Testing a Protection System Using the RTDS Batch Mode Facility

Sérgio do Espírito Santo
Electrical Studies Department
FURNAS Centrais Elétricas S. A.
Rio, RJ 22283-900, Brazil
sesanto@furnas.com.br

Victor Alexandre Belo França
Electrical Studies Department
FURNAS Centrais Elétricas S.A
Rio, RJ 22283-900, Brazil
vfranca@furnas.com.br

Hélio Hayashi de Almeida
Electrical Studies Department
FURNAS Centrais Elétricas S.A
Rio, RJ 22283-900, Brazil
hhayashi@furnas.com.br

Abstract – **Over the last 10 years FURNAS has been performing protection systems tests in a regular basis. The number of tests has been increasing during the years and so the needs to improve the facilities and the automation of the process in order to get complete results using a small period of time. At the same time, the experience obtained showed us that each protection test is unique. There is not a standard for the disturbances applied to the electrical system simulated, not only due to the different persons involved in each test, but also due to the different type of tests and the constant improvements of the tools used to perform them. Since 1996, most of the protection tests have been performed in closed loop using the RTDS to simulate the electrical network. So we realized that the development of a program to perform the tests automatically would be very useful. The challenge was to write a program adequate for all cases required in the tests, no matter what they are. The last version of this versatile program was used to test a FURNAS protection and both the program and the test are described in this paper.**

Keywords: Protective Relay Testing, Closed Loop Testing, Real Time, Digital Simulation.

I. INTRODUCTION

FURNAS is the largest electric utility in Brazil. Its area covers the most developed region inhabited by half of the country's population, which consumes more than two thirds of the energy produced in Brazil.

FURNAS Transmission System includes two 500 kV Cachoeira Paulista – Adrianopolis transmission lines. These lines are very important Brazilian grid interconnections, linking São Paulo to Rio de Janeiro, and transporting energy from Parana, Minas Gerais and São Paulo power plants to Rio, including the energy from Itaipu Power Plant.

Due to the importance of these lines, FURNAS recently decided to use new digital relays instead of the old analogue units to perform the same protection function. In order to do that, a laboratory test was planned to verify the correct setting of the Multilin relay model SR 760 [1] and to test its performance in the transmission line during disturbance conditions. In spite of the major purpose was to avoid the incorrect operation of the protection, the training of the maintenance personnel was also achieved.

The test was performed last year (2000) at FURNAS´ Simulator Center using the RTDS - Real Time Digital Simulator [2] to run the cases. Several single-phase, phase-to-phase and three-phase AC faults were applied in both lines, varying the location of the fault through the transmission line.

To run the cases, a program developed by FURNAS using the batch mode operating software facilities [3] was used. This program allows the user to be just an observer, without any kind of interaction with the equipment in test and the simulator tool. Executing the program, the RTDS runs the cases automatically at the sequence programmed, applying the faults on the electrical system and generating output reports from the relay. Every time a fault is applied, the voltage and current plots are updated as well as a report showing the relay output is written on the screen. For further analysis, files containing these results are also stored. During all the time, the user can watch and verify the simulation in real-time and even pause the tests or change the operation mode to manual instead of automatic and vice-versa.

II. THE FURNAS' REAL TIME SIMULATOR

The Real Time Power System Simulator was acquired by FURNAS as part of the Itaipu HVDC project. At that time, in early eighties, it was composed by analogue models for the electrical components and the real HVDC control and protection. The main purpose of the Simulator was to verify and to improve the behavior of the HVDC Transmission System. In this case, a set of the real control was connected to the analogue models of transmission lines, filters, generators, convertors, transformers, breakers and so on.

Later on, in the middle of the nineties, with the acquisition of current and power amplifiers, it became possible to perform protective relay tests in the Simulator [4], a task with a great demand due to the number of relays owned by FURNAS. In the beginning, a data file generated by an electromagnetic transient program such as EMTP was converted to analogue signals and sent to the relay through the power amplifiers. The outputs from the relay were acquired and analyzed later. However FURNAS wasn't only composed by HVDC systems and relays. So the upgrade of the simulator would be fundamental to improve the capacity of AC network representation, allowing tests in any part of its system.

