VIII SEPOPE
19 a 23 de maio de 2002
May, 19th to 23rd – 2002
Brasília (DF) – Brasil

VIII SIMPÓSIO DE ESPECIALISTAS EM PLANEJAMENTO DA OPERAÇÃO E EXPANSÃO ELÉTRICA

VIII SYMPOSIUM OF SPECIALISTS IN ELECTRIC OPERATIONAL AND EXPANSION PLANNING

IP–093

TCSC at Serra da Mesa Substation
[Brazilian North-South Interconnection]
Control System Improvement and Behavior Assessment

Guilherme Sarcinelli Luz (*) Cesar Ribeiro Zani Nilo José P. de Macedo
Luis Roberto C. de Moura Salvatore Mantuano Filho Saulo Salgado Wanderley
FURNAS Centrais Elétricas

TCSC at Serra da Mesa Substation

[Brazilian North-South Interconnection]

Control System Improvement and Behavior Assessment

Guilherme Sarcinelli Luz (*) Cesar Ribeiro Zani Nilo José P. de Macedo
Luis Roberto C. de Moura Salvatore Mantuano Filho Saulo Salgado Wanderley

FURNAS Centrais Elétricas

ABSTRACT

Two Thyristor Controlled Series Capacitors [TCSC's], one at Serra da Mesa Substation in the Furnas' System and the other at Imperatriz Substation in the Eletronorte's System, both part of North-South Interconnection, make it possible to damp out the oscillation mode of the two interconnected systems, reducing the risk of instability. This paper presents Serra da Mesa TCSC control testing history, and a description of the monitoring system developed by Furnas operation engineers to follow-up the control performance at head office, in Rio de Janeiro.

KEYWORDS: Thyristor Controlled Series Capacitors, FACTS, Performance monitoring, Electrical System Operation.

1.0 - INTRODUCTION

The initial operation of new equipment or systems, especially when including new technologies like FACTS elements, requires detailed follow-up from the operation engineers. It is necessary to clearly identify any control performance problems, in order not to characterize them as problems coming from the Electrical System

The TCSC's mentioned above are the first ones in the world used to damp out power oscillations of two interconnected electrical systems. Because of this, Furnas included the requirement for a real time simulation model in the TCSC purchase specification, to represent the detailed behavior of the new equipment. This made analysis of the equipment behavior possible, as well as validation of its modeling for ANATEM, the stability program used for FURNAS and a Brazilian ISO, in operational planning studies. After commissioning the TCSC's, an Event Recorder was installed to monitor the equipment performance during real electrical system occurrences, not only in the quantitative aspect, but also qualitatively.

Detailed commissioning results[1], as well as results obtained from the digital model analysis[2,3,4] were presented in other technical meetings. This paper presents a summary of the analysis, and the monitoring system implemented, as well as some remarks written after one year of observation of the electrical system behavior.

2.0 – TESTS APPLIED TO THE TCSC CONTROL

Initially, factory tests were applied to the real TCSC control, connected to a model of the reduced equivalent system in the RTDS [Real Time Digital Simulator]. This testing produced only qualitative evaluation of the control performance, showing that generally its behavior was satisfactory, with an exception for a function called AWC [Anti-Windup Control], which in some circumstances degraded the desired damping. The AWC function was designed to release the TCSC action when facing a large power variation caused by load or generation rejections.

During commissioning tests in which some disturbances were produced, specially the loss of a 300MW generator at Tucuruí Power Plant, the TCSC control of Serra da Mesa performed fairly well, being capable of damping out the inter-area mode of oscillation, in spite of the fact that the interconnected

(*)Rua Real Grandeza, 219- Bl. E sala 110 - CEP 22283-900 – Rio de Janeiro-RJ
Telefone : (021) 2528-4116 - Fax (021) 2528-5528 – Email: guiluz@furnas.com.br

system was more unstable than foreseen in the initial digital studies. Figure 1 shows the active power in the Brazilian North-South interconnection with only the Power Oscillation Damper (POD) of Serra da Mesa TCSC control activated. Nevertheless, for an occurrence in the São Paulo area (see Figures 2 and 3), during which there was generation and subsequent load loss, the TCSC control actuation did not produce the desired damping, resulting in the interconnection switching off, through loss of synchronism protection.

