FURNAS Strategy Regarding Real-Time Tests: A Practical Case – Campos Static VAr Compensator

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ABSTRACT

The use of power electronic devices has been improving the performance of the electrical power systems. In spite of the fact that the use of these types of equipments optimizes the performance of the system, it increases the complexity of the power system. Therefore a special attention for the power system representation is required, as well as the correct modeling of the transfer function of the controllers is fundamental to achieve correct results on simulations and permit reliable and accurate analyses.

Actual real-time simulators allow a detailed representation of the network and its components, even for very large and complex power systems. Those improvements have helped the real-time tests to become more realistic and easier to be performed. In Brazil, additionally, due to the fact that the deregulation of the energy market, with more strict rules and severe penalties associated, real-time power system tests have been widely used to ensure that the controllers and protections are working in an efficient way.

The main purpose of this article is to present the FURNAS' reasons for including real time tests in the specification of new equipments that include power electronics devices and protective relays. The paper will focus in the recent purchase of a Static VAr Compensator installed at Campos substation, which was tested in two different real-time laboratories during commissioning process and then reevaluated in a different power system configuration in FURNAS' laboratory.

Keywords: Equipment Testing, Real-time Simulation, Power Electronics, Electrical System Operation

1. INTRODUCTION

In the last 30 years the power system engineering has passed by significant changes due the technology evolution process. Different factors, acting combined, have contributed for that. In the equipment area, with the advent of power electronic, traditional equipments are being connected to power electronic devices, controlled by computer-based modules. Starting with HVDC links, this process continued with static VAr compensators (SVC), thyristor controlled series compensator (TCSC), static synchronous compensator (STATCOM), static synchronous series compensator (SSSC), converter-based voltage regulator and others. In the protection area, the electro-mechanical relays became static and then digital. While in the past each type of protection required one type of relay, the same type of relay is now a multi-function protection. Therefore the settings of the relay have changed from few to a large number of parameters. In the power system area, the complexity is increasing. Besides, the network is more coupled, too. Both reasons resulted in a different and more efficient performance of the system, however requiring special attention in its representation. On the other hand, the evolution of tools to study the electrical system is also evident. Digital off-line programs were developed and are continuously being improved. Real-time simulators became digital and more powerful.

Nowadays, a great variety of equipments and tools to study the performance of these equipments are available. So, there is a necessity to define strategies regarding the tests and studies – off-line and real-time tests - that have to be performed by the electrical utilities is becoming more evident everyday.

2. REAL-TIME SIMULATORS

Transient Network Analyzer (TNA) was one of the oldest equipment available to study the power system and its equipments. Basically, a TNA was a set of tools that permitted real-time studies using scaled down analogue models of actual power system components. However, the number of TNA available in the world was reduced due to the high purchase and operating costs and reduced modeling accuracy and flexibility.

With the advancement of the digital technology, a new approach to perform real time tests was introduced in the market. Using digital technology, real-time digital simulators offer much more flexibility, reliability and accuracy in the network modeling process to the user. The representation of the actual power system is performed through software models.

Real–time digital simulators are particularly useful to perform closed loop tests. In this case, a device is interfaced to the simulator, interacting with the digitally modeled system. It's the best way to define, verify and validate controllers and protections, because the actual device is used in the tests.

The major limitations of real-time digital simulators are related to the maximum power system that can be represented and to the minimum time step that can be used. In application involving firing pulses, where the time-step is a critical issue, some special techniques have been used to try to overcome or reduce this limitation.

3. FURNAS CENTRAIS ELÉTRICAS

FURNAS [1] is one of the largest electric utilities in Brazil. It has an installed generated capacity of 9,292 MW, an installed transformation capacity of 91,797 MVA and a total extension of 18,717 km of transmission lines. It includes 7070 km of 500 kV lines or above and 1612 km of 600 kV DC line [1]. Its area covers the most developed region inhabited by 48 % of the country's population, responsible for 65 % of the Brazilian Gross Domestic Production (GDP) and an electricity consumption of 58.8 % of the total

The company was introduced in the application area of power electronic devices due to the Itaipu project in the 70's. Itaipu power plant is composed by 50 Hz and 60 Hz generators and FURNAS is responsible to transmit the whole energy to the 60 Hz São Paulo area. In order to allow the transmission of the energy generated by the 50 Hz machines, an HVDC transmission system with a nominal capacity of 6300 MW was built. Later on, two SVC were installed at the Bandeirantes and Barro Alto Substations, respectively. After that, FURNAS installed a TCSC in the 500 kV Serra da Mesa-Gurupi transmission line [2]. More recently a SVC was installed at Campos Substation.