Simultaneously, the digital technology was applied to develop a fully digital real time simulator for power system studies, named RTDS. In this case, the electrical components were represented by software, instead of hardware. So the new technology gave more flexibility to the process and then, after some evaluation, FURNAS decided that it was the best option to upgrade the existent simulator. In 1993 FURNAS start the arrangements to buy a RTDS Simulator from RTDS Tech., which was commissioned in the year of 1996.

Since that, FURNAS has been using the RTDS to perform several tests in equipment including protection system tests [5].

III. RTDS

The RTDS is a Power System Simulator with capacity of continuous real time operation. It works as a digital TNA, due to a combination of specialized hardware and software.

The RTDS can be used to perform different types of electrical studies such as:

?? HVDC Dynamic Performance studies;
?? Electromagnetic Transient studies;
?? Control System Performance studies;
?? Statistic evaluation of Switching Control;
?? Relay tests.

Due to the real time operation, it is possible to interconnect the RTDS with real equipment (relays, control systems, synchronizers and so on), which facilitates commissioning and performance evaluation tests.

For those tests, voltage and current amplifiers usually do the interface between the output from the simulation and the equipment being tested. The response from the equipment during the simulation is sent back to the RTDS forming a closed loop test.

To simulate a case using the RTDS the following sequence of procedures has to be fulfilled:

1. The electrical system has to be modeled using the Draft module. The Draft consists basically of a working area – to prepare the circuit – and the library containing the electrical power system models
2. The events have to be prepared in order to define the disturbances that will be applied on the case. This file is prepared by the Sequencer module
3. The compilation has to be done, aiming to create the executable code to be downloaded to RTDS hardware
4. The simulation is ready to be performed using the "RunTime" module to control and watch the signals. In a general way, the "RunTime" is responsible for the interface between the user and the RTDS Simulator.

IV. SCRIPT

One of the features available in the "RunTime" module is the "record/playback" function. The "record" function is designed to record actions that are usually performed manually by a user. The "playback" function is designed to run the actions previously recorded. In fact, the "record" function stores the actions in a script file, allowing the "playback" function to work later. So, the user interaction is no longer necessary. The script file can be edited or modified by the user in order to change the playback actions as desired. The script file gives to the RTDS simulation the capacity to perform a study in batch mode or automatically, we mean, without any user interaction.

