

ONS INTEGRATED DISTURBANCE ANALYSIS SYSTEM

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ABSTRACT

The **O**perator of **N**ational **P**ower **S**ystem - ONS (Brazilian ISO) is responsible for the operation and control of power generation and transmission system of Brazilian grid. As such, one of its tasks is the analysis of disturbances which occur in the National Interconnected System - NIS. In order to do that ONS uses data from fault recorders from multiple generation and transmission utilities.

The disturbance recording system installed on the NIS is composed by analog and digital fault recorders at power plants and substations owned by these utilities. Its main goal is to record power system voltage and current waveforms for late analysis of fast transient disturbances (mainly faults), and relays and protection systems performance.

Digital Fault Recorders - DFRs have intrinsically capacity to be accessed remotely allowing recorded data files, with digital and analog measurements, to be transmitted to utilities data concentrators - UDCs, usually located on utilities central office. The communication media among DFRs and UDCs, the DFR network architecture and how these data is collected by each utility varies immensely. The data gathering can be automatic or requested manually. In most utilities these records are stored on UDCs located in the corporative intranet. These UDCs usually have access to Internet, but seldom can be accessed from it.

This paper describes ONS efforts on developing an integrated system to automatically acquire and analyze DFR records. One of its components is SCAP, a web based client-server system for acquiring DFR records from utilities. With SCAP, ONS staff can easily locate any disturbance file, and analyze it using SINAPE. SINAPE is a universal DFR analysis tool developed by CEPEL, the electric energy research center supported by the Brazilian government. Based on SINAPE technology, advanced tools are being added to SCAP in order to achieve automatic and full analysis of DFR records. As examples, an automatic fault analyzer and a two terminal transmission line fault locator are under implementation.

INTRODUCTION

Brazil electric energy production and transmission system is a mix of hydroelectric and thermal power plants with multiple owners and strong predominance of hydroelectric energy. The NIS is formed by the transmission systems of the south, southeastern, center-west, northeast and a small part of the north regions of Brazil and is responsible for supply almost 98% of total Brazilian electric energy market.

The Brazilian electrical system has continental dimensions. For comparison, in the end of 2005, the installed capacity in the NIS reached the total power of 82,110 MW, being 69,760 MW from hydroelectric plants, (including one half of Itaipu Power Plant installed capacity, that is a joint Brazil-Paraguay enterprise and totalize 12,600 MW), and 12,350 MW from thermal plants (being 2,007 MW of nuclear fuel). The total production corresponded, in 2005, 400,4 TWh, (372,5 TWh from hydroelectric plants and 27,9 TWh from thermal plants). Only a small amount of Brazil electric energy production is outside the NIS, in small non-interconnected systems, mainly located in the Amazon region.

Following the world-wide effective trend in the 90's, the transference of the utilities property from the state for the private sector, the opening of the electric energy market to competition and the institution of free access, the Brazilian electric sector was restructured, going, basically from a model with few regional state utilities that actuated in generation, transmission and distribution, to a segregated model with well defined generation, transmission and distribution only companies. This

allows investments in new transmission lines and substations, and consequently the increase of the number of transmission companies - TRANSCO.

The NIS' Main Network, which includes transmission lines with nominal voltages from 230kV to 765kV, reached in 2005, a total extension of 83,049 km and a total transformation capacity of 185 GVA, distributed in 321 substations. It is expected that in 2008, these numbers will increase to 90,347 km of transmission lines, 351 substations and 195GVA of transformation capacity.

In this new model, ONS was created by federal law in August of 1998 as a non-profit entity of private law. ONS is responsible for the coordination, control and operation of generation and transmission installations in the NIS, and has its performance supervised by the National Electric Energy Agency – ANEEL, the regulatory agency of the Government of Brazil.

