FURNAS TCSC - An example of using different simulation tools for performance analysis

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Abstract - **This paper presents the conclusion of extensive work aimed to verify the satisfactory performance of new equipment, the TCSC (Thyristor Controlled Series Compensation). From factory tests to commisioning tests and from real time simulations to digital program simulations with a validated model, two years of studies were spent to assure that the system control of this new equipment provides enough damping for the inter-area oscillation mode of the interconnected North/Northeast and South/Southeast system. Such experience pointed out the importance of having good tools to represent the real behavior of any important equipment, especially when new knowledge is involved.**

Keywords: Real Time Simulation, Modelling, Electromechanical Stability, FACTS, TCSC, RTDS.

I. INTRODUCTION

The Brazilian North-South Interconnection has been determined to be a more economic and better technical solution to provide 600 MW average to the South/Southeast system from the available energy of the North/Northeast system and, when required, in the opposite direction. An AC series compensated line connecting Serra da Mesa substation, in the FURNAS system, to Imperatriz substation, in the Eletronorte system, was designed and built. At that time, the planning studies pointed out a low damped oscillation mode (around 0.2 Hz) between those areas and the TCSC technology was presented as a solution for this problem [1].

Some experiments with TCSC had already been made elsewhere in the world, but no one had yet been installed with this purpose. The installation of one TCSC (from 13 to 40 ohms vernier capacitive and 2.45 ohms inductive in switched mode) was defined for each extreme of the interconnection and a POD (Power Oscillating Damping) control was designed to damp that oscillation mode.

However, despite electromechanical stability programs showing adequate damping for the inter-area oscillation mode, it was considered necessary to check performance in practice and during any unexpected situations that appeared in the real system.

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II. FACTORY TESTS

In order to check the correct control action before the installation, SIEMENS (the manufacturer of FURNAS TCSC for Serra da Mesa substation) performed tests with the real control equipment, in October of 1998, utilizing its RTDS (Real Time Digital Simulator) [2]. An equivalent network and the whole TCSC, except for the control itself, were represented in the RTDS. The firings to the thyristors were produced by the real control that received all necessary measurements from the RTDS. The equivalent network was calculated to reproduce the same short circuit currents around the TCSC at Serra da Mesa and the oscillation mode frequency and damping obtained from the electrical studies. Several simulations were recorded while the POD control and the system protection were being checked.

On that occasion, the POD control presented good performance, but some limitations regarding a specific function, called AWC function, were detected. This function was designed to release the TCSC action when facing a large power variation caused by load or generation rejections. Fig.1 shows an example of such unfavorable behavior taken from the recorded factory tests. This behavior of the AWC function had not been observed in the digital studies where the electrical system was represented in much more detail. Therefore, the results from digital studies prevailed and the final analysis was postponed to the commissioning tests.

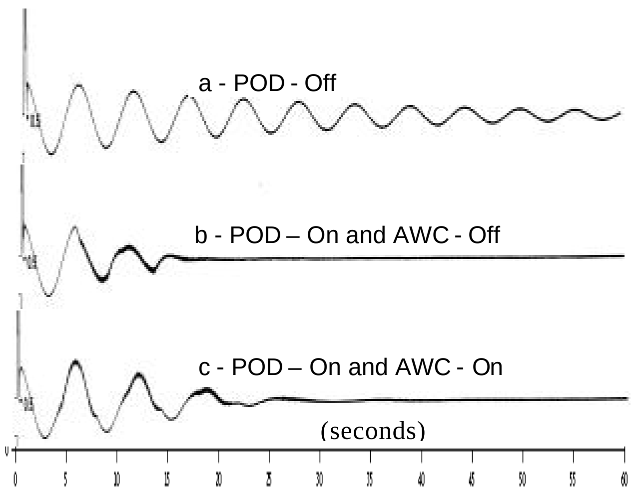

Figure 1 – Factory tests result for one case

III. COMMISSIONING TESTS

Just before starting commercial operation, commissioning tests were performed in February of 1999 with the interconnection line closed and both TCSC's in operation [3]. In order to confirm their individual performance, disturbances were applied to the system for several POD operating conditions in both TCSC's. A 300 MW generator trip at Tucuruí power plant was found to be sufficient to excite the inter-area oscillation mode with good observability, while causing no problems to systems operation.