Fig. 1 - Overview of FURNAS Simulator

In order to perform real-time tests, FURNAS has an 8-rack RTDS [3,4], which is used for control and protection systems tests. Actually it is composed by first (TPC) and second (3PC) generation processor boards and it is being upgraded to a configuration with second and third (RPC) generation processor boards.

Figure 1 shows an overview of FURNAS Power System Simulator, installed at Rio de Janeiro.

4. FURNAS' STRATEGIES FOR REAL-TIME TESTS

As mentioned before, the importance of the simulation studies associated with the great variety of tools to perform it, represented by real-time simulations and off-line programs, demands from the companies a deeper analysis in order to decide what sort of evaluation would best fit with the importance of the project. Basically, due to the costs associated, real-time simulations are more restricted. Therefore it has been used more often to test controllers, whose complexity would need a good representation in off-line programs demanding for a previous validation using real-time tests. In the protection area, testing transmission line protections whose settings play an important role regarding it behavior and there is a high probability on having a fault somewhere in the line due to its extension.

FURNAS strategy considers both real-time and off-line studies. The decision on using real-time tests is based on the good results obtained with this type of test. The first experience was the Itaipu project. In this project, additional HVDC controls and protections cubicles were connected to an analog simulator and most of the studies were performed on real-time. The HVDC experience encouraged FURNAS to require additional controllers, identical of the one that will be installed in the plant, in the next purchases involving power electronics.

On the other hand, it means that another control module, similar to that which will be installed on site, has to be included in the purchase, in order to be installed on the laboratory and used for the simulations. However we have to consider that the software development is used to be the most expensive part of the control cost. So, preparing another module does not mean necessarily a substantial change in the cost, as the software used has to be the same of the main module and the development cost is already included in the original price. This strategy allows FURNAS to perform any future evaluation of the behavior of the controller, to change and test modifications of the parameters and the system performance associated with, and, for certain cases, test control software modifications made for any reason, and also to use it for training purposes.

Following this strategy, SVC controllers from Bandeirantes, Barro Alto and Campos Substations were installed at FURNAS real-time digital simulator.

The strategy described above is applied in new acquisitions. However, every time a modification in the power system could affect the behavior of the control system, FURNAS carry out a reevaluation of the device settings. These reevaluations are only possible if control modules for real-time tests or suitable off-line models validated by real-time tests are available

The strategy used for real-time test of protections systems is similar. FURNAS has increased the number of real-time tests performed since a RTDS simulator was bought. Several new protection systems, especially distance relays, were evaluated in order to check its behavior and settings in the system in which it will be connected. In the same way, real-time tests of switching devices started to be performed to check its statistical performance. Due to the good results obtained from those tests, FURNAS is now including real-time test requirements in the specification for new protection systems. The only difference between both strategies is that an extra device is not being required in the supply, as the device that will be installed on site is being used for the real-time tests.

5. CAMPOS' SVC PROJECT

The technical evaluation of the voltage profile of the Espirito Santo region in Brazil indicated that it area demanded for a voltage support. The studies indicated that a Static VAr Compensator System, installed at CAMPOS Substation, would be the best economical and technical solution. The Campos SVC provides a fast voltage control in the 345kV bus following a pre-defined voltage x current curve.

Campos SVC system is composed by two thyristor-controlled reactors, four filter capacitor banks and one step-down transformer (345kV/15 kV). Each reactor has a nominal reactive power of -80 MVAr and the total reactive power of the filters is 100 MVAr. As the filter banks are always connected, the range of the SVC is from -60 to + 100 MVAr.

There are 16 mechanically switched reactive elements – 10 capacitors and 6 reactors - at Campos Substation. The SVC control has a function (MSRE) that defines a strategy to switch those elements. It has the purpose to keep the TCR elements in a region of operation that assure a supply of dynamic reactive power.

Figure 2 shows the one line simplified diagram of Campos Substation.

Campos SVC Specification Requirements

The acquisition of the Campos SVC was executed through a bid process, as usual for a government company in Brazil. Following FURNAS strategy regarding real-time tests, technical specification included that the factory tests should perform real-time tests of the SVC Control. Besides, the scope of the supply included an extra control, as well as any additional hardware necessary to connect it to the FURNAS RTDS Simulator [5].