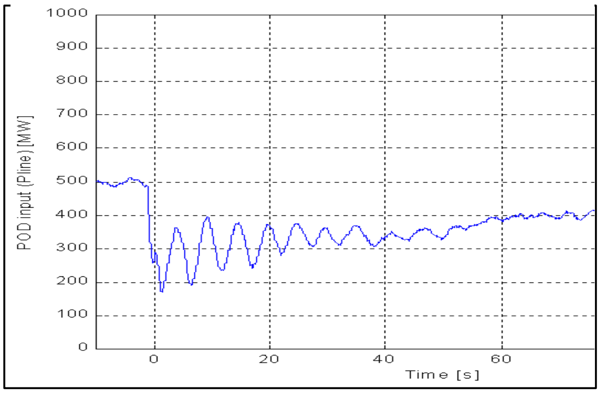


FIGURE 1

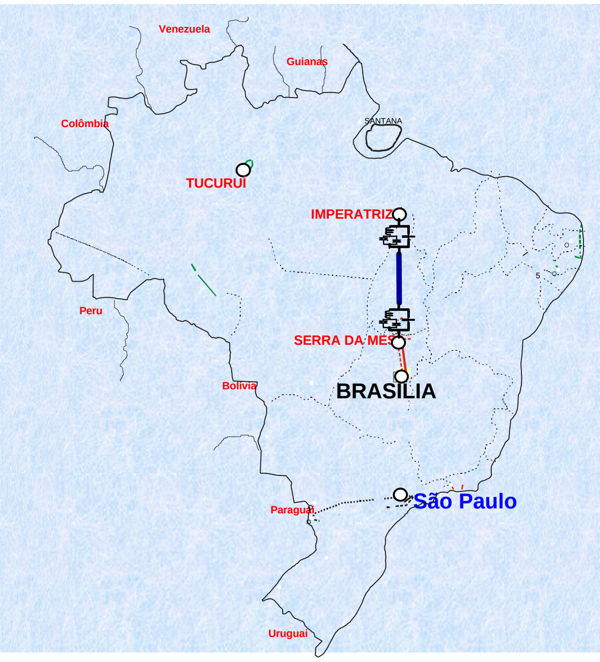


FIGURE 2

The real time simulation model used with the Furnas' RTDS simulator, proved to be invaluable for the investigation of this phenomenon. The factory test results were used to validate the model, using the same equivalent system. Afterwards, a further detailed analysis of its performance was begun considering the poorest damping condition of the inter-area mode of oscillation, according to observations made at site. At that time, it was concluded that the AWC function degraded the control action under conditions of low

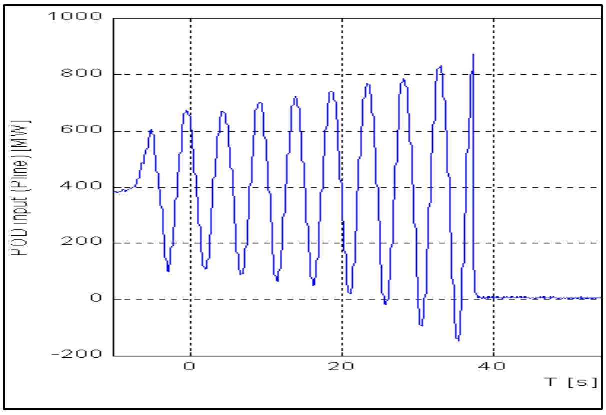


FIGURE 3

oscillation frequency and poor damping, if it were kept permanently active. However, if activated for a period of only 5 seconds, its behavior was satisfactory, without jeopardizing other situations.