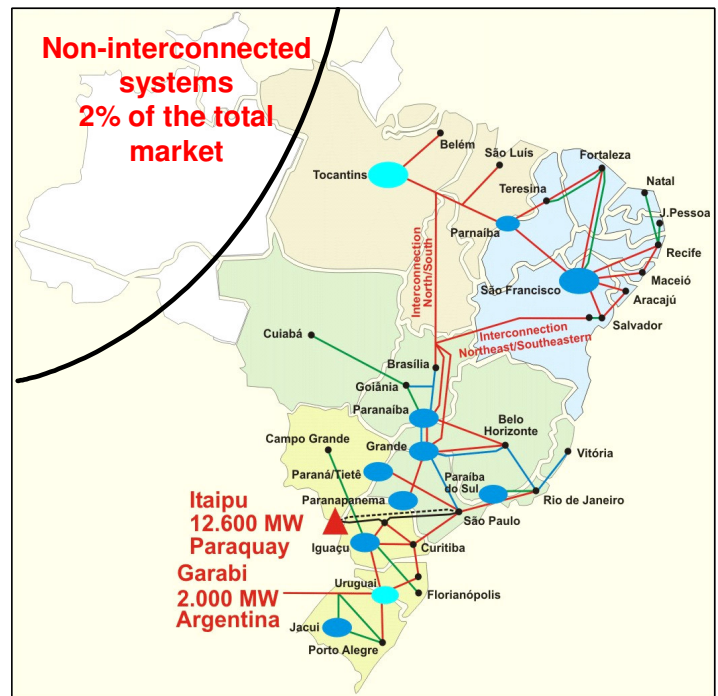


Figure 1 – The National Interconnected System – NIS

Due to the predominant hydro generation and the power plants located far away from load centers, the NIS' Main Network, besides the energy transmission role, is the main vector for system economic optimization, making possible the optimal use of hydro resources and hydro thermal optimal dispatch, by the exploitation of hydro basins weather conditions complementarities and allowing synergic gains that could postpone a large amount of investments in power generation expansion.

This new regulatory scenario, associated to the large disturbances that occurred recently in the NIS (blackouts of March, 1999 and January, 2002), emphasized the necessity to enhance the available capacity of post-operational analysis. The need to comply with the requirements of availability and reliability, as stated by the current regulation, covers with utmost importance the adequate register of NIS performance, as a form to identify the causes of non-conformity with the demanded quality of supply, the involved responsibilities and to take the corrective actions.

So, ONS is investing to develop the existing disturbance analysis capability, through the following actions:

- a) Development of an automatic system for Digital Fault Recorder's COMTRADE file acquisition and analysis;
- b) Development of computational tools for disturbance analysis.

AUTOMATIC COMTRADE FILE ACQUISITION AND ANALYSIS SYSTEM (SCAP)^[1]

The current short term disturbance recorder systems installed in the NIS' Main Network are mainly composed by DFRs installed in agent's generation plants and substations (agents are generation,

transmission or distribution utilities). Its main goal is to record power system voltage and current waveforms for late analysis of fast transient disturbances, relays and protection systems performance.

DFRs have intrinsically capacity to be accessed remotely allowing recorded data (digital and analog measurements) to be transmitted to utilities data concentrators (UDCs). The communication media among DFR and UDC, the DFR network architecture and how these data is collected by each utility varies immensely. The data gathering can be automatic or requested manually. In most agents these records are stored in UDCs located in the corporative intranet, but at others there are no servers for this task, and the data are stored in the same computer used for analysis. These UDCs usually have access to Internet, but seldom can be accessed from it.

By ANEEL's determination, DFR's files registering faults occurred in NIS' Main Network must be transmitted to ONS in, at most, 48 hours after the disturbance occurrence.

Based on that, ONS consulted the Agents in order to define how these short term disturbance data should be made available to it. Agents chose Internet as their preferred way to transmit the data, and so, ONS developed an automatic transmission system which considers that the COMTRADE data file to be transmitted are stored in a UDC (or in a regular PC which mirrors the UDC) with access to Internet. The transmission process is done using the Secure Shell protocol (SSH).

This system architecture can be seen in the next figure.

