal stability and control of oscillations in large scale AC/DC power systems.
PacDyn employs state-of-the-art algorithms for the calculation of dominant eigenvalues, transfer function zeros, transfer function residues, step response and frequency response plots and synchronizing and damping torques.
The program can be effectively used in the following applications:

- Verification of the suitability of the numerous machine controllers, based on individual machine tests;
- investigation of small-signal electromechanical stability, control interaction problems and voltage stability;
- reduced models of transfer functions for large scale systems;
- determination of the most suitable generators in the system for placing power system stabilizers;
- determination of the most suitable buses and circuits in the system for placing FACTS devices to damp system oscillations or to improve voltage stability;
- identification of system controllers (AVR, PSS, Governor, SVC, HVDC link, FACTS devices) whose base case tuning is detrimental to oscillation damping;
- controller design (AVR, PSS, Governor, SVC, HVDC link, FACTS devices) through frequency response techniques, considering either a full model or a simplified model of the large scale system;
- choice of control loops and combination of signals best suited for power system stabilization;
- time response to changes in controller setpoints or load increments applied anywhere in the system;
- analysis of the impact of load modeling on small-signal electromechanical or voltage stability;
- automatic stability assessment of multiple scenarios;
- impact of multiple fast controls.

PacDyn employs state-of-the-art algorithms for the calculation of:

- System Eigenvalues

Full eigensolution algorithms (up to 500 eigenvalues)
Partial eigensolution algorithms
Dominant transfer function poles algorithms

- Transfer Function Zeros
- Transfer Function Sensitivities

Residues
Controllability Factors
Observability Factors
Participation Factors

- Frequency Response Plots
- Synchronizing and damping torques
- Linear Time Response Plots
- Reduced Order Model
- Root-Locus Plots.

The PacDyn can model the following equipments:

- Generators
- Automatic Excitation Systems
- Stabilizing Signals (for Generators, HVDC Converters and FACTS Devices)
- Governors
- Induction Motors
- HVDC links
- FACTS Devices

Static Var Compensators
Advanced Series Capacitors
Static Phase-Shifters

- Dynamic Loads

The program has user-defined-controller subroutines that allow complete freedom in defining the order and topology of the various controllers in the system (AVR, PSS, Governor, SVC, HVDC link, FACTS devices). A large number of local and remote variables may be simultaneously used as inputs to any given controller.

2.4 AC Optimal Power Flow Analysis Program (FLUPOT)

The Optimal Power Flow consists in determining the state of an electric power system which optimizes a given objective function and satisfies a set of physical and operating constraints. Besides the electrical network, the OPF is composed of a list of available controls used to accomplish the objective function avoiding violations of the constraints.
CEPEL's OPF program is based on the most advanced existing optimization technique which is the direct primal-dual interior point method. One important aspect of the program is its flexibility in the specification of the objective function, controls and constraints to be satisfied in the optimization.
Examples of the types of objective functions available in FLUPOT are :

- Active Power generation cost minimization;
- Active Power loss minimization;
- Minimum interchanging deviation;
- Minimum load shedding;
- Minimum number of changing controls to correct system operating violations;
- Voltage control;
- Reactive Power generation cost minimization;
- Minimum Cost allocation of reactive power shunt equipment;
- Minimum Cost allocation of series capacitor.

With respect to controls the following options are available:

- Active power dispatch;
- Generator voltage level;
- Reactive power generation;
- Taps of LTCs;
- Shunt susceptance of capacitor/reactor banks;
- Series capacitor reactance.

With respect to constraints, besides bounds on control and state variables, there are the functional constraints such as the circuit power flow limits and the power factor at area interconnections.
With this flexibility, FLUPOT can be used in a wide range of studies on power system planning and operation as well as in the analysis of voltage collapse phenomena.

