SPIRA-SICRE: an integrated software tool for static and dynamic analyses of large power systems

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Abstract

The scenario for power systems has greatly changed in recent years following the liberalisation of the electricity market. The main consequences are a greater interconnection level (with increased cross-border exchange) and an exploitation of the capability of the network components close to their technical limits.

Therefore, to keep the pre-established reliability indexes and security levels, very accurate analyses need to be carried out. These are related to optimisation functions and dynamic studies. The optimisation functions are aimed at assuring minimum cost solutions when comparing different alternatives and probabilistic algorithms to take into account all the uncertainties that characterise this type of study. Dynamic analyses are devoted to investigating the behaviour of the electric systems at the occurrence of perturbations to detect eventual transient instabilities and identifying the most appropriate remedial actions.

In this context, it is very important to have tools to investigate in greater detail the network performance both in operation and planning stage, with static computation, but also with assessment of the dynamic behaviour of the system.

This paper will describe the integrated tool developed by CESI together with ENEL (Italian Electricity Board). These studies set up many research activities devoted to developing advanced methodologies and the relevant computing models to support the operation and the planning of the national transmission system.

This integrated tool was born merging into a common environment two different software packages: SPIRA, a set of tools for static network studies, and SICRE, a simulator for the dynamic behaviour of the power networks. The integrated tool now offers the end user the possibility of interacting with it in a simple way using the same network database.

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1 Introduction

Transmission systems have a strategic role in the economic and social life of a country. Expansion of transmission plans calls for significant investment, even though this is lower than that required by generating power plants and the expected life may be many tens of years. Moreover, the reliability of the transmission system, ensured at the planning stage, is the basis for the subsequent provision of adequate security levels and quality of the services during the operation of power systems [1].

Planning the development of a transmission system has the following objectives:

- to select the base options, such as voltage levels, transmission technology (i.e. AC vs. DC), design criteria,
- to assess the need of transmission network reinforcements and to identify location and size of new links and transformer substations,
- to assure the minimum of the total cost, i.e. capital charges, operating costs, risk costs.

Accurate and fast time domain simulations are becoming a mandatory task for the analysis of the electrical power system behaviour either at the operation stage (on-line or extended-real-time analysis) or at the planning and at the operational planning stages. Indeed, the greater interconnection among power systems, the planned installation of new transmission equipment and the increasing complexity of both control and protecting devices mean that the operator and the planner need to be fully aware of the stability margins of the system. Static security analysis, which is a function running in almost every EMS, could give insufficient results in the cases when the system trajectory between the pre- and post-contingency steady state is affected in a determinant way by the dynamics of the control devices and by the protection interventions.

The variety of these aspects calls for the need to use integrated computing procedures able to analyse all the technical problems related to the operation of interconnected electric networks. Furthermore, the requirements of costs minimisation and environmental constraints lead the planner to exploit as much as possible the capability of the components (e.g.: higher loading of lines) [2]. Therefore, to keep the pre-established reliability indexes and security levels, very accurate analyses should be carried out at planning stage. These are related to optimisation functions and dynamic studies [3].

This led ENEL and CESI to the realisation of an integrated environment for static and dynamic analyses.

2 An integrated environment

Considering the complexity of analyses to be performed for network planning, the huge amount of data and the interrelationships of the various planning stages, the availability of an integrated computing system is of the utmost importance to ensuring a sufficient efficiency for the execution of the study and a full consistency in the data handling.

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Figure 1 depicts the procedure developed and used to study the evolution of a generation and transmission system.