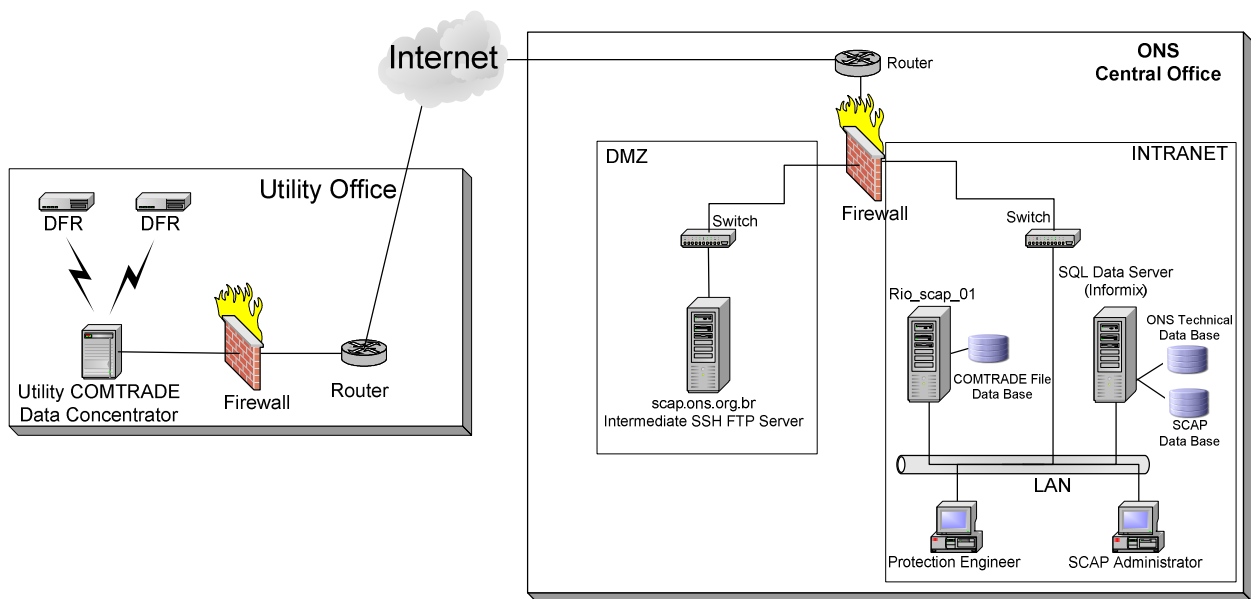


Figure 2 - SCAP System Architecture

As shown in Figure 2, SCAP is divided into three subsystems:

- Transmitter client (installed in the agent's UDC);
- Human Machine Interface (HMI) and the receiver (installed in the intermediate repository at ONS);
- Final COMTRADE file repository.

The transmitter is basically a client software which runs as a MS-Windows service in the Agent's UDC (or in UDC mirror) and uses a SSH FTP client to transmit COMTRADE files. This software detects when a new disturbance file is copied to a set of pre-defined folders. Once it detects this condition, it checks if the new disturbance file is a valid COMTRADE file, and if so, it transmits it by SSH to ONS SSH server.

The client software can be configured to detect the disturbance files in two different ways:

- 1) The client assumes that the COMTRADE CFG file has the correct information about the substation and the DFR's name in its first line. In this case, all COMTRADE files gathered from the DFRs must be copied to a single folder in the UDC (flat configuration).
- 2) The substation and DFR names are not corrected set in the DFR, and therefore the CFG file has incorrect information. In this case, the Agent must assemble a folder structure where the first level name corresponds to the substation identification and the second level name to the DFR's identification. If this setting is used, the client software ignores the existing information inside the CFG and identifies the COMTRADE file as proceeding from the substation and DFR depicted by the folder structure. The CFG file's first line is substituted with this new information (structured configuration).

After detecting a new COMTRADE file on the supervised folder, the client checks if it is a valid COMTRADE comparing it against the related COMTRADE standard (1991, 1995 or 1999) informed in the CFG's first line. If so, the client zips the COMTRADE files set (CFG and DAT compulsorily; INF and HDR if they exist) and name it to the format "*agent_name.current_path.CFG_name.zip*". Once it is zipped, the client sends the file via SSH.

On ONS side, there are two servers. One running the receiver, an Apache web server and a SSH server and another running just a SSH server. The SSH server running in the first PC receives the zipped disturbance file and stores it in a temporary folder. The receiver is a MS-Windows service which runs cyclically. It detects when a new zip file has been transferred and starts a translation process before applying the IEEE-COMNAME proposal. But why use a standardization process?

As already mentioned, in Brazil there are several different agents. These agents do not necessarily use the same name convention for their substations as ONS does. So it would be very difficult to ONS to keep a disturbance file database with the original substation names used by agents. Furthermore, nowadays in Brazil several agents can co-exist at the same substation operating different transmission lines which would lead to a situation where disturbance files from a same occurrence would have different substation identification since then come from different agents.

To overcome this issue, the agent has to inform the relationship *agent_substation_name* ⇒ *ONS_substation_name* in SCAP HMI. This register can be done before or after the disturbance file is sent. Depending when this is done, the disturbance file will have a different status when it comes to ONS server. The same thing is demanded for the DFR name. The difference is that ONS does not have a convention for DFR names as it has for substations, so ONS only asks the agents to register their DFRs with the same name they use for them.