2.5 Composite Reliability Evaluation Program (NH2FPO)

The NH2FPO program is a computational tool for analysis of contingencies and probabilistic analysis of power system performance, including the evaluation of the composite generation and transmission reliability of large hydrothermal systems.
To achieve its objective, the NH2FPO program incorporates features which combine effective computer processing with flexibility in system modeling and diagnostics.
Flexible modeling was achieved by using the scenario concept and by allowing the user to specify the method for selecting states (enumeration or Monte Carlo simulation), and the model for performance analysis (AC or DC power flow).
Computational efficiency is achieved by adopting variance reduction techniques implemented in Monte Carlo simulation and by using an efficient optimal power flow in the remedial actions model (rescheduling of system generations, adjustments on voltage profile, changes on transformer taps, minimum load shedding), which considers specific solution strategies for each contingency.
The complete diagnostic of the system under study is obtained not only by means of the reliability indices, but also through the information of the most severe cases, probability distribution for selected variables, violation statistics by circuit and by bus, loss statistics by area and sensitivity to system reinforcements.
The analysis of each system state can also be performed by an optimal power flow (OPF). To achieve a reasonable accuracy in estimating the probabilistic indices, a great number of system states may be analyzed, including the combination of generator and circuit outages and load uncertainty. Therefore, in the contingency analysis process, specially in dealing with heavily stressed systems, there may be situations where the Newton-Raphson algorithm does not converge to a solution. This may occur due to poor starting points, ill-conditioned problems or because the power flow equations have no real solution. These system solvability problems are alleviated by calculating the minimum load shedding in order to bring solvability to an otherwise insolvable power flow. The computation of the minimum load shedding is carried out through an optimal power flow using the interior point method.

2.6 Optimal Expansion of Reactive Compensation Program (PLANVAR)

PLANVAR is a software tool for optimal sizing and sitting of reactive power compensation devices such as reactors, capacitor banks, static VAr Systems, etc..
Regarding ecomic information about installation costs at the candidate sites and obviously the network data, the program determines a minimum cost expansion plan

which ensures feasible system operation simultaneously for the normal state as well as during contingency situations.

Besides ensuring feasibility, the program can also take into account the economic effect of loss reduction resulting from VAr investment in the overall cost minimization.

The solution methodology to solve the VAr optimization problem implemented in PLANVAR is based on hierarchical decomposition of the problem into two parts.

- The investment and base case operation subproblem, where decisions about the location and sizeof new Var sources are made and at the same time a base case operating point is computed;
- The operation subproblems for the contingency configurations, in which these sources are used to make system operation feasible.

The global solution is obtained by the iterative solution of those subproblems. The first one initially produces a trial set of VAr capacity additions and a base case operating point. The effect of these additons and of the base case operating point in terms of operating feasibility is evaluated by the contingency operating subproblems. If no operating constraint violations are detected, the optimal solution has been found. Otherwise, feedback information about problem infeasibility is provided to the investment and base case operation subproblem, which then produces a revised trial expasion plan. This iterative process proceeds until a fesible solution is found.

Several aspects related to reactive planning are considered in the program. For instance the ability to represent multiple network cnfiguration is particularly impotant in reactive power planning since reactive requirements may significantly differ from one configuration to another. Planning under contingencies depends on the type of corrective action that can be taken after the contingency. With this respect, PLANVAR offers two kind of planning approach: *corrective* and *preventive*. In the first one, reactive sources and transformer taps can be readjusted after the contingency occurrence. The objective is to install new reactive equipment in such a way that the readjustments are sufficient to quarantee feasible system operation. In the preventive mode no readjustment are allowed. The objective is to install new reactive equipment in such a way, for a given base case operating point, system operation remain feasible even after a contingency occurs.

Recent developments implemented PLANVAR attempt to give some suggestions of price allocation of reactive ancillary services based on game theory (Aumann-Shapley).

2.7 Short Circuit Analysis Program (ANAFAS)

Developed for interactive use for analysis of faults in large power systems, the computer software ANAFAS is designed to have a reduced run time and to ease and expedite the engineering analysis of the many studies calling for the simulation of fault conditions in electric power systems, such as equipment rating, occurrence analysis, protection coordination, etc.

ANAFAS main solution algorithm is based on generalized Thévenin equivalent and compensation techniques. The methodology combines sequence network disconnection for the whole system (balanced), with phase coordinate representation for the unbalanced portion of the system (only a few buses).

ANAFAS can be run on a case-by-case (individual execution mode) or on a “sequential cases” (macro mode).