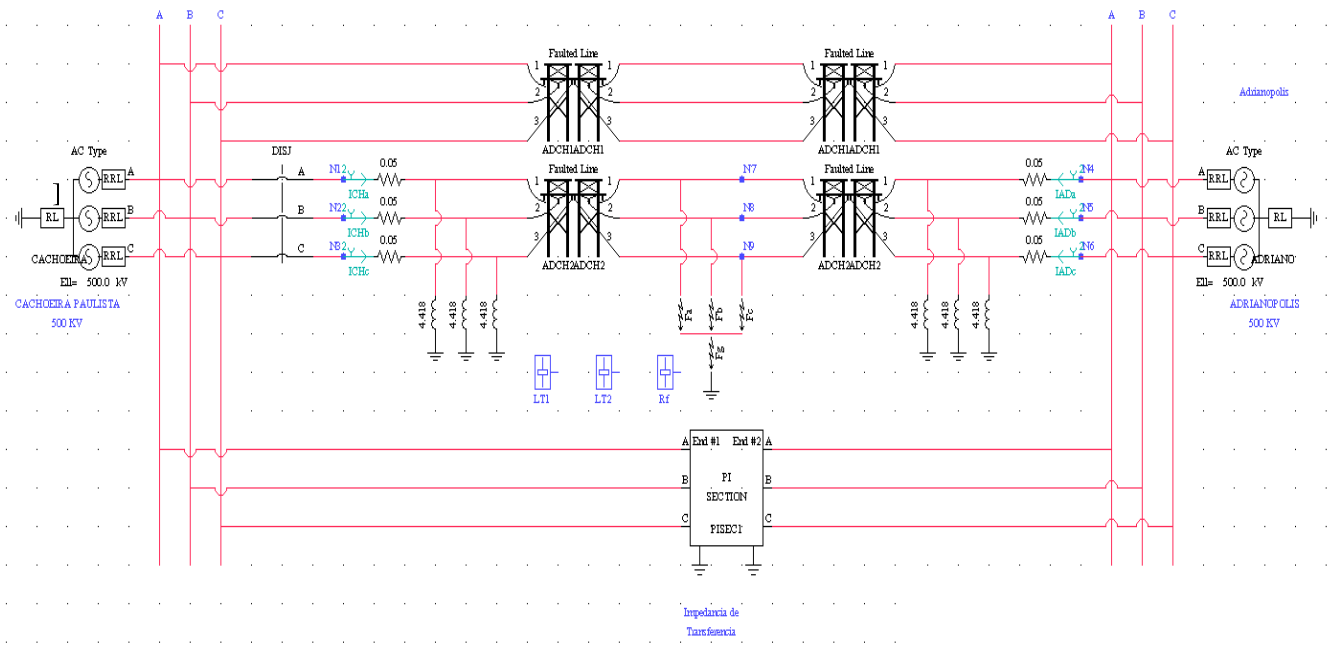

Fig. 1. System Modelled in the RTDS

A script file can include individual commands, such as: load a simulation case, start a case, change a set point, apply a fault, close a breaker and others. It is also possible to include new functions.

V. SYSTEM STUDIED

To evaluate the relay, two 500kV transmission lines between Cachoeira Paulista and Adrianopolis Substations were modeled in the RTDS. The lines were represented either as two independent lines or as a twin circuit. In both configurations, the relay was connected at Cachoeira Paulista terminal. The disturbances were applied at 0%, 25%, 50%, 75% 100% of the length of the transmission line, and also in the parallel one. Faults were applied at the Cachoeira Paulista bus, too. The Brazilian interconnected system associated was represented by two equivalents sources behind short-circuit equivalent impedance. The equivalent impedance between both substations was also modeled. Besides, a switch breaker at Cachoeira Paulista was represented. The breaker was controlled by the trip signal from the relay, and delayed by 2 cycles for opening. The current and voltage transformers were not represented, because the focus of the study was only to verify the relay performance. Anyway, these transformers haven't had presented any saturation problem with the old relays. The electrical system configuration used in this study is shown in Fig. 1.

For this relay evaluation, the bus voltages and the branch currents on the RTDS simulation, where the relay was supposed to be connected, were converted to analog signals and sent to the real relay, using voltage and current amplifiers to interface the signals. The trip and block output signals from the relay were connected to the digital input port of the RTDS for breaker opening control and/or monitoring purposes.

The study consisted in checking the relay performance during several different disturbance conditions. During the tests, the relay setting was optimized in order to improve the behavior of the protection associated to the electrical system. Therefore, most of the disturbances were applied several times, due to the use of different relays setting or just to confirm that the relay output remained the same.

VI. SCRIPT DEVELOPED BY FURNAS

In order to achieve the requirements regarding the versatility and flexibility to perform the protection tests automatically, we realized that the best solution was to use a description of the disturbances to be applied on the system, usually supplied by the protection engineers involved in the study. In fact, using that solution, we could even use totally different electrical systems, such as a detailed representation of a specific system or a simplified representation of the same system, or any other system configurations without any problem. So the program was really versatile, but if we still have to prepare 100 different circuits to run 100 different disturbances, it was unpractical. However, taking some special care at the circuit preparation we noticed that it was possible to run a multiple combination of cases. In this case, we need to use some advanced features of the RTDS like the faulted line model, which allows applying the fault along the length of the line, together with suitable node names and fault branch. Using this methodology, the number of cases would be the product of the number of circuits, the number of sequencers and the number of faults along the line.