The availability of the model was also useful as a reference for validating the TCSC model in the electromechanical stability program [ANATEM], initially using the factory tests results [2]. Later, ANATEM was used to reproduce the results that verified the modification to be implemented in the AWC function, by using the reduced test, equivalent electrical system. As the Brazilian Electrical System was already comprehensively represented in the Furnas' ANATEM package, it was possible to make a more accurate analysis on the TCSC control performance [3]. In this way, it was possible to reproduce, the commissioning test results and that of the real occurrence already mentioned, properly depicting the real behavior of the Electrical System and of the TCSC at Serra da Mesa. Figure 4 presents the ANATEM results related to an occurrence in the São Paulo area, for three modes of the TCSC control: 1 - POD off, 2 - both POD and AWC on, and 3 - POD on, with the AWC function off.

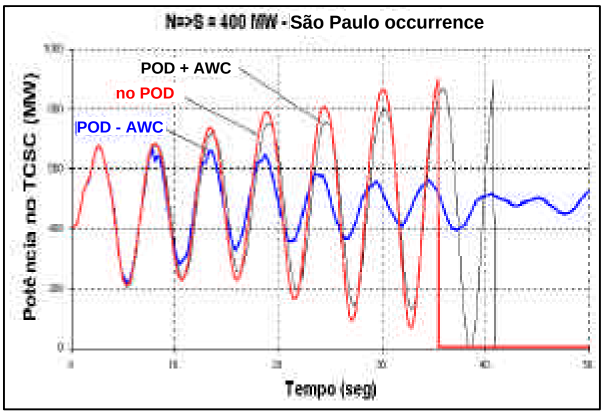


FIGURE 4

Similar behavior can be observed in Figure 5, if both the first two modes are compared to the third, where the AWC function is on for only in the first 5 seconds of POD operation.

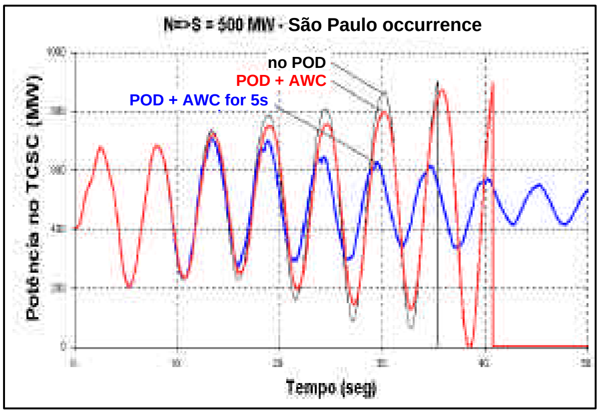


FIGURE 5

This analysis confirmed the ability of the TCSC control to damp out inter-area oscillations. It also confirmed the recommendation to time delay the AWC function and to activate the TSR [Thyristor switched reactor] mode of operation. In pre-operational studies, the TSR mode did not present advantages. Although it was included in the Furnas' Specification, it was not initially activated. However, its activation enlarges control possibilities, and has shown itself to be especially useful during the largest oscillations experienced by the electrical System. Figure 6 presents the results from the program ANATEM for an event in the São Paulo area, considering the control with and without the TSR mode activated.

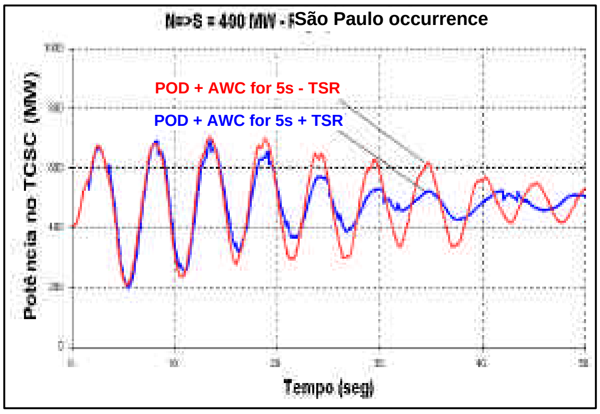


FIGURE 6

The proposed modifications were finally implemented in November 2000. Starting in February 1999, this analysis, and interaction between the Utility and the Manufacturer, allowed the modifications to be made on account of several reliability results. The results showed themselves very compatible, despite coming from different sources, as can be seen at[2,3,4], thus confirming the decision safe.