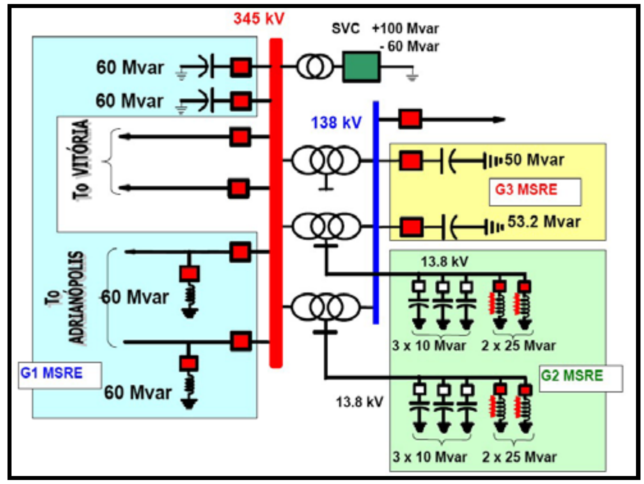

Fig. 2 - Campos Substation Diagram

Interfacing the SVC Control

In order to perform the real–time tests, the Campos SVC control system had to be interfaced to the RTDS Simulator. However, for several reasons, not all equipments at Campos were modeled in the RTDS Anyway a large number of digital and analog signals were exchanged between both RTDS and SVSC control.

The interface required the installation of additional hardware in the RTDS. Analogue to digital converter cards to allow analogue signal (4 internal signals from the SVC controller) to be monitored by the RTDS, digital to analogue cards to export analogue signals from the RTDS (15 voltage and 3 current signals) and a optically isolated I/O card to handle the digital signals (24 breaker open/close commands inputs and 11 breaker status outputs). Regarding the firing pulses, the 12 pulses signals from the two TCR were connected to the RTDS through special cards called DITS. The DITS card samples the input port every 90 nanoseconds and provides time stamp information of the firing to the simulation.

Figure 3 shows the interface between the RTDS and the SVC controller.

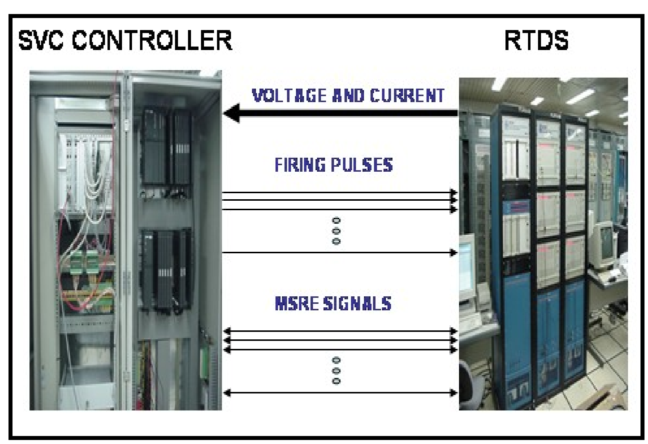

Fig. 3 – RTDS and SVC Controller Interface

Factory Real-Time Tests at RTDS Technologies

Two different circuits were digitally modeled on the RTDS Simulator to represent the power system on the studies performed at RTI laboratory in Winnipeg, CA.

The detailed system representation was used to observe the influence of the SVC in the system performance. In this case, Campos Substation and both adjacent Adrianopolis and Vitoria substations were represented in the circuit. Four mutually coupled twin-circuit transmission lines between the substations were modeled. Three step-down transformers (345 kV/138 kV), one in each substation, were also represented. The SVC, as well as the sixteen reactive elements (capacitors and reactors) and the two three-winding transformers, were represented at Campos Substation. One equivalent (source and equivalent impedance) of the system was modeled at Adrianopolis 345 kV bus and other at Vitoria 345 kV bus.

Figure 4 shows the circuit modeled for the test in the RTDS.