Other important information is the phase sequence identification that is used by agent. As phase rotation and identification varies among agents, there is a practice to identify the phases in substations by colors (red, blue and white). This means that when a new agent is registered to transfer files to SCAP, he must provide his color – phase identification code. With this information SCAP system could change the CFG file from the agent phase identification to the common color code that was chosen to be used by ONS.

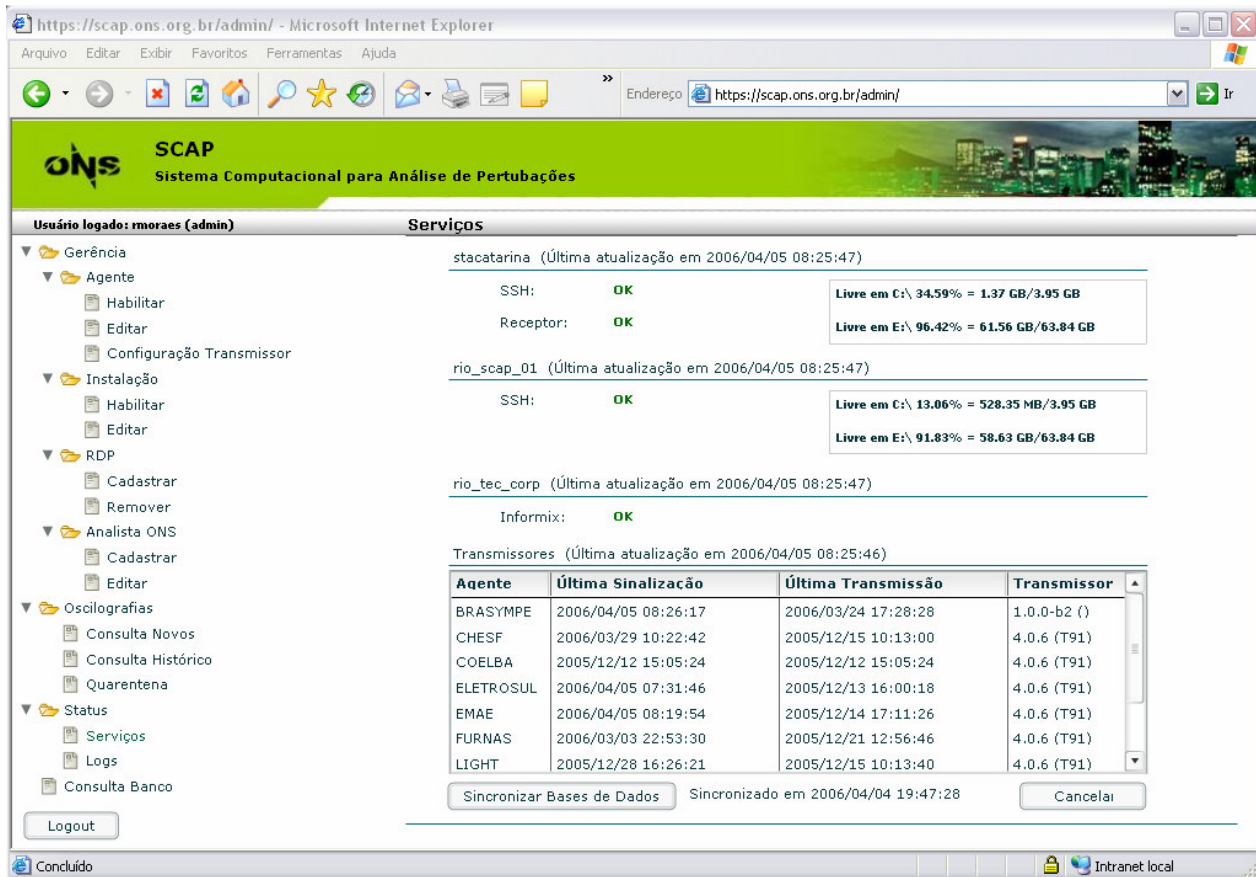


Figure 3 - SCAP HMI

Figure 3 shows the SCAP administration screen. The tree menu on the left allows agent, substation and DFR data management. In this menu is also possible to browse the new received COMTRADE files and files in quarantine.

As depicted, when a new disturbance file comes, it has in its CFG file the substation and DFR names. The receiver checks if the agent has previously informed the translation from *agent_substation_name* \Rightarrow *ONS_substation_name* and if the DFR name is in SCAP database. If both conditions are met, the CFG first line is changed based on *ONS_substation_name* and the DFR name. Then all files (CFG and DAT, INF and HDR if they exist) are renamed using the IEEE COMNAME proposal and zipped to a file with the same name as the CFG. This new file is transferred to the final repository via SSH and a new register pointing to this file is created in the SQL database in order to facilitate indexing, searching and recovering of disturbance files. The user can now download the newly added disturbance file using the SCAP HMI.