3.0 – DATA ACQUISITION SYSTEM

In March 2000, a new disturbance recorder was installed in the TCSC control room, but with a different objective from the customary one. This new recorder is used to monitor the TCSC performance, creating a new recording at each control [POD] actuation, in which the inter-area [North-Northeast and South-Southeast] oscillations are damped out. The most important variables are the power going through the interconnection, the ordered and measured impedances, as well as the activation signals for the control and the TSR mode. Voltage and current are also measured. Another fundamental difference of the recorder is the long acquisition time required, since the frequency of the inter-area mode of oscillation is around 0.2Hz, i.e. 5seconds per cycle.

After placing the new recorder in operation, a very high daily operation frequency was observed, exceeding an average of 500 recordings, sometimes exceeding 1000. To make analysis of the recorded events feasible, it was considered necessary to have them available in the Furnas' Head office, facilitating access and analysis of the data by the in-charge engineers. A type of data transmission system, commonly used in Furnas for fault analysis, was then employed to receive the data from the POD actuation. The communication system was implemented using a PC in Serra da Mesa for acquiring and sending data to another PC in the Furnas' Head office, via MODEM.

As the data accumulated daily includes events not really related to faults, it was decided to process it at site, keeping only the most important information, but always extracting the following:

- Day
- Time
- Duration of POD activity
- Estimated frequency
- Average, minimum and maximum active power
- Difference between minimum and maximum power
- Maximum and minimum ordered impedances
- Maximum and minimum measured impedances
- Maximum and minimum current

Figure 7 shows the general scheme of the implemented system. Since January 2001, the main information of each reading, and the selected recorded events are sent daily to the Furnas' Head office. The criterion chosen to select the recorded events, is the amplitude of the oscillation (DP>Dpmax). Initially, the limit was set at 50MW. During the first month, it was observed that the limit could be increased to 75MW, and afterwards to 100MW. Increasing the threshold considerably reduced the number of events to be sent, and also reduced the risk to the data transmission.