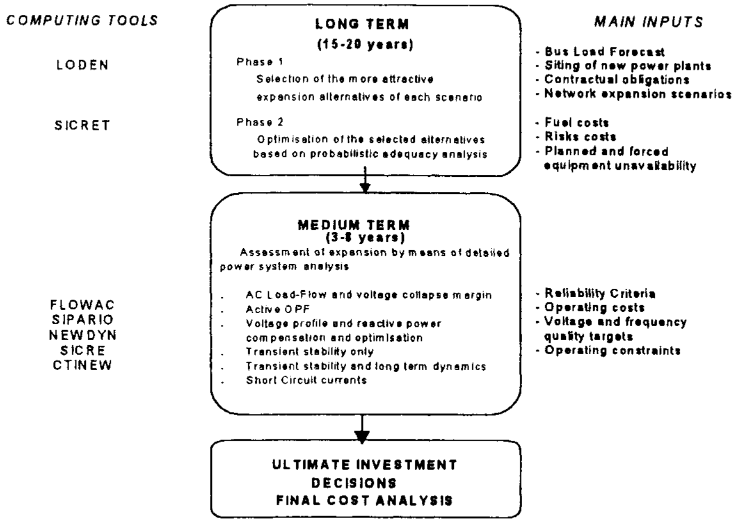

Figure 1: Planning procedure developed and used by CESI.

The methodology, schematically presented, is based on a few fundamental aspects, namely:

- the reliability evaluation of transmission systems,
- the optimisation of system operation,
- the careful analysis of operating aspects related with the need to assure voltage and frequency quality targets even under emergency conditions,
- the use of integrated computing systems based on the use of the more advanced information technology tools.

As can be seen, the adopted planning methodology helps to select the optimum development strategy for an electrical network through the analysis of several factors appraised in the various study stages into which the strategy is divided.

2.1 Integrated environment for electrical system planning studies

In the 1970s many research activities devoted to the development of new methodologies to be implemented in digital programs for the study of the complex problems related to the planning and simulation of the behaviour of electrical networks were carried out. In the mid 1980s, in order to make planning computation procedures easier and more effective, the SPIRA Project was started, with the aim of transferring all the application programs onto graphic workstations capable of high computation performance. Furthermore, the

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integration of programs with commercial graphic and relational database packages was devised to make possible an effective "friendly" utilisation by system engineers [4]. Today, the SPIRA environment makes available to the system engineer different tools for electrical system planning, such as [5]:

- preliminary optimisation of the medium and long network's expansion plan;
- probabilistic analysis of network adequacy;
- AC load flow analysis in the normal state with and without automatically selected contingencies;
- short circuit current levels in the network;
- optimum active and reactive dispatching and optimisation of generation with network constraints;
- network equivalents for load flow and adequacy analysis;
- network equivalents for short-circuit current assessment;
- appraisal of "flicker" disturbances caused by arc furnaces;
- current/voltage harmonic propagation analysis;
- network equivalent impedance as a function of frequencies.

The environment also makes available the link to the dynamic simulation database (Figure 2).

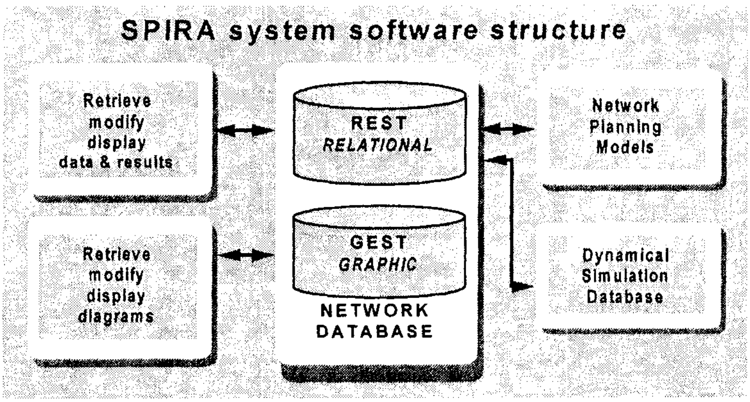

Figure 2: SPIRA, an integrated computing environment for network studies.

Following the logic that only necessary data are supplied to the tools that need the data, SPIRA only supplies and updates data that are common to both static and dynamic simulations, while an automatic procedure can update the database with the non-supplied dynamical data.