The natural system damping observed for this oscillation mode was much lower than that calculated with the digital programs. For the worst system configuration permitted by ONS (System National Operator), negative damping was observed. Fig. 2 shows the measured active power in the interconnection, which opens after 70s due to a 300MW Tucurui generator trip. Nevertheless, both Serra da Mesa and Imperatriz TCSC have provided, independently, enough damping to reduce the provoked oscillation and avoid the interconnection opening. Fig. 3 shows the same as Fig. 2 but with Serra da Mesa POD activated.

However, a new fact appeared to add doubts to the POD performance analysis. A not provoked disturbance in São Paulo area caused the interconnection opening due to the inter-area oscillation mode instability when only Serra da Mesa TCSC was operating, as shown in Fig. 4. On that occasion, this disturbance, not clearly defined, was considered as a multiple contingency and, therefore, out of only one TCSC action range.

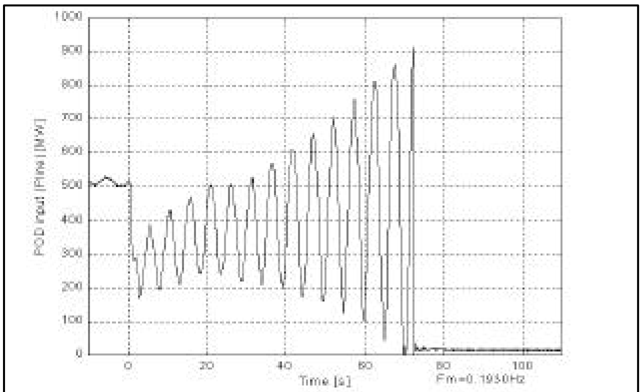

Figure 2 – both PODs deactivated

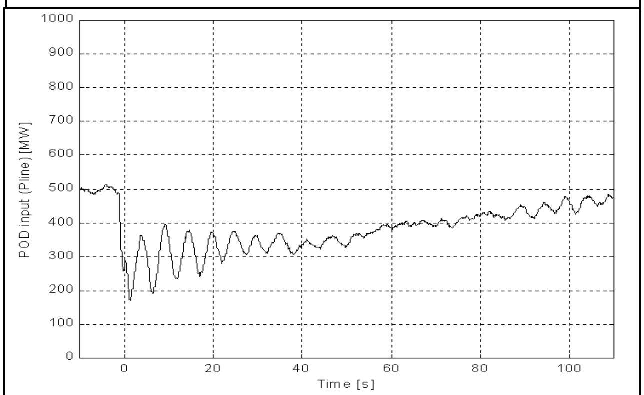

Figure 3 – only S.Mesa POD activated

IV. RTDS MODEL

A. RTDS Model Validation

Inside the contract scope for the equipment purchase, the manufacturer also provided an RTDS model of the TCSC control. In May of 1999, this model was installed in the FURNAS RTDS. Some simulations performed in the factory tests for the POD control using the equivalent network were rerun in this new environment and compared in order to validate the RTDS model. Fig. 5 shows the same results compared to Fig. 1.

Following this, new simulations were performed with the oscillation mode damping changed to reproduce a similar condition observed on site. The objective was to verify how the problem detected with the AWC function would respond in this condition.

Fig. 6 shows the active power and the TCSC impedance considering the POD control with the AWC function activated and inactivated. As can be seen, the appointed problem increased and a solution needed to be found as the North/South interconnection had already started commercial operation.

The RTDS model permitted a deeper analysis of the POD control and it was possible to conclude that the AWC