For this evaluation, all the drafts were prepared keeping the nomenclature of the nodes in both breaker switch and fault positions. The mainly difference between the drafts was the fault position. The fault branch was configured as four single-phase fault models on wye connection and impedance adjustable by a slider in the "RunTime" module. Several sequencers were created defining the type and duration of the fault. The disturbance was applied at 0 or 90 electrical degrees considering the phase "A" voltage as reference. With this configuration, the same circuit allowed to run any type of fault, according to the sequencer chosen, with any impedance of fault, defined by the setting in the "RunTime". For the cases in which the disturbance was applied along the line, a slider in the "RunTime" defined the position of the fault. The fault impedance, the type of fault (sequencer) as well as the fault position were parameters read from the input file. Part of this file is shown in Fig. 2.

```
1    C001 1   Base_New_0  AG_0a 0.01  50    50    1
2    C002 1   Base_New_0  AG_90a      0.01  50    50    1
3    C003 1   Base_New_0  AB_0a 0.005 50    50    1
4    C004 1   Base_New_0  AB_90a      0.005 50    50    1
5    C005 1   Base_New_0  ABG_0a      0.005 50    50    1
6    C006 1   Base_New_0  ABG_90a     0.005 50    50    1
7    C007 1   Base_New_0  ABC_0a      0.01  50    50    1
8    C008 1   Base_New_0  ABC_90a     0.01  50    50    1
9    C009 1   Base_New_0  AG_0a 10.0  50    50    1
10   C010 1   Base_New_0  AG_90a      10.0  50    50    1
11   C011 1   Base_New_0  AB_0a 5.0   50    50    1
12   C012 1   Base_New_0  AB_90a      5.0   50    50    1
13   C013 1   Base_New_0  ABG_0a      5.0   50    50    1
14   C014 1   Base_New_0  ABG_90a     5.0   50    50    1
15   C015 1   Base_New_0  ABC_0a      10.0  50    50    1
16   C016 1   Base_New_0  ABC_90a     10.0  50    50    1
17   C017 1   Base_New    AG_0  0.01  25    50    1
18   C018 1   Base_New    AG_90 0.01  25    50    1
19   C019 1   Base_New    AB_0  0.005 25    50    1
20   C020 1   Base_New    AB_90 0.005 25    50    1
21   C021 1   Base_New    ABG_0 0.005 25    50    1
22   C022 1   Base_New    ABG_90      0.005 25    50    1
23   C023 1   Base_New    ABC_0 0.01  25    50    1
24   C024 1   Base_New    ABC_90      0.01  25    50    1
25   C025 1   Base_New    AG_0  10.0  25    50    1
26   C026 1   Base_New    AG_90 10.0  25    50    1
27   C027 1   Base_New    AB_0  5.0   25    50    1
28   C028 1   Base_New    AB_90 5.0   25    50    1
29   C029 1   Base_New    ABG_0 5.0   25    50    1
30   C030 1   Base_New    ABG_90      5.0   25    50    1
31   C031 1   Base_New    ABC_0 10.0  25    50    1
32   C032 1   Base_New    ABC_90      10.0  25    50    1
33   C033 1   Base_New    AG_0  0.01  50    50    1
34   C034 1   Base_New    AG_90 0.01  50    50    1
35   C035 1   Base_New    AB_0  0.005 50    50    1
36   C036 1   Base_New    AB_90 0.005 50    50    1
37   C037 1   Base_New    ABG_0 0.005 50    50    1
38   C038 1   Base_New    ABG_90      0.005 50    50    1
39   C039 1   Base_New    ABC_0 0.01  50    50    1
40   C040 1   Base_New    ABC_90      0.01  50    50    1
41   C041 1   Base_New    AG_0  10.0  50    50    1
42   C042 1   Base_New    AG_90 10.0  50    50    1
43   C043 1   Base_New    AB_0  5.0   50    50    1
44   C044 1   Base_New    AB_90 5.0   50    50    1
```