2.2 Integrated environment for dynamic simulation

In addition to static system optimisation, dynamic analyses are also necessary to check if the system is stable against large contingencies that are likely to hit the

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system (transient stability). Moreover, no inter-area oscillations or voltage collapse phenomena shall arise following a perturbation; consequently, so-called long-term dynamic analyses shall be carried out. Finally, in some special cases of system interconnection formerly isolated, steady state instability can arise. Therefore, the system stability against small perturbations shall be investigated by linearising the system components and the associated controls around the operating point and evaluating the related eigenvalues and eigenvectors. When a potential instability is detected, the planner defines the best location and parameters for stabilising the apparatus (e.g.: Power System Stabilisers to be added to the Automatic Voltage Regulators in a power plant). All the analyses mentioned require accurate and fast time domain simulations during operational (on-line or extended-real-time analysis), planning and operational planning stages [6].

In general, two major problems arise when dealing with simulators covering fast, slow and very slow transients. The first issue is the adequacy of the transmission system representation and of the models of the control devices and protections, depending on the dynamic phenomenon being simulated. The second is the choice of a suitable integration step in order to speed up as much as possible the simulation consistently with the stability region of the chosen integration method. These two problems must be solved while keeping the more general requirements of robustness in the calculation, accuracy of the results, speed, interactivity, modularity, and portability [7].

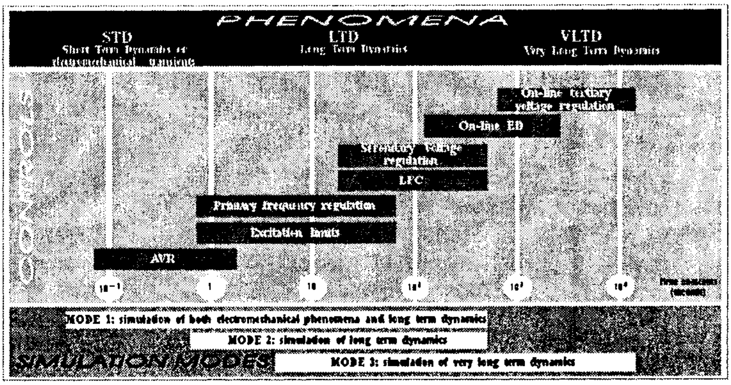

Figure 3: Dynamic phenomena and simulation modes of the SICRE simulator.

In the 1990s the project of a modern interactive simulator was started. A first overview of the newly realised power system simulator, named SICRE, was given, which specifically addressed the models and special techniques used for fast simulation of transient stability, or short-term dynamics (STD), and long-term dynamics (LTD). The solution adopted in SICRE is based on a time dichotomy strategy, where two different models of the system components are automatically adjusted during the simulation in order to accurately represent large time scale phenomena spanning from STD to LTD (Figure 3).

When designing a simulator, models, algorithms and Human Machine Interface (HMI) to be implemented must be tailored to the established objectives. The SICRE simulator was conceived in order to fit a large variety of application domains, mainly related to:

- post-event analysis and reconstruction of major disturbances;
- quasi-on-line dynamic security analysis;
- testing and comparing control strategies and defence plans;
- stability assessment in planning and operational-planning stages;
- checking of system protection characteristics and settings;
- planning and testing restoration plans;
- verification and tuning of parameters related to various control loops;
- training engineers and dispatch operators;
- testing different control functions to be included in the Energy Management Systems in the Control Centres.

System components are modelled with variable detail depending upon the dynamic conditions of the system (very high detail during STD, simplified modelling during LTD). A criterion for automatically switching from STD to LTD and vice versa has been designed. LTD only is simulated, with a consequent simplification of the component modelling; this turns out to be very effective for real-time simulations of large power systems.

As for the integration algorithm, in the SICRE simulator a set of explicit methods has been developed, either self-starting (Euler method, modified Euler, fourth-order Runge–Kutta), or multiple step (Adams–Bashforth methods). The optimal compromise among accuracy, stability and computation time turned out to be the modified Euler method (or Heun's method), which has been adopted as the standard.

3 Software environment

Today SICRE is available on three UNIX platforms (a Linux version for Intel platform is under development): HP-UX, TRU64, IBM-AIX; SPIRA is also available both on IBM-AIX and, on PC, under Windows.