On Individual Execution Mode, it is possible to simulate almost any fault situation, described as a simultaneous combination of one or more of the basic types of faults:

- Any type of solid or impedance shunt fault involving any phases;
- Opening of a breaker (any one or more phases) with optional grounding on open phases;
- Removal of circuits;
- Any type of intermediate shunt fault;
- Any type of intermediate opening with optional shunt fault.

On Macro Execution Mode, the user easily set-up a sequence of cases, each one comprising a single shunt fault and a single, double or triple contingency. The Macro is specified by defining the following data:

- Types of fault: solid LG, LL, LLG, LL faults or any non-solid fault (combination of complex impedance values);
- Types of contingency: removal and/or disconnection of adjacent and/or coupled circuits and line-end-fault in adjacent lines;
- Fault points, defined as a set of busses or circuits (lines), easily specified, using typical data-base query primitives, such as union, exclusion and/or intersection of busses subsets, defined by enumeration of bus numbers, area numbers or voltage level;

ANAFAS allows the user to define “monitoring points” and “monitored quantities”, that resembles “protection quantities”, such as “measured impedance”, “current balance”, etc., providing a powerful and easy-to-use tool, specially for protection coodination studies and occurrence analysis, since the user can “model” the “relaying quantities”.

The solution output reports, for both individual and macro execution, can be oriented by fault-point (conventional), or by monitoring point.

2.8 Transmission Systems Expansion Planning Program (ANASIN)

The ANASIN software is an interactive system for power network analysis and synthesis. It is the result of the integration of the network analysis program (ANAREDE) and the network expansion planning program (SINTRA).

Besides the basic network analysis features such as power flow, rescheduling and contingency analysis, the program offers synthesis functions.

The synthesis functions are planning tools that help the planner in medium and long term studies of network expansion planning. These studies comprise establishing which, where, the amount and when new equipment (such as transmission lines, transformers, etc.) should be installed, so that the forecasted load can be economically supplied along the planning horizon with reliable performance. The generation expansion plan must be available.

Finding the optimal expansion plan is a very difficult problem because it involves the consideration of an enormous number of combinations of candidate circuits. There are no combinatorial optimization

techniques capable of reaching the optimal solution for large scale problems. Therefore heuristic techniques that allow choosing good solutions with an affordable computational effort, are attractive for network expansion planning problems.
These techniques aim at obtaining the set of circuit additions that allow an economic and reliable supply of the forecasted load along the planning period without violating operating limits. Given the set of candidate circuits, the problem is solved in stages, where at each stage the best circuit is chosen by a cost-benefit analysis. This is done for all circuits belonging to a candidate list. This process is repeated until all violations are eliminated, or no attractive circuit is found.
The candidate list, used to choose the best circuit addition, is based on sensitivity indices that measure the impact of circuit additions to the network. These sensitivities could be evaluated by two ways:

1) sensitivities of "minimum effort", derived from the linearized power flow solution, representing the changes on the "natural" flow distribution with respect to small variations on circuit susceptances;
2) sensitivities obtained from minimum load shedding (optimal active power flow dispatch) problem: provides simplex multipliers representing the changes in the load curtailment required to alleviate overloads with respect to small variations on circuit susceptances.

Another interesting feature is related to the multi-scenario analysis and planning. Several load, generation and network scenarios can be input along the planning horizon. Once a trial transmission plan has been obtained for a certain scenario (say the most severe), its performance can be checked against any other one, and new circuit additions or removals can be manually or automatically done on a yearly basis, so as to seek for a robust expansion plan that takes into account the most important and severe scenarios.

2.9 Harmonic Behavior Analysis Package (HARM)

The HARM program is a set of five modules specially designed in order to.

- calculate harmonic injections from thyristor controlled devices such as HVDC converters, thyristor controlled reactors and industrial rectifiers.
- investigate the harmonic propagation in extensive networks, caused by one or more injection sources.
- determine the frequency response of the system impendance, obtained from one bus (self), or the mutual one betwem two buses.
- calculate the parameters of HVDC main circuit.

The results derived from these features enable filtering projects, and consequently improves the power quality supply.
Usual distortion indices may also be evaluated.