Fig. 2. Initial lines of the Input File

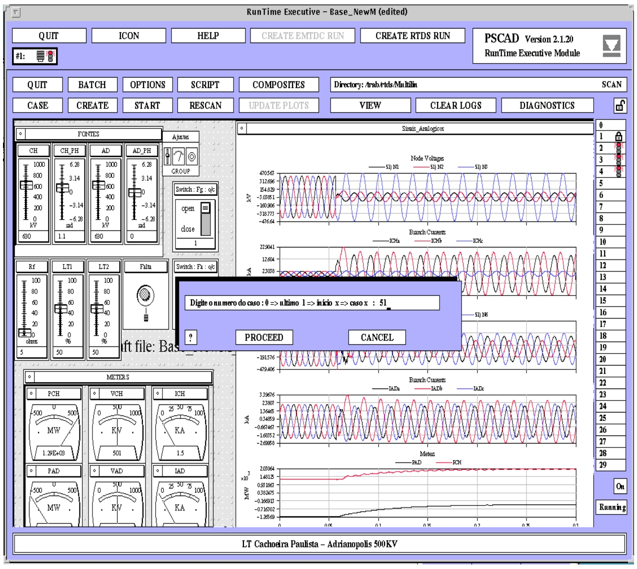

Fig. 3. Running the Program

In fact, the input file was composed by the following information: case number, output filename, load-flow, draft filename, sequencer filename, fault impedance, line 1 length, line 2 length and end-of-file flag. The load-flow parameter was used to set the voltage and angle of the equivalent sources. Only the line length parameter of the faulty line (defined by the draft in use) was important. For the other line, the parameter was set to 50% by default. For the faulty line, the line length corresponds to the position of the fault along the transmission line.

Although most of the cases had been performed in the automatic mode sometimes it was necessary to run each case manually, or even to repeat the case. So there was a flag, checked every time a new case was executed, which defined if the program should run in automatic or manual mode. This flag could be changed even when the program was running. In manual mode, it was possible to repeat the case, run the next case or stop the program.

To perform the test the user was required to inform in which directory the output files should be recorded, and the case number he wants to run, where one of the options available was “run the next case.” This screen is shown in Fig. 3. As a rule, all the cases simulated in each day were recorded in a specific directory, named as a composition of month and day at that time.

While the study was being performed the user could watch two output plots on the screen. One plot exhibited voltages and currents in both terminals of the transmission line where the relay was connected and the electric power transmitted by the line. The other plot monitored the digital output signals from the relay.

Figure 4 shows the voltages, currents and active power plots for the case number 50. In this case, a single-phase fault was applied at 75% of the transmission line protected by the relay, considering the Cachoeira Paulista terminal as the reference. The fault was applied in the phase A at 90 electrical degrees. The relay took 46.64 milliseconds to operate. Figure 5 shows a plot containing the digital outputs signals sent by the relay to the RTDS for the same case.