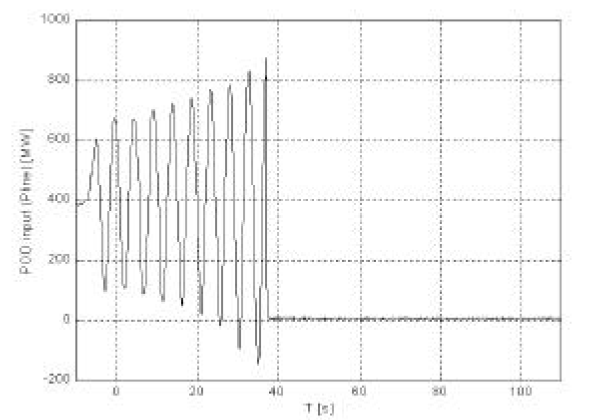

Figure 4 – São Paulo area disturbance with only S.Mesa POD activated

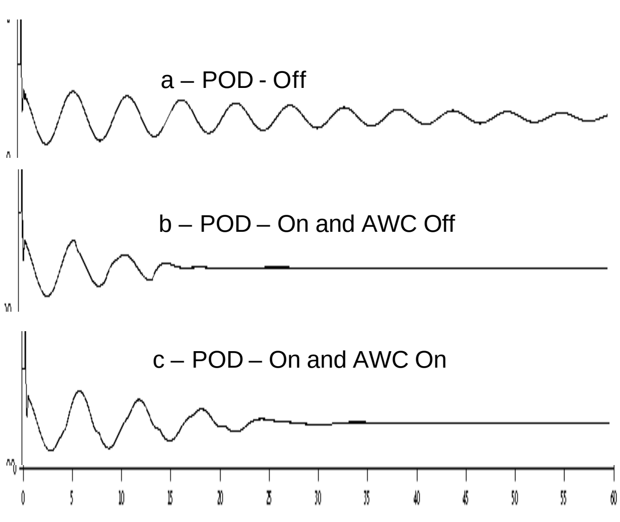

Figure 5 – RTDS model results

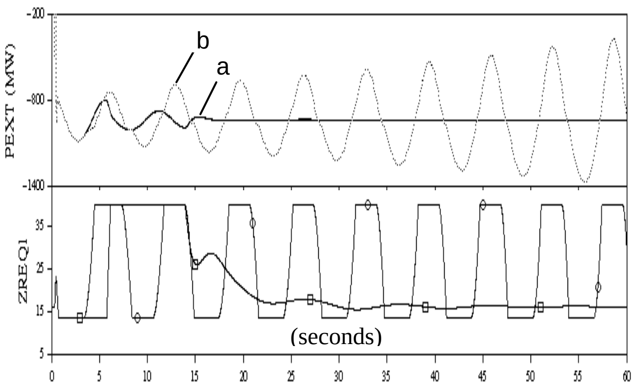

Figure 6 – RTDS results with less damped condition
a – POD On AWC Off b – POD On AWC On

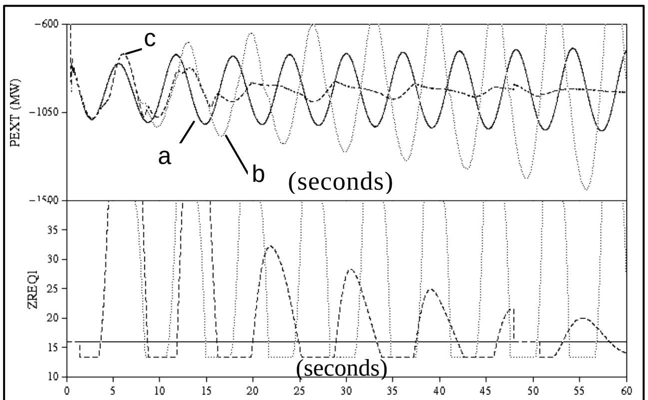

Figure 8 – RTDS results: a – POD Off
b – Permanent AWC c – Temporary AWC (5s)

function produces a phase shift in the transfer function depending on the mode frequency value.

The equivalent network, which was initially tuned to 0.17 Hz, was re-adjusted to 0.20 Hz. Fig. 7 shows this case for three conditions: without POD, with POD and AWC function activated and inactivated. Therefore, for frequencies higher than 0.2 Hz, the AWC function would not damage the POD control operation.

This last figure illustrates the cases with the POD control being activated by a trigger. This trigger only activates the POD control when the active power variation is higher than 25 MW/s and deactivates it 10 s after the power variation drops below 10 MW/s. This avoids unnecessary POD operation for small system disturbances.

B. AWC temporary actuation

FURNAS decided to analyze, in the RTDS model, an intermediate solution where the AWC function would be active only in the beginning of the disturbance. A time of 5 seconds was considered good enough to permit POD control action compatible for frequencies below and above 0.2 Hz. Fig. 8 shows the comparison with the result considering the temporary actuation of AWC function.

This conclusion, in July of 1999, raised the question of whether or not the situation that was being examined could be considered realistic. The manufacturer accepted these results, but suggested a prior evaluation in the stability program to verify if such results could be present with a more complete system representation.