For both the tools, great effort has been spent to guarantee the portability of the code and, above all, of the HMI.

The main objectives to be achieved during the realisation of the HMIs of both tools were the ease of use and the high interactivity with the end user.

Pop-up menus and masks for data-entry are intensively used in order to allow the user to create and manipulate displays of the network plans and diagrams, as well as send commands to the core of the simulation. Furthermore, all the operations can be easily accomplished through the mouse and the keyboard for data-entry. The whole HMI has been realised using criteria detailed in the OBJECT ORIENTED theory (data hiding, modularity, inheritance etc.), with all the advantages that the use of such technology offers.

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3.1 HMI facilities

Since static and dynamic network analyses have different needs, both SPIRA and SICRE are supplied with their own powerful HMI.

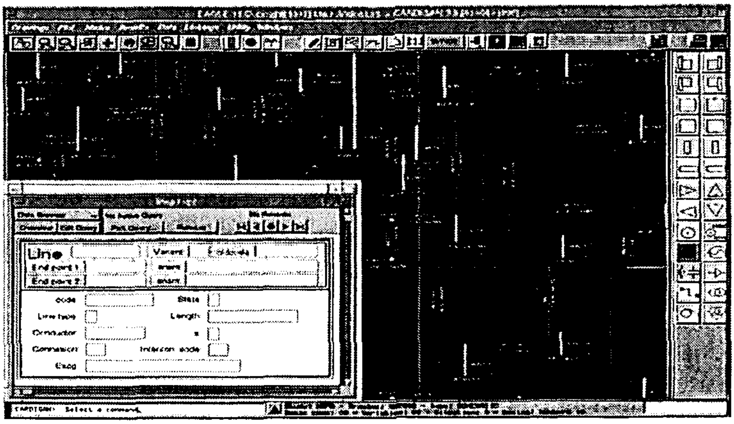

Figure 4: Example of HMI for network configuration and result representation.

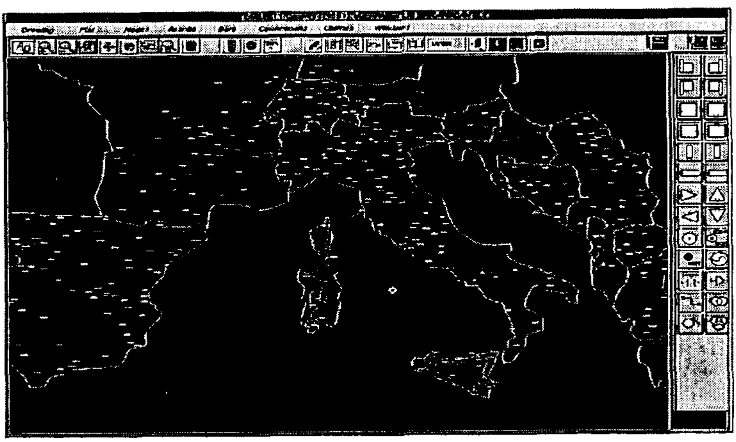

Figure 5: Geographical network diagram facility in the SPIRA environment.

In SPIRA, the results of studies that are more frequently carried out (load flow, short-circuit current evaluations) can be displayed on screen and on paper, but also on the network diagram in order to facilitate their analysis (Figure 4).

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Graphic functions also enable the more interesting network sections to be selected for the graphic presentation of results in study reports and for representing results on a geographical network diagram (Figure 5).

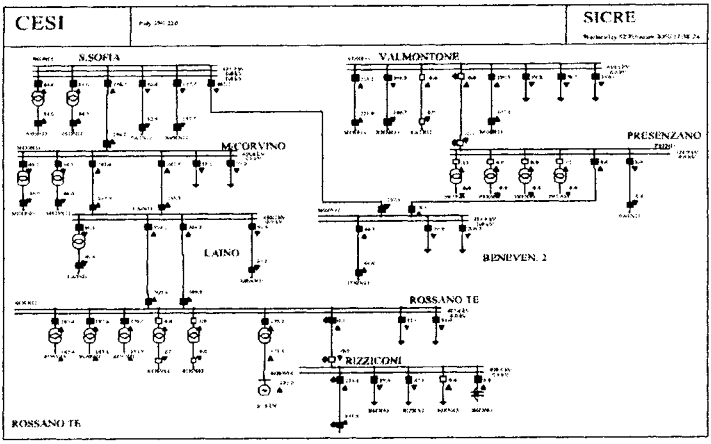

Figure 6: Geographical network diagram facility in the SICRE environment.