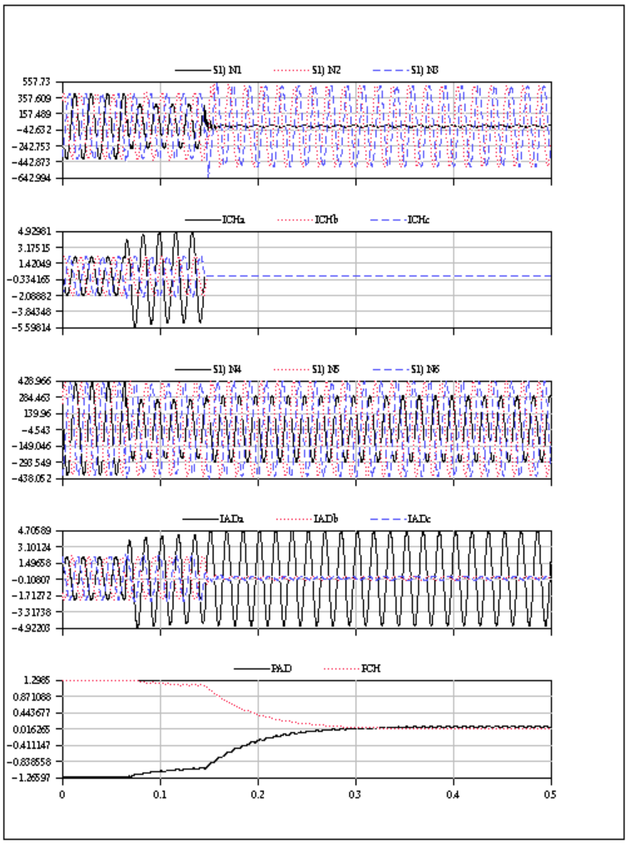

Fig. 4. Voltage and Current Plots
Case Number 50

At the same time a report was written in a console window of the screen describing the action that was being performed by the program. This report included a description of the case and a relay output report, informing the instant of the fault, which digital signal was set on and the instant it occurred.

All plots and report shown on the screen were saved for future analysis. For a quick reference, the name of the files included the number of the case. Moreover, the main table of results, used in the final report of the study, was generated as an event report. This report was composed by the information obtained from the input file, by the date of each case simulated and by the outputs of the relay, as shown in Fig. 6. All files were generated automatically, without any user interaction, optimizing the time waste in the study and minimizing the error risks.