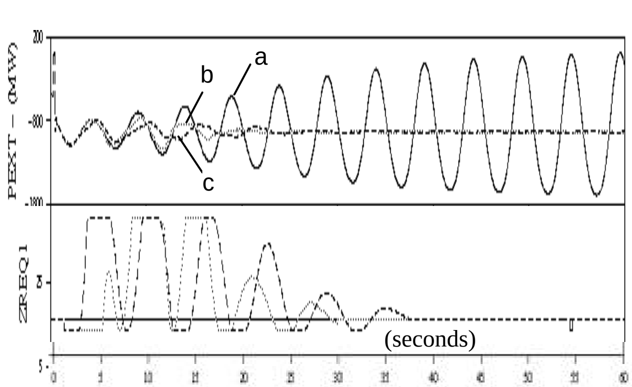

Figure 7 – RTDS results with frequency variation
a – POD Off b – POD On AWC Off c – POD On AWC

V. POD CONTROL MONITORING

Before the TCSC started to be commissioned, FURNAS had decided to implement a permanent monitoring of the POD actuation. This equipment would permit FURNAS not only to analyze the POD control performance, but also to provide the measurement of the oscillation mode frequencies. After many difficulties, such equipment was installed in March 2000. It saves one record for each POD activation.

However, the electrical system does not work in ideal steady state condition, but varies constantly due to the load changes. Since the POD acts always when the active power variation is higher than 25 MW/s, in practice, the POD monitor is activated very often. Therefore, it had to have a very large buffer to keep results in memory for many days. With a limited memory, always that important disturbances involving the North-South interconnection occurred and the record was decided to be extracted, the desired information had already been overwritten.

In order to avoid such inconvenience, a program is being implemented, using two microcomputers. One to extract all POD records and select which information are important. The other, located in FURNAS Headquarter, will receive the selected information to analyzed by

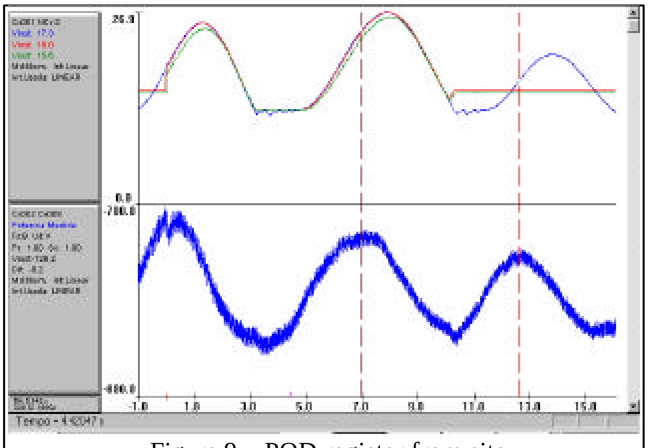

Figure 9 – POD register from site

Electrical Studies Department. Meanwhile, at least the frequency can be measured from some saved samples before being overwritten. Fig. 9 is an example where the frequency presented the value of 0.177 Hz. This result had confirmed the existence of inter-area oscillation frequencies below 0.2 Hz, where the AWC function does not work properly.

VI. ELETROMECHANICAL STABILITY PROGRAM

A. TCSC Model in ANATEM program

The manufacturer designed the POD control using the PSS/E program and study data provided by FURNAS. However, operation planning studies are performed using ANATEM, an electromechanical stability program developed by CEPEL (Brazilian Electrical Research Center), where the complete Brazilian system is represented in detail.

Therefore, the strategy decided by FURNAS was to represent the POD control of Serra da Mesa TCSC in this program. For this, the RTDS model was used as a reference for validation, since this model had already been validated by the real control.

Starting from the equivalent network used for the factory tests, each important part of both electrical system and TCSC control was validated. The same results shown in Figs 1 and 5 were obtained with ANATEM. After that, using a less damped network, the same comparison was performed. Fig. 10 shows RTDS and ANATEM results, where it can be observed that both are quite consistent. The unadequate performance of the AWC function in the POD control for a less damped network was reproduced. The oscillation mode is damped in both tools when the temporary activation of AWC function is activated, as shown in Fig. 10c.