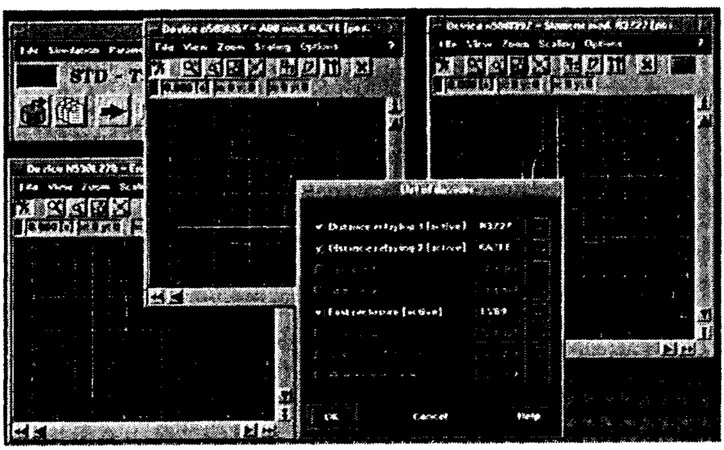

Figure 7: Cartesian diagrams facility in the SICRE environment.

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A specific HMI, oriented to the analysis of power systems, has been designed and built for SICRE. The main functions of this HMI are:

- electrical or geographic diagrams showing different hierarchic levels and having the function to easily find the interesting zone (Figure 6);
- electrical plans of stations or areas displaying and updating the data on-line with the simulation;
- block diagrams and tables displaying local regulations or area regulations.
- Cartesian diagrams $f(t)$ and $f(x, y)$ offering sophisticated methods in order to analyse the behaviour of the variables (Figure 7);
- events trace (breaker opening, protection switch either requested by an operator or automatic, etc.).
- activation starting from a predetermined initial situation;
- request of manoeuvres on line with the simulation (breaker opening, set-point change, etc.);
- stopping and restarting from an operating point previously saved;
- saving the state of the simulation (snap-shot of the system) in order to make either off-line analysis or to restart the simulation later;
- realisation of a predefined simulation, according to a previously scheduled scenario;
- creation of displays of the network using either automatic builder of displays or interactive graphic tools, or modifying existing displays.

4 Applications

Both SPIRA and SICRE are today used at the Engineering and Dispatching departments of GRTN (the Italian Transmission System Operator), in many Distribution and Generation Companies of Italy and abroad and at CESI.

The efficiency of the SICRE–SPIRA package has also been proved over the years by several studies performed on large electric systems.

Among the several applications, the SPIRA–SICRE package was used in the framework of the activity of a UNIPEDE group of experts, called SYSTMED and belonging to the Study Committee 40.SYST (Large Systems and International Interconnections), in charge of studying the possible synchronous interconnections along the Mediterranean Basin Europe, having Spain and Greece as "terminals"; the network included North African countries, Middle-East countries and Turkey. Such a huge system, which has a geographical extent of about 6000 km in longitude and 2500 km in latitude, has been carefully examined both from steady state and dynamic viewpoints.

Indeed, an Operator Training Simulator for the National Control Centre of GRTN is under development and it is based on the SICRE simulation engine of SICRE. For networks having about 600 busbars and 200 power stations, LTD simulation of SICRE is able to keep the real time on condition that a workstation with a computing power of about 50 MFlops is utilised. This is, for instance, the case of the Italian 380/220 kV system in its interconnected operation with the remainder of the European one (represented by suitable dynamic equivalents).

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