If the translation *agent_substation_name* \Rightarrow *ONS_substation_name* or the DFR name have not been informed in the HMI interface, the receiver will put this disturbance file in quarantine and report what need to be done to transfer this disturbance file to the final repository. The agent can check if all disturbance files are being correctly stored in ONS repository checking the SCAP HMI. If the agent has disturbance files in quarantine, the HMI will report to it and tell what he need to do (to inform the relation *agent_substation_name* \Rightarrow *ONS_substation_name* or the DFR name).

The main difficulties faced during SCAP developing were:

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- 1) The lack of convention for substation coding by agents when setting DFRs. Sometimes the same agent configures different DRFs located at the same substation with different codes.
- 2) Disturbance files generated in non-COMTRADE format. Some DFRs generate files which seem to be in COMTRADE format, but with some fields out of standard. In some cases there were problems to rename the disturbance files based on COMNAME since the disturbance file didn't match COMTRADE standard perfectly. The solution found for this problem was to accept disturbance files out of the standard, and correct them at the transmitter level. If it was impossible to correct the problem, the transmitter does not send the file and reports the problem. In this case, the agent will have to contact the DFR manufacturer and request a new version of its COMTRADE translation software.

In our opinion is very important to assure DFRs manufacturers fully attend the COMTRADE standard in their translation software. This little effort for manufacturers could greatly reduce the work involved on integrating disturbance files coming from different DFR models and different manufacturers. In our case, we currently intend to include in our Grid Code a request for DFR COMTRADE file certification for DFR to be installed in the NIS. An independent certification organization would check if the specific DFR model is compatible with the COMTRADE standard it claims it is.

One aspect that demanded care was the security of the involved computer networks. SCAP could not bring fragilities to the Agent's computer network nor to ONS'. This was one of the reasons that led to a solution based on a client running at the agent's data server, instead of opening a COMTRADE file server at the Agent's office.

The use of the client program in the agent server was considered more secure for the following reasons:

- First because it needs only connections through INTERNET from the agent's servers, located in their intranet, to the ONS SSH server. This allows keeping agent's network more protected, as it is not necessary to open the access from outside.
- Second because it needs the maintenance of only one SSH server on the INTERNET for COMTRADE files upload, in contrast to keeping one SSH server in each agent. It is well known the security cautions that should be taken to maintain such kind of server connected to the INTERNET.

Another advantage of the use of a client program in the agent's server is the possibility of using filters to select the desired COMTRADE files before transfer them to ONS server. Filtering files that have no relevant information could save communication bandwidth. For instance, some agents trigger their DFRs once a day to check if they are working correctly. The COMTRADE files generated are of no use for disturbance analysis, and their transmission to ONS should be avoided.

AUTOMATIC DISTURBANCE ANALYSIS SYSTEM (SINAPE.NET)

As described, SCAP is one part of ONS Integrated Disturbance Analysis System. It is responsible for COMTRADE file transfer from agent's UDC to ONS. When disturbance files arrive in ONS final data repository, SINAPE.NET takes control.

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SINAPE.NET is a computer tool responsible for automatic pre-analysis of COMTRADE files, when a new disturbance file is stored by SCAP. It reads the disturbance file and searches the current and voltage channels for variations and specific patterns which could indicate which equipment was involved, what are the faulted phases, if there was occurrence of transmission line automatic reclosing, etc. The automatic pre-analysis module measures the voltage and current values before, during and after the fault and also the fault duration time. This information is stored in the same SQL Database as SCAP.

Through SINAPE.NET web interface, the protection engineer can consult the results of the automatic pre-analysis and easily retrieve the associated COMTRADE file.