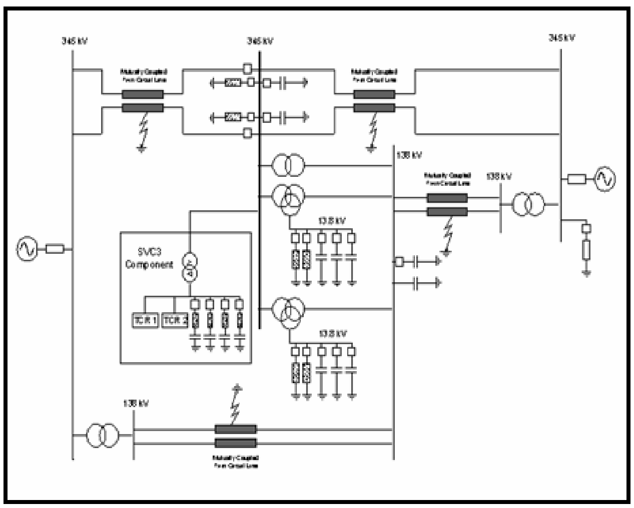

Fig. 4 - Circuit Modeled in the RTDS for the Factory Test

Regarding the power system, the initial idea was to model the Campos Substation in detail, considering the representation of all equipments. However due to RTDS hardware limitations existent at that time, it was noticed that some simplifications would be necessary.

One of the limitations was related to the maximum number of nodes allowed in the same substation. Each subsystem in the RTDS can have up to 21 nodes, which was not enough to represent all equipments existent in the substation. So, based on the purpose of the study, some equipment were not represented or represented by equivalents.

The other limitation was related to the number of breakers that could be modeled in the RTDS at the same time, which was limited to 28 single-phase switches. Considering the 16 mechanically switched elements, there was not enough switches available. To solve this, some elements were not commanded by the SVC control. On the other hand, the signal of each breaker required by the supervision system of the SVC was modeled using a SR-flip-flop in the RTDS. These flip-flops are driven by open and close commands from the supervision system and the outputs of each flip-flop are returned it to indicate the breaker status.

A problem related to the interface was noticed in the very beginning of the tests. SVC synchronization is sensible to the discrete voltage signal variations from the RTDS. In order to reduce the jitter in the synchronization, the voltages used as reference for synchronization were over sampled by a RTDS software block which was included.

The analysis of the preliminary test showed that the SVC reactive range was not totally reached. The explanation remained in the fact that two time delays were introduced during the RTDS simulation. Firstly, the DITS card introduces a time delay from when the firing pulse arrives at the card and the effect can be seen on the currents. The DITS card determines exactly when the firing pulse arrives in relation to the RTDS time step. This time information is given to the RTDS near the end of the current time step and the RTDS can only correct the current in the next time step. Secondly, the over sampling function used introduces a time delay on the simulation. One time step is used to calculate the line-to-line voltages with the controls compiler and the other to do the actual over sampling.

To overcome these time delays the firing pulses must be given earlier in order for it to have effect at the right time during the simulation

The results indicated that some final adjustments, mainly in the MSRE logic, should be necessary. These modifications demanded for a new evaluation of the behavior of the SVC control system. In the meantime the modifications were been implemented, the manufacturer purchased a RTDS and carry out the complementary test in their own simulator.

Commissioning of the SVC Control at FURNAS

The real-time tests at FURNAS had the purpose to set up the Campos SVC control system ready for RTDS studies and to verify its overall performance [6]. The tests were performed at FURNAS Simulator in Rio the Janeiro.

For this study the power system represented in the previous test was updated considering the network configuration for the year 2005. Macae power plant was represented between Campos and Adrianopolis Substations. Another substation, Ouro Preto, was added in the represented system, with its associated transmission lines and a system equivalent. Besides, two synchronous compensators installed at Vitoria were now modeled, too.

As there are several switched reactive elements, the synchronous representation was important, because both the SVC and the synchronous contribute for the reactive support any time one element is switched.

Figure 5 shows the modifications implemented by FURNAS concerning the original system modeled.

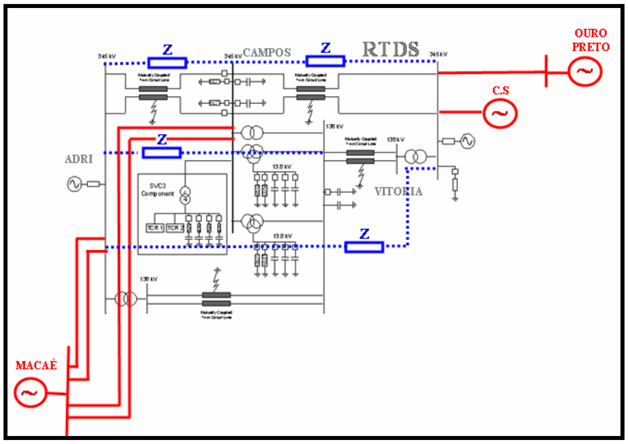

Fig. 5 – System Modeled for the Commissioning Tests

Examples of the results are illustrated in the following figures. Figure 6 presents the behavior for a 3-phase short circuit at Vitoria 345 kV bus. Figure 7 shows the comparison between real-time and off-line simulations for a 60 MVAr shunt reactor switching-off.