B. Eletromechanical Stability Study

Considering the ANATEM model as validated, the definitive study could now be made to decide whether or not to change the FURNAS TCSC POD control. The detailed system representation in ANATEM was considered and the load damping, which is represented in the turbine model, was changed in the North-Northeast area in order to reproduce the negative damping measured on site during the TCSC commissioning. Fig. 11 shows both the original and the adjusted damping for the natural system oscillation mode without POD control action associated with the site measurement shown in Fig. 2. An oscillation mode frequency lower than 0.2 Hz was also obtained through the opening of a line in the Southeast system and its influence was also analyzed.

Fig. 12 shows the TCSC action considering the POD control with and without the AWC function (curves b and c, respectively) compared with no POD control action (curve a). As can be observed in these conditions the AWC function interferes with the POD control performance.

These results, obtained in a digital program with a detailed network representation, confirm what has been

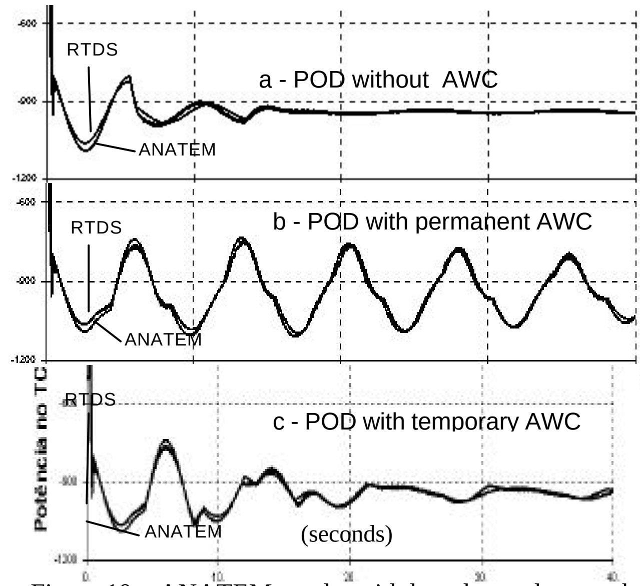

Figure 10 – ANATEM results with less damped network

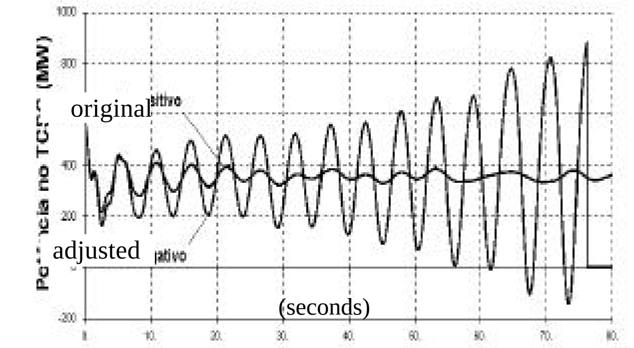

Figure 11 – 300 MW Tucurui generator trip with positive and negative natural damping

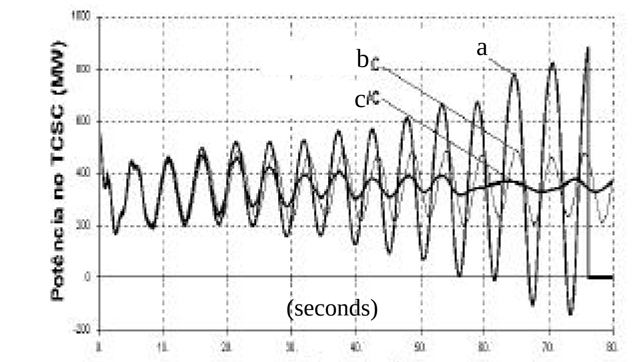

Figure 12 – 300 MW Tucurui generator trip
a – POD Off b – POD On AWC On c – POD On AWC Off

concluded utilizing an equivalent network in the RTDS. The same results are observed in the simulation of the São Paulo area disturbance, shown in Fig. 13, where the AWC function has almost nullified the damping provided by the POD control (curves 13b-c). This last case leaves us with the conclusion that if the AWC function had been deactivated during the commissioning, probably the FURNAS TCSC would have damped the disturbance shown in Fig. 4.