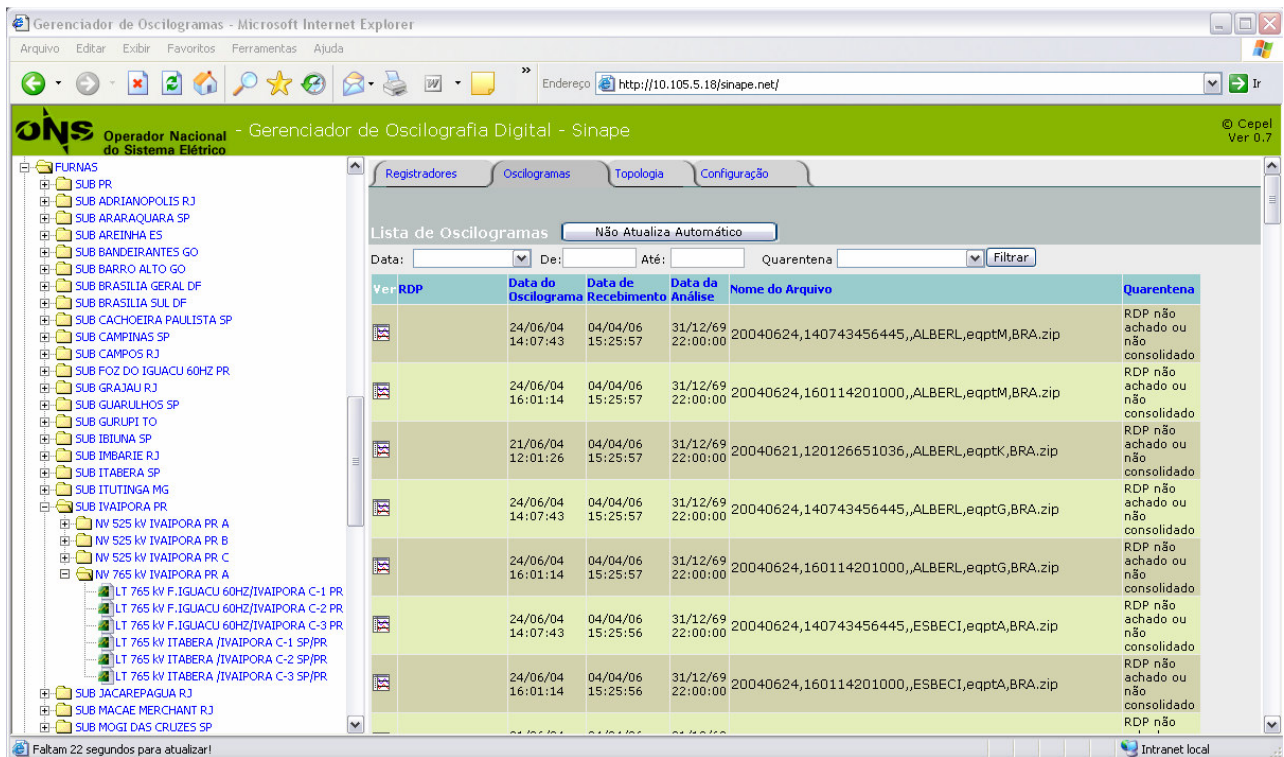


Figure 4 – SINAPE.NET

SCAP and SINAPE.NET were developed independently by different software suppliers. This occurred because each supplier worked and had expertise in different areas. SCAP supplier is a traditional DFRs manufacturer with great background in COMTRADE file interpretation and transmission while SINAPE.NET supplier (CEPEL) has large experience in automatic COMTRADE analysis. This development approach was challenging, and was not easy to get both systems working together. Even so both systems use the same SQL database.

ONS is presently working to improve and unify the system user interface. In the near future, we intend to develop a Graphical User interface - GUI that uses the NIS' Main Network topology stored in ONS Technical Database in order to obtain the disturbance files from a specific transmission line by point and click selection. To do that, the user will inform a time window for the disturbance occurrence, select the transmission line and SINAPE.NET will report all stored disturbance files that comply with the search criteria in both line terminals. He will then choose for each terminal one of the possible disturbance files and select which channels he wants to see. With this information

SINAPE.NET will assemble a new virtual COMTRADE file. These are simple procedures that will greatly improve the protection engineer work since nowadays he has to do it manually.

To achieve this, besides registering the substations and DFRs, the agents will be responsible for DFR's channels registration. The disturbance file receiver software will detect when a disturbance file with unregistered channels comes in, put it in quarantine and ask the responsible agent to register the data configuration and all digital and analog channel labels. The disturbance file will only be transmitted to the final repository when all information comprised in the CFG file is included in the DFR database. This procedure will be done for all transmission lines that belong to the NIS' Main Network.

Based on the association of the topological information with the DFR database, the use of more elaborated tools for the automatic analysis of transmission lines faults, such as transmission line fault location algorithms that uses measures from both terminals of the line, will be possible.