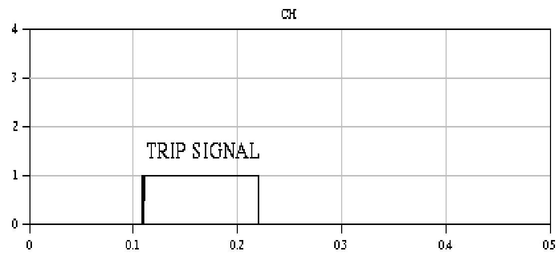

Fig. 5. Digital Output Signals from the Relay
Case Number 50

```
25 ; C025 ( Base_New / AG_0 ) ; Wed May 24 15:11:50 2000 ; 24Mai ; 49.453079 mSeg ; X ; - ;
26 ; C026 ( Base_New / AG_90 ) ; Wed May 24 15:12:28 2000 ; 24Mai ; 45.117149 mSeg ; X ; - ;
27 ; C027 ( Base_New / AB_0 ) ; Wed May 24 15:12:59 2000 ;24Mai ;  0 ;  - ; - ;
28 ; C028 ( Base_New / AB_90 ) ; Wed May 24 15:13:26 2000 ;24Mai ;  0 ;  - ; - ;
29 ; C029 ( Base_New / ABG_0 ) ; Wed May 24 15:13:56 2000 ; 24Mai ; 50.156204 mSeg ; X ; - ;
30 ; C030 ( Base_New / ABG_90 ) ; Wed May 24 15:14:25 2000 ; 24Mai ; 45.117146 mSeg ; X ; - ;
31 ; C031 ( Base_New / ABC_0 ) ; Wed May 24 15:14:54 2000 ;24Mai ;  0 ;  - ; - ;
32 ; C032 ( Base_New / ABC_90 ) ; Wed May 24 15:15:27 2000 ;24Mai ;  0 ;  - ; - ;
33 ; C033 ( Base_New / AG_0 ) ; Wed May 24 15:15:56 2000 ; 24Mai ; 49.335892 mSeg ; X ; - ;
34 ; C034 ( Base_New / AG_90 ) ; Wed May 24 15:16:25 2000 ; 24Mai ; 46.523399 mSeg ; X ; - ;
35 ; C035 ( Base_New / AB_0 ) ; Wed May 24 15:16:54 2000 ;24Mai ;  0 ;  - ; - ;
36 ; C036 ( Base_New / AB_90 ) ; Wed May 24 15:17:22 2000 ;24Mai ;  0 ;  - ; - ;
37 ; C037 ( Base_New / ABG_0 ) ; Wed May 24 15:17:51 2000 ; 24Mai ; 49.335896 mSeg ; X ; - ;
38 ; C038 ( Base_New / ABG_90 ) ; Wed May 24 15:18:20 2000 ; 24Mai ; 45.937458 mSeg ; X ; - ;
39 ; C039 ( Base_New / ABC_0 ) ; Wed May 24 15:18:49 2000 ;24Mai ;  0 ;  - ; - ;
40 ; C040 ( Base_New / ABC_90 ) ; Wed May 24 15:19:17 2000 ;24Mai ;  0 ;  - ; - ;
41 ; C041 ( Base_New / AG_0 ) ; Wed May 24 15:19:45 2000 ; 24Mai ; 50.742142 mSeg ; X ; X ;
41 ; C041 ( Base_New / AG_0 ) ; Wed May 24 15:19:45 2000 ; 24Mai ; 50.390583 mSeg ; X ; - ;
42 ; C042 ( Base_New / AG_90 ) ; Wed May 24 15:21:33 2000 ; 24Mai ; 45.468712 mSeg ; X ; - ;
43 ; C043 ( Base_New / AB_0 ) ; Wed May 24 15:22:02 2000 ;24Mai ;  0 ;  - ; - ;
44 ; C044 ( Base_New / AB_90 ) ; Wed May 24 15:22:30 2000 ;24Mai ;  0 ;  - ; - ;
45 ; C045 ( Base_New / ABG_0 ) ; Wed May 24 15:22:58 2000 ; 24Mai ; 49.921829 mSeg ; X ; - ;
46 ; C046 ( Base_New / ABG_90 ) ; Wed May 24 15:23:26 2000 ; 24Mai ; 45.820274 mSeg ; X ; - ;
47 ; C047 ( Base_New / ABC_0 ) ; Wed May 24 15:23:54 2000 ;24Mai ;  0 ;  - ; - ;
48 ; C048 ( Base_New / ABC_90 ) ; Wed May 24 15:24:24 2000 ;24Mai ;  0 ;  - ; - ;
49 ; C049 ( Base_New / AG_0 ) ; Wed May 24 15:24:53 2000 ; 24Mai ; 49.453087 mSeg ; X ; - ;
50 ; C050 ( Base_New / AG_90 ) ; Wed May 24 15:25:21 2000 ; 24Mai ; 46.640591 mSeg ; X ; - ;
51 ; C051 ( Base_New / AB_0 ) ; Wed May 24 15:25:49 2000 ;24Mai ;  0 ;  - ; - ;
52 ; C052 ( Base_New / AB_90 ) ; Wed May 24 15:26:17 2000 ;24Mai ;  0 ;  - ; - ;
53 ; C053 ( Base_New / ABG_0 ) ; Wed May 24 15:26:47 2000 ; 24Mai ; 50.039021 mSeg ; X ; - ;
```

Fig. 6. Some lines of the Output Report

This table of results file was imported directly by Microsoft Excel and handled by it. The Excel tools were used to reorganize the results, sorting the database by name and date, in order to show only the last result of each case in the table and not considering the previous results. This procedure was necessary because some cases were repeated using different relay settings.

VII. RESULTS

Due to the large number of cases simulated in the test, the Table 1 presents part of the results obtained, just to illustrate its performance.

The table contains 7 (seven) columns. The "Description" shows the name of the case and the draft and sequencer files used. To identify the case, the nomenclature used was the letter "C" followed by three digits. We decided to use that as a fast reference to find the case and/or the output files. The name of the draft identifies the type of representation used for the transmission lines and the fault location. It was composed by a common name "Base_New" plus some additional letters. For this table, the letter "M" means that the mutual between the lines was represented. The numbers "0" and "100" means a fault at the beginning of the line (Cachoeira Paulista side) and at the end, respectively. A "P" means that the fault is in the parallel line, and an "O" informs that the parallel line was open. Finally, an "E" represents a reverse fault for the relay, at Cachoeira Paulista bus.

The sequencer name informs the type of the fault and the electrical angle where it was applied, considering the positive zero crossing in the phase A as the reference. Concerning the sequencer name, we used the characters "A", "B", "C" and "G", meaning phases A, B, C and ground, in this order.