The ANATEM results also confirmed the RTDS results regarding the AWC function sensibility with respect to the frequency. Fig. 14 shows the same case as Fig.12b, where the AWC function is activated, considering included the line before opening. As the oscillation mode frequency has changed from 0.186 Hz to 0.192 Hz, the AWC function behavior has also changed. This confirms the POD control performance in the commissioning case shown in Fig. 13, since the measured frequency in that case was 0.193 Hz.

The same was performed with the simulation of the São Paulo area disturbance, shown in Fig. 15, where the frequency has changed from 0.180 Hz to 0.190 Hz. This frequency change was not enough to drop out of the range where the AWC function has its negative interference, but has shown its influence in delaying the line opening protection action.

C. AWC temporary actuation in ANATEM

The solution proposed in the RTDS analysis was verified in the ANATEM simulations. The results have shown that it is an effective solution, since it removes the main dc component, that occurs in the beginning of the active power variation. This allows the TCSC to vary the impedance, in its actuation range, when the almost pure oscillation mode is present.

Therefore, with this modification, the necessary damping is produced. Fig. 16 presents the 300 MW Tucurui generator trip for the lowest frequency case. The undamped oscillation mode in curve “b”, where the AWC function is permanent, became satisfactorily damped and disappears after 60 s when the AWC function is deactivated after 5 s, in curve “c”.

This same effect can be better observed in the São Paulo area disturbance simulation shown in Fig. 17.

D. TSR mode activation in ANATEM

The other decision about Serra da Mesa TCSC control was made with respect to the TSR (Thyristor Switched Reactor) mode activation. This operation mode is available in the TCSC control, but it was not initially considered necessary, since the commissioning tests had indicated enough damping coming from TCSC control, except for the disturbance in the São Paulo area, not clear in that time. Therefore, once more, the digital studies should provide the elements to analyze this option.

The same cases presented in Figs. 16 and 17 were simulated considering the TSR mode activated and not activated. For such analysis, the AWC function was considered with its temporary actuation. Fig. 18 and 19 present the simulation in ANATEM showing the influence of the TSR mode, respectively, for the 300MW Tucurui

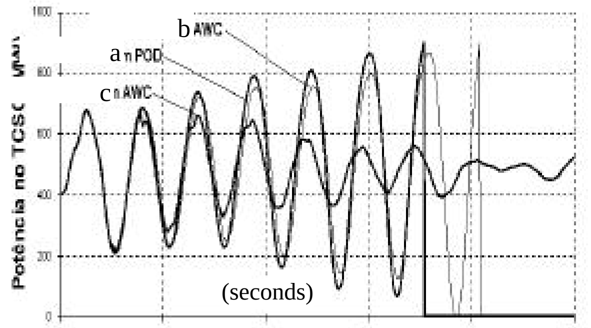

Figure 13 – Disturbance in São Paulo area
a – POD Off b – POD On AWC On c – POD On AWC Off