2.10 Global Transient Stability Analysis Program (SLEP)

This tool provides an initial assessment of transient stability. It issues a simplified automatic analysis based on Liapunov's Second Method and Invariant Sets, providing critical times and energy margins.
The classical dynamic model is used, preserving the network's structure, and uses the Transient Energy Function as a Liapunov function, with the concept of Potential Energy Surface Limit. The energy margin allows ranking critical contingencies by severity, providing a safety margin for the system.
This interactive user-friendly tool is compatible with ANAREDE and ANATEM programs, and can also be used in a parallel or distributed computational environment.

2.11 System Dynamic Monitoring (MONDIN)

The natural growth of the electrical power systems resulted in huge interconnected networks with multiple oscillation modes. The analysis of such systems concerning electromechanical stability demands simulation through digital stability programs (either linear and non-linear models).
Due to uncertainties of system components data and approximations of the respective models, the simulation results will be approximations of the real system. For this reason the decisions based on these results have to be conservative and operating margins must be large. However, conservative plans and large operating margins do not meet the interests of an increasingly competitive environment.
With this issue in mind, simulation results need to be moved closer towards the actual response of the system by improving the data quality. Essentially it means that one has to know better the power system natural characteristics. One of the actions in that trend is an adequate monitoring of the system dynamic response, by installing dynamic system monitors (DSMs) at key locations of the system, in association with dedicated software to analyze the collected data.
On the other hand, the power system is being pushed to operate nearer its transmission limit for the sake of a greater efficiency. This is another factor why a better understanding of the system is essential to prevent a system collapse.
CEPEL is engaged in a project, named as MONDIN, to implement a national monitoring scheme of the system dynamic performance after major disturbances. This project involves several activities as follows:

- integrated development of software for data analysis
- development of a methodology for the interconnected power system dynamic response improvement
- monitoring system equipment specification
- determination of monitoring locations
- validation of large-scale system models

Software development includes digital signal processing programs. In this package it is included a Prony analysis program, which will be able to estimate the system oscillation modes based on measured time-domain response.
Another important stage of this project will be the development of a methodology to improve the system dynamic response following the analysis of the disturbance recordings. The validation of the recommended control actions (change settings and/or new controllers) may be accomplished through simulation with ANATEM and PACDYN programs.

2.12 Integrated Database (BDAD)

The Integrated Database Project has been developed during the last two years. The objective is to integrate

operation and planning software developed by Cepel under the same conceptual model.
This approach allows the integration of different programs so that studies can be carried out from planning to operation using the same network data. Programs can evaluate calculations and add information to cases, but basic data remain untouched guaranteeing integrity, consistency and uniqueness.
The main module will act as an input/output manager and program launcher, checking all operations performed over network data. Menu's appearance, the type of data window available for each network component and the program to be launched are defined by the execution mode set. This execution mode is set by the user and make possible to fill data requirements step by step, only when it is necessary to run a program, and not at once.
Once a network is created, cases using its data can be created by different users although only the owner of the network has authorization to alter it and, consequently, create a new version of it. Versions are necessary to guarantee the integrity of users' cases based on previous versions of the network.
Different load and generation configurations can be easily used, making possible to carry out studies without altering network original data.
At this moment Cepel's power flow and short-circuit applications are being altered so that they can be easily integrated with this database. Other programs will be integrated, one at a time, according to facilities' needs.