The second column shows the date - day and month - when the simulation took place, where "Mai" corresponds to "May". The third column, informs the fault position,

Description	Date	Fault location (%)	Fault impedance	Trip time (msec)	TRIP	BLOCK
C001 (Base_New_0 / AG_0a)	24/Mai	0	0.01	51.328087	X	-
C002 (Base_New_0 / AG_90a)	24/Mai	0	0.01	46.992146	X	-
C003 (Base_New_0 / AB_0a)	24/Mai	0	0.005	0	-	-
C004 (Base_New_0 / AB_90a)	24/Mai	0	0.005	0	-	-
C005 (Base_New_0 / ABG_0a)	24/Mai	0	0.005	49.804642	X	-
C006 (Base_New_0 / ABG_90a)	24/Mai	0	0.005	45.703087	X	-
C007 (Base_New_0 / ABC_0a)	24/Mai	0	0.01	0	-	-
:	:	:	:	:	:	:
C050 (Base_New / AG_90)	24/Mai	75	0.01	46.640591	X	-
C051 (Base_New / AB_0)	24/Mai	75	0.005	0	-	-
C052 (Base_New / AB_90)	24/Mai	75	0.005	0	-	-
C053 (Base_New / ABG_0)	24/Mai	75	0.005	50.039021	X	-
C054 (Base_New / ABG_90)	24/Mai	75	0.005	46.054649	X	-
:	:	:	:	:	:	:
C080 (Base_New_100 / ABC_90)	24/Mai	100	10.0	0	-	-
C081 (Base_New_E / AG_0a)	24/Mai	Externa	0.01	0	-	X
C082 (Base_New_E / AG_90a)	24/Mai	Externa	0.01	0	-	X
C083 (Base_New_E / AB_0a)	24/Mai	Externa	0.005	0	-	-
:	:	:	:	:	:	:
C153 (Base_New_100P / AG_0)	24/Mai	100P	10.0	66.210884	X	-
C154 (Base_New_100P / AG_90)	24/Mai	100P	10.0	62.812447	X	-
C155 (Base_New_100P / AB_0)	24/Mai	100P	5.0	0	-	-
C156 (Base_New_100P / AB_90)	24/Mai	100P	5.0	0	-	-
C157 (Base_New_100P / ABG_0)	24/Mai	100P	5.0	66.914009	X	-
		:	:			
C347 (Base_NewM_O / AB_0)	24/Mai	100PA	5.0	0	-	-
C348 (Base_NewM_O / AB_90)	24/Mai	100PA	5.0	0	-	-
C349 (Base_NewM_O / ABG_0)	25/Mai	100PA	5.0	0	-	X
C350 (Base_NewM_O / ABG_90)	25/Mai	100PA	5.0	0	-	X
C351 (Base_NewM_O / ABC_0)	24/Mai	100PA	10.0	0	-	-
C352 (Base_NewM_O / ABC_90)	24/Mai	100PA	10.0	0	-	-

Table 1. Table of Results

which is specially important when the fault was applied along the line. The nomenclature adopted was similar to that used to create the draft name. The forth column, named “Fault impedance”, informs the resistance value, in ohms, used in the fault modeling.

The fifth column shows the time needed by the relay to recognize a fault and send a trip signal, where a time of zero (0) means that the relay didn’t trip. The next one shows if the trip signal had occurred in the case. Finally, the last column shows if a block signal was generated by the relay.

VIII. CONCLUSION

The program developed proved to be versatile and appropriated to be used during any type of protective device test. It saves a lot of time during the test in the automatic mode and optimizes the time involved in the research to find the best settings in the manual mode. Regarding the final report, the use of the program is fundamental in a study with a large number of cases simulated, due to the capacity to create the table of results using a spreadsheet program to import the data. Using the program, the duration of the test is not directly dependent of the number of disturbances that will be applied in the electrical system. The main issue is the time spent in the analysis of the results by the persons involved.

Concerning the results from the test, the relay had a suitable performance, mainly with the last setting used, indicating that the replacement of the old analogue relays is possible.

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