DEVELOPMENT OF COMPUTATIONAL TOOLS TO COMTRADE VIEWING AND ANALYSIS

Beyond developing SCAP and SINAPE. NET, ONS is starting a Disturbance Analysis Center with computational tools that will increase productivity of the protection engineers responsible for fault analyses. The tools that are being developed will allow a more detailed automatic analysis of COMTRADE files, the performance simulation of protection equipment, and the digital processing of the currents and voltages waveforms.

The main computational tool is the software called SINAPE^[2], developed by CEPTEL.

SINAPE - Integrated System for Disturbance Analysis Support - is a software that runs on Microsoft Windows operational system, conceived for the visualization of the waveforms stored in COMTRADE files, with an wide variety of functions and tools for disturbance analysis.

SINAPE was developed using a modular structure where the integration of software modules for the accomplishment of specific tasks is possible. Its main parts are:

a) Basic Module

It is the software core, responsible for the management of the main functions, such as: reading, translation and saving files; graphical viewer, waveform analysis and system contextual help.

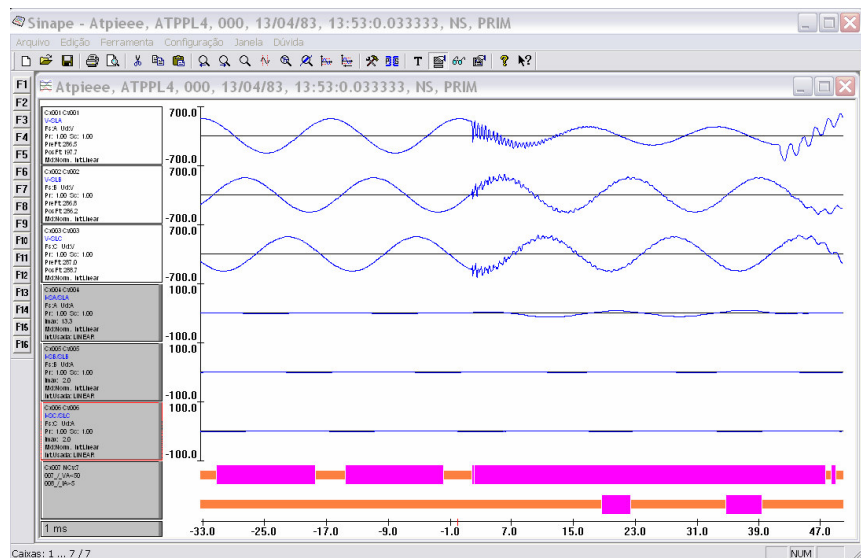


Figure 5 – SINAPE Basic Module: COMTRADE viewer

This module is based on a graphical interface responsible for visualization and analysis of the DFR recorded waveforms.

SINAPE GUI was designed to help COMTRADE files manipulation, allowing changing the scale factors of the signals in time and amplitude ("zoom"), and changing the channels layout to user desired order and the setting of different color options to facilitate the channel identification.

Another important functionality of SINAPE is the possibility of merging different channels of different COMTRADE files, producing a new file that acts like a virtual DFR.

The software allows the user to create specific ways of COMTRADE file visualization through the use of templates, to include text-boxes over the waveforms to clarify the analysis and to set different scales to show values referred to the primary or secondary side of instrument transformers.

SINAPE modular structure allows including new software modules to read DFR proprietary format data without the need of source code re-compilation.

b) Additional Modules

They are composed by specific functions which use the signals seen in the GUI. Currently there are modules for: harmonic analysis, RMS and symmetrical components calculation, fault location, active and reactive power calculation, computation of distance relay measured line impedance, and basic arithmetical operations, such as, addition, subtraction, division, multiplication, etc.

For example, the symmetrical module presents in the GUI the phasor diagram for the signal fundamental component and the phasors correspondent to the symmetrical components (positive, negative and zero sequence). The phasors can be obtained in any part of the signal using a sliding window. The harmonic analysis module allows observing the evolution of the harmonic components through time. The fault location module uses the Takagi^[3] method based on one terminal data. This module has been tested with simulated and real events, presenting excellent performance in both cases.

c) Protective relay simulation module^[4]

This module is the evolution of relay dynamic modeling software called WRSIM, also developed by CEPEL.

WRSIM's main characteristic is to permit the user to graphically assemble a relay through the use of representative blocks of its internal functions. WRSIM has blocks for the typical components and functions found in protective relays.