3. SOME PROGRAM APPLICATIONS

Some of these computational developments, as previously focused, have resulted in outstanding tools able to deal with a comprehensive number of applications.
A closer collaboration among ELETROBRÁS, GCPS/GCOI (The highest level committees for the Brazilian electrical system planning and operation respectively) and CEPEL over the last few years, through joint working groups, have produced more effective computer programs and related engineering studies. Some examples are presented in sequence.
The Brazilian North-South Electrical Systems Interconnection is a very interesting application to show an extensive and combined utilization of these tools. Initially, during the planning phase, different alternatives for the connection of the systems were conceived with the help of ANASIN program. Later on, the studies for verification of the system dynamic performance incorporating this new link and equipment specifications have been carried out extensively using ANAREDE, ANATEM and PACDYN programs, and more punctually, HARM program.
This experience was also useful to confirm the importance of the participation of CEPEL's researchers team in the studies, together with utilities personnel. This procedure involves more closely CEPEL with the companies requirements, contributing to the users satisfaction and also to the tools improvement. In fact, this was what really happened in the mentioned case: the engineers involved in the studies were responsible for the fast feedback of necessary modifications or enhancements in the programs to CEPEL's development personnel. Also, more recent equipment models, such as the TCSC (Thyristor Controlled Series Capacitor-FACTS), could be exhaustively tested, with a permanent assistance of the development team.
Another relevant example on how the combined efforts of utilities task forces with the CEPEL personnel support may contribute to improve the existent software, supplying the companies with the necessary features demanded from the studied phenomena, was experienced during the investigations of Rio de Janeiro and São Paulo areas voltage stability problems.
In this case, FLUPOT, ANAREDE, PACDYN and ANATEM programs were widely used. As a result of this work a first approximated model for HVDC links was incorporated in the first one, as well as a continuation power flow routine in the second program and automatic tap variation and automatic load/generation growth in the last digital tool.
From the long term viewpoint, the 10-years ahead transmission planning studies for the Brazilian electrical system have been carried out with the NH2 program application.
CEPEL has developed these tools considering the highest international quality standards, in order to provide competitive products for the Brazilian power sector companies. With this objective, CEPEL has submitted its programs to international evaluation through the execution of related engineering studies. These products have been used in some foreign countries, such as Argentina, Sweden, Canada and USA.
For instance, the Optimal Power Flow and reactive compensation planning models were evaluated in a project contracted by EPRI, named "Assessment of Voltage Stability Methods and Tools", conducted by BCHYDRO with participation of several major utilities in USA and Canada such as BPA, ONTARIO HYDRO, PUDGET POWER, etc. As a result of this evaluation, the OPF from CEPEL was considered the best tool for steady state voltage collapse analysis. Moreover, CEPEL is carrying out another project with BCHYDRO and EPRI for the development of the new computer model for reactive planning. This model will be officially adopted by EPRI for all affiliated American and Canadian utilities, opening a promising potential market.
Another important example was the application of the Small-Signal Stability Analysis program in a comprehensive study to CAMMESA, from Argentina, focusing the stabilization of the whole Argentinean electrical system. The study, in a brief description, included the modification and/or retuning of the power system stabilizers in order to damp dynamic oscillations. The results were implemented in the power plants and proved to be highly satisfactory, demonstrating the effectiveness of the program.
Recently, CEPEL was invited by ABB Power Systems to include in ANAREDE, PACDYN and ANATEM programs a detailed model of the HVDC configuration considering the CCC (Capacitor Commutated Converter) technology, which is now concluded. In order to verify the accuracy of this new model, successful comparisons were performed with results derived from another electromechanical stability program.
It is important to note that this technology has been considered in all new HVDC projects studied by ABB, taking into account technical and economical advantages.

As consequence of this development, those CEPEL's programs are able to represent an equipment only available in one or two similar programs in the world, and of course, making it accessible to the Brazilian utilities.
In fact CEPEL had also a chance to validate these implementations and submit the programs to an important international evaluation, performing a study for ABB, focusing the electrical interconnection between countries of MERCOSUL.
Finally, other points to be mentioned are a detailed study carried out by CEPEL for NEES Global Transmission Inc., from USA, particularly interested in the new Brazilian electrical system model, and the opportunities for new enterprises in terms of power delivery. The CEPEL's programs involving Optimal Power Flow, Electromechanical and Small-Signal Stability Analysis could be once more extensively used.
As result of all these developments and validations, CEPEL has additionally accumulated an expressive experience in conducting power system engineering studies, with international participation .

4. FUTURE PERSPECTIVES

Taking into account the current structural changes in the Brazilian electrical sector, it is necessary to evaluate new projects and provide the answers for the consequent modified market demands. Besides, natural improvements in the computational modeling used are also necessary in order to obtain a better accuracy in the results.
New participants, such as the Independent System Operator (ISO) and the Indicative Planner (IP), suggest a new market for the execution of projects in a competitive basis. Notably, some possible new projects to be carried out in cooperation with ISO and IP are listed below:

- Transmission Costs appropriation;
- Ancillary Services identification and costing;
- Control System adjustment optimization;
- Electrical Evaluation of possible interconnections with boundary countries;
- Security Analysis including dynamic aspects;
- Supply Reliability in the new model;
- Data Base Structure modernization to new applications;
- Electrical and Energetic Optimization improvement during pre-dispatch period;
- Transmission Expansion planning in competitive basis.