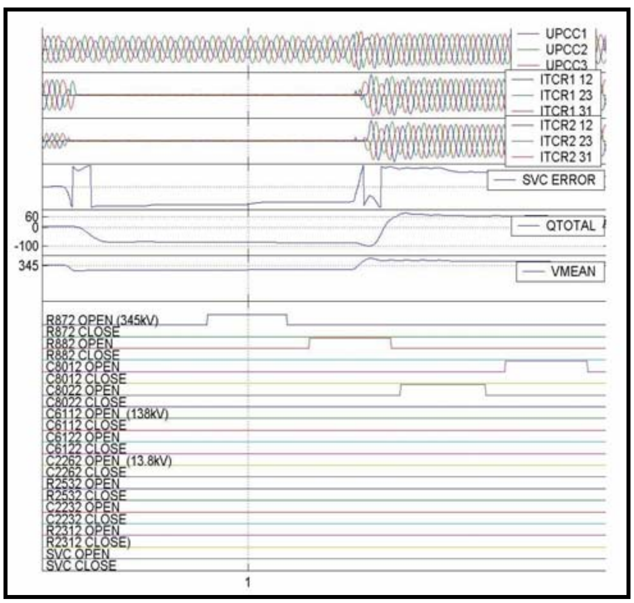

Fig. 6 – Three-Phase Short Circuit at Vitoria 345 kV

During the tests we realized that the interfacing type used for this project is the most precise available, but it’s not perfect. A high number of signals have to be connected to the simulator. This means that the work involved is reasonable, especially checking that the connections are working fine. And the hardware required for the interface is directly related to the number of signals used in it. So, a high number of exchanging signals means that the interface process will require several cards. Even so the cards are available in the simulator, keeping the interface will make them unavailable for another studies. On the other hand, disconnecting the equipment will require the same interfacing work in the next time. An intermediate solution is to disconnect the wires only when the card being used is necessary to interface other equipment. This is the solution that is being adopted by FURNAS.

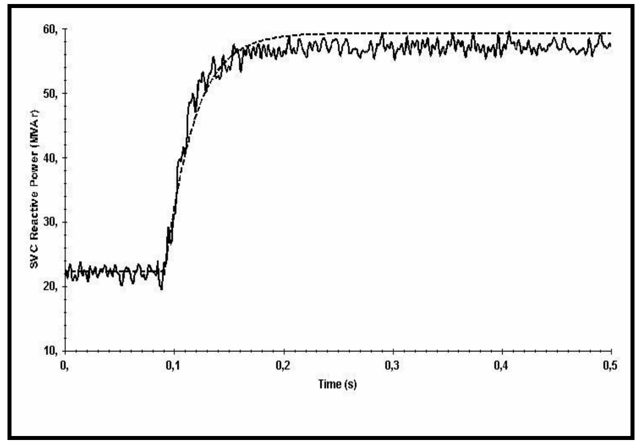

Fig. 7 – Real-Time and Off-Line Comparison
60 MVAr Reactor Switching

The most interesting aspect about the commissioning test was the good overall performance. The test was performed as scheduled and proved that the difficulties found in previous tests were really solved.

6. CONCLUSIONS

The strategies planned and followed showed to be very useful for the analysis, improving the project described. The main advantage was to detect and fix the problems before the on-site commissioning of the equipment.

The performance of the SVC control and the behavior of the power system for the several disturbances applied in the system were as expected. Additionally, these results were used to validate the Campos SVC off-line model.

Besides, the tests proved that the interface between the Campos SVC controller and the RTDS simulator is working very well, as required by the technical specification.

The difficulties found in the beginning of the studies, related to the SVC control performance, interfacing delays and power system modeling, were all satisfactorily solved, as confirmed during the commissioning of the SVC control at FURNAS simulator.

Campos SVC on-site commissioning and initial stages of operation are showing the same performed obtained during the real-time tests.

One final comment, the new RTDS processor board increased the maximum number of nodes to 54 and switches to 58, allowing an even better representation of the system.

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9. BIOGRAPHIES

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