The functional blocks are defined by input and output nodes, and parameters specific for each function. Based on them, the protective relay is modeled using a set of functional blocks which take as inputs the voltage and current waveforms deriving from SINAPE GUI. In the same

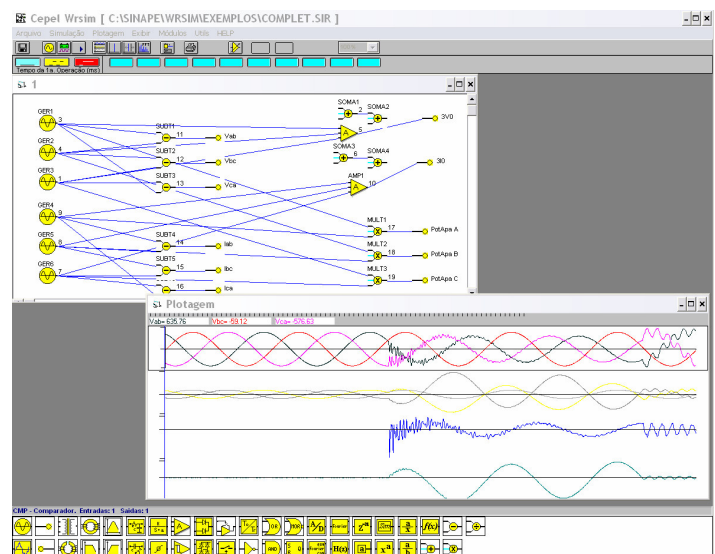


Figure 6 – WRSIM and SINAPE

way, a selected output from these functional blocks can be shown in SINAPE GUI, usually the trip signal.

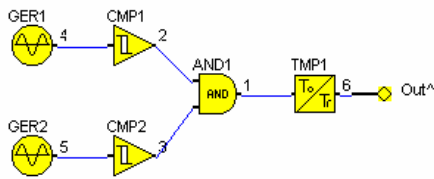


Figure 7 – Phase-Comparator Modeling

Once the relay is modeled, the user can simulate its behavior through successively iterations.

The software calculates the output value of each block based on its input variables and the time step is determined by the analog signal input sampling rate, in another words, determined by the DFR sampling rate. WRSIM's integration to SINAPE provided more elaborated fault analysis results, and faster fault analysis, bringing more quality to this process.

CONCLUSIONS

The disturbance analysis process consists in one of the most powerful resources for the optimization of NIS operation. During faults, the protection systems, relays and automatic control systems are requested to actuate, and under these conditions their performance can be analyzed and evaluated. This procedure has an important role to uncover hidden failures present in these equipments that can cause the propagation of a disturbance. The analysis results can indicate corrective and preventive measures to be taken, and consequently, improve the NIS integrity.

Similarly, the disturbance analysis is also used for the system post-fault restoration routine evaluation and allows the investigation and optimization of this crucial process, reducing the disturbance consequences and its impacts to society.

In order to improve the disturbance analysis process quality, ONS is extending and improving its infrastructure in order to automatically receive agent's disturbance files and store this great amount of data. With this new infrastructure ONS expects to accelerate the disturbance analysis process through the use of appropriate and customized computational tools.

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BIOGRAPHIES



Rui M. Moraes (IEEE and Cigré Member) was born in 1954 in Rio de Janeiro, Brazil. He received a B.Sc. degree in electrical engineering from the Fluminense Federal University – UFF in 1977 and M.Sc. degree in electrical engineering from the Rio de Janeiro Federal University in 1981. From 1978 to 1985 he was a Protection Engineer with LIGHT, a distribution utility in Rio de Janeiro, where he worked with relay testing and maintenance. From 1985 to 2000 he was a Senior Research with the Brazilian Energy Research Centre - CEPEL, working mainly with protective relay design and testing. He joined ONS - the Brazilian Independent System Operator - in 2000 where presently he is a Protection Specialist Engineer. He is the responsible for the implementation of disturbance analysis tools and infrastructure at ONS, and for the Synchrophasor Measurement System, a national wide project conducted by ONS. He can be reached by e-mail at rmoraes@ons.org.br.



Renan Giovanini (Cigré Member) was born in Porto Ferreira, Brazil in 1974. He received a B.Sc., M.Sc. and PhD degree in Electrical Engineering from EESC - University of São Paulo at São Carlos, Brazil in 1998, 2000 and 2005, respectively. He is currently working for ONS where he is a Senior Protection Engineer. He is involved with the development and installation of ONS Integrated Disturbance Analysis System and ONS Synchrophasor Measurement System. He can be reached by e-mail at renan.giovanini@ons.org.br.