A consistent base of computational models are available for some of these possible projects, and only a few modifications are required for a competitive environment.
The requirements of dealing with a high growth of the Brazilian electrical energy consumption demands an increased investment level. During the expansion planning, for instance, the technical analysis of both attractive and feasible alternatives may be done by the existent companies or new agents, consequently generating new possibilities of applications to CEPEL's software, as well as new studies for these clients.
The procedures and criteria for utilization of the CEPEL's tools in specific studies is also an interesting way to negotiate new projects.
Another important activity to be explored are projects related to the implementation of modern data base in the companies, as consequence of the project BDAD.
From the international viewpoint the external usage of CEPEL's products is highly expected. As an example, the projects and studies developed to CAMMESA, EPRI, BCHYDRO, ABB and NEES may be pointed out. The continuity of this process depends on the excellent obtained results, on CEPEL's credibility and, fundamentally, on a structured marketing action to detect new opportunities and partners. As a function of the proximity and recent modifications in the electrical energy industries, the Latin America is low explored, with a high potential market.
The cooperation with BCHYDRO, which may be considered a traditional partner of CEPEL, probably will be augmented with the extension of the reactive planning project scope and with a project in the composite reliability area.
The continuation of the collaboration with ABB Power Systems is also expected, regarding new emerging interconnection projects with neighboring countries, possibly using the HVDC/CCC technology. This same tendency may be expect from NEES.
Finally, the usage of CEPEL tools in the subsequent studies of the Brazilian North/South interconnection by ELETROBRÁS and involved utilities, in association with the equipment suppliers, is a good opportunity to demonstrate the characteristics of these digital tools.

5. CONCLUSIONS

CEPEL has devoted a considerable effort to develop digital tools, in order to supply the main requirements from the Brazilian power sector companies. ELETROBRÁS and its subsidiaries have also permanently participated of this work, with important contributions obtained from practical applications, besides the financing.
The result of this close cooperation is tailor-made software, specially designed considering the main characteristics of the Brazilian power system.
These software have characterized by the inclusion of the state of art in several knowledge areas involved in power systems analysis.
An example is the usage of the prime-dual interior point method, indicated when dealing with systems presenting convergence problems, as heavily stressed networks. The software comprising this method had fundamental importance in analyzing the voltage stability problems occurred at Rio de Janeiro and São Paulo Areas in 1997.
In terms of new equipment, several FACTS devices models are available in some of those programs, which have been intensively used in the Brazilian North/South Interconnection studies.
Besides the participation in these studies, together the Brazilian companies, in order to guarantee a high quality of their software, CEPEL has also developed engineering studies to foreign companies, from Argentina, Sweden, Canada and USA, with the application of these tools. Important examples are: the association with EPRI to develop the new reactive compensation planning model; and the evaluation of the optimal power flow program, which was considered the best tool for steady state voltage collapse analysis.
Another example is the inclusion of the new HVDC

configuration regarding the CCC (Capacitor Commutated Capacitor) in some of the programs. This model has been used in studies to ABB and NEES Global Transmission Inc.

As consequence of this work, CEPEL has also accumulated an expressive experience in conducting power system engineering studies, with international participation.

All this procedure, in terms of more quality and competitive products, converge to the future environment and to adjust CEPEL for the new challenges will arise, considering the current structural changes in the Brazilian electrical sector.

The Independent System Operator (ISO) and the Indicative Planner (IP) will be new participants, representing an important market for the execution of projects in a competitive basis.

The continuation of the joint work with ELETROBRÁS and its subsidiaries is expected, resulting in the continuous development of CEPEL digital tools.

New agents will participate of the expansion planning and the system operation, consequently generating new possibilities of applications to CEPEL's software, as well as new studies.

Possible intensification of external collaboration and application of CEPEL's products will be also pursued. The projects and studies developed to CAMMESA, EPRI, BCHYDRO, ABB and NEES may be considered as successful examples. As a function of the proximity and recent modifications in the electrical energy sector, Latin America is also a high potential market.