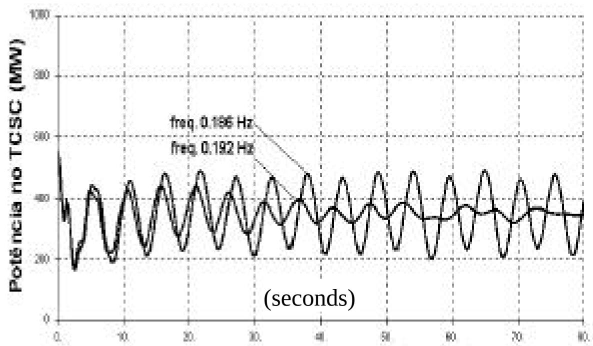

Figure 14 – Influence of the frequency variation in 300MW Tucurui generator trip

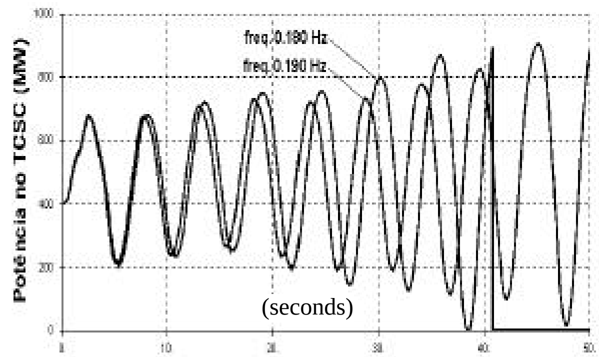

Figure 15 – Influence of the frequency variation in S.Paulo ocurrence simulation

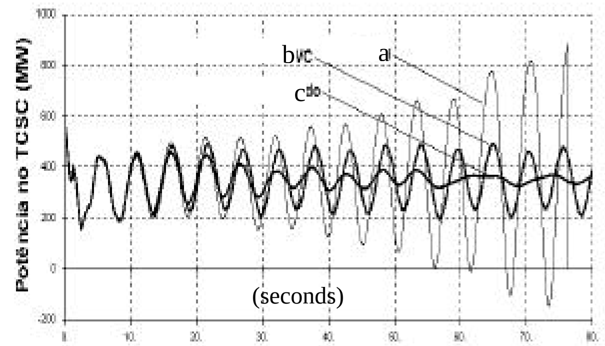

Figure 16– 300MW Tucurui generator trip
a – POD Off b – POD On AWC On c – POD On AWC t=5s

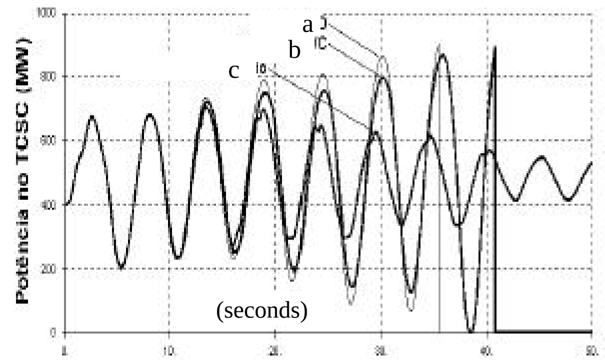

Figure 17– S. Paulo area disturbance simulation
a – POD Off b – POD On AWC On c – POD On AWC t=5s

generator trip and for the São Paulo area disturbance.

As can be observed, mainly in Fig. 19, the TSR mode brings some benefits for this undamped condition. This condition was not initially considered in the pre-operational studies, but the commissioning has proved that it is presented for certain electrical system configurations.

Simulations analyzing the TSR mode in the positive damping condition have presented no problem and it was decided to activate this mode.

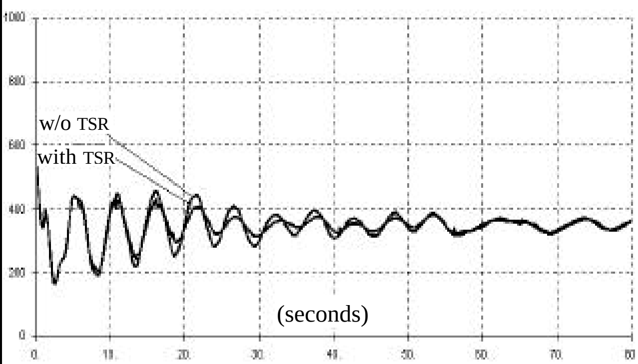

Figure 18– 300MW Tucurui generator trip

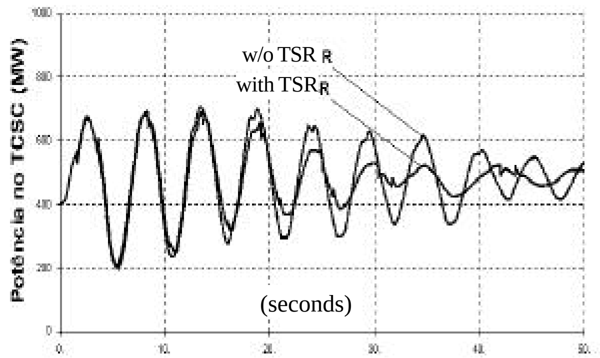

Figure 19– S. Paulo area disturbance simulation

VII. CONCLUSIONS

This paper has described the utilization of different tools in order to examine control changes in this relatively new equipment. Each one of the tools offers certain advantages and from the real TCSC control using the equivalent network in RTDS to the digital program TCSC control model, using a complete network representation, the validations warranted the results reliability.

The availability of a good reference, as supplied by the TCSC control model in RTDS checked with the real control, was decisive to validate the digital model for the stability program where the complete system could be analyzed. This has permitted to take decision, with confidence, to perform the following modifications in real control:

- to keep activated the AWC function only for the first 5 seconds
- to activate the TSR mode operation

Such modifications have been already implemented on site.

VIII. REFERENCES

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