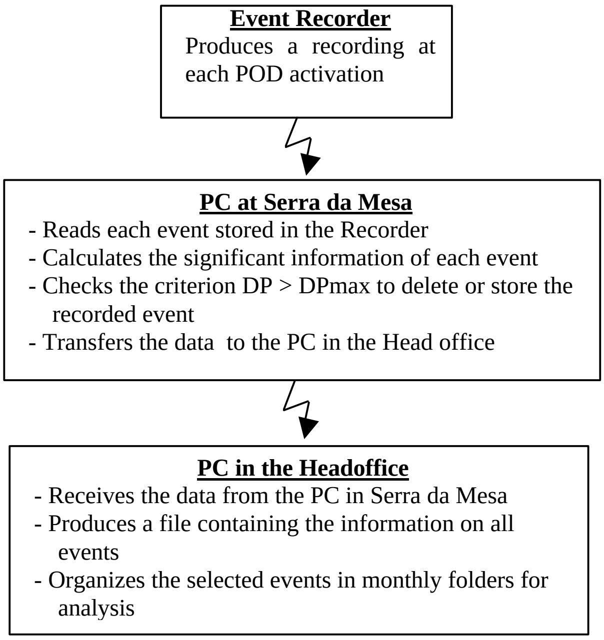
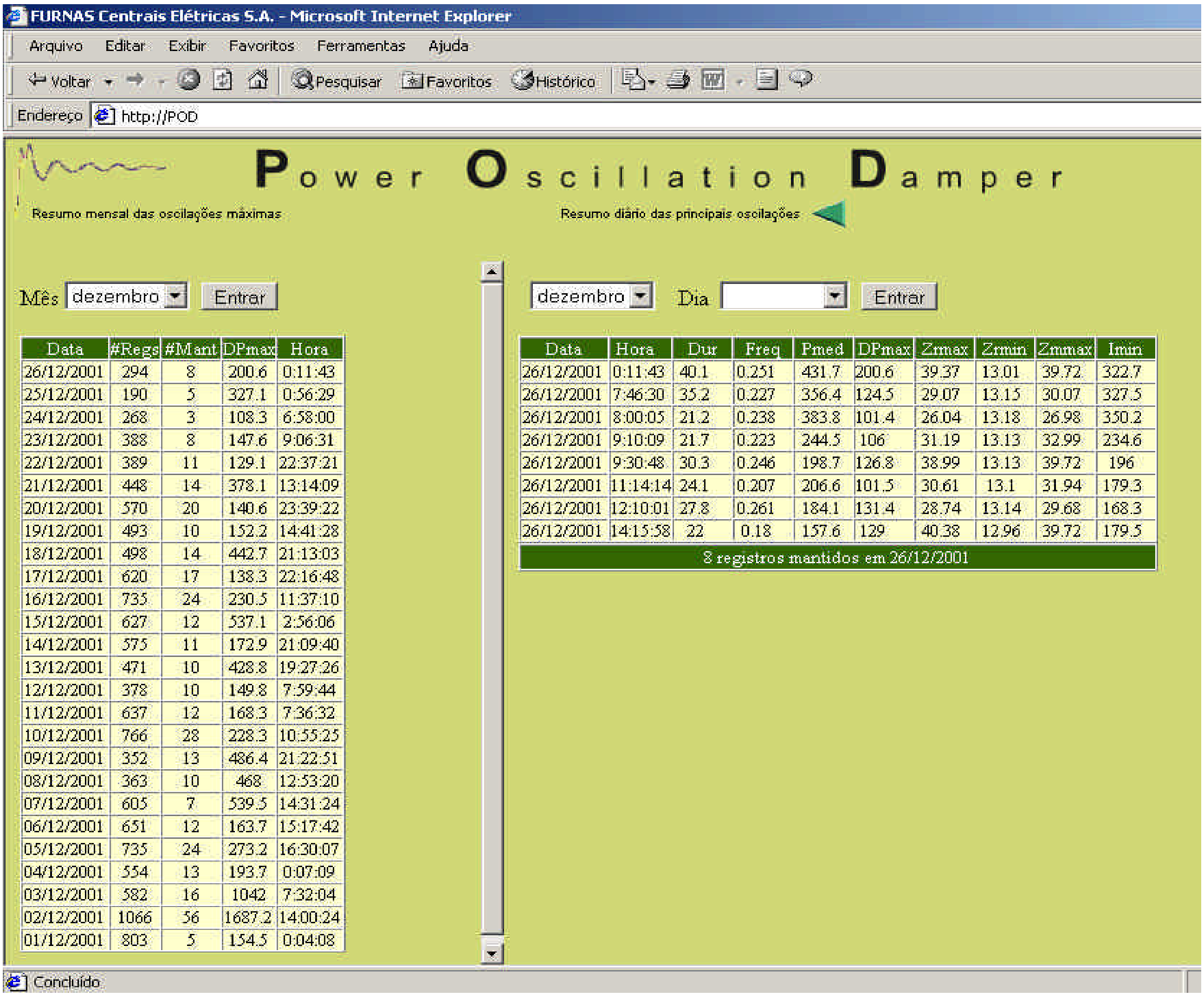


FIGURE 7

4.0 – EVENTS ANALYSIS PROCEDURE

As the volume of data was still inconveniently large, a new process was created to automatically obtain a summary and to identify significant items. Consequently, a file with all events of the chosen day and month is transformed into an ACCESS DATABASE. This can be seen in the Furnas' INTRANET page, where tables including essential information are produced. Figure 8 shows one example page, where the first set of columns contains the monthly summary from the set of maximum oscillations, December being the chosen example. The set of columns at the right contains a daily summary of the most significant oscillations, the selected events being on the 26th, the day this article was be written. Of 294 POD activations, 8 were kept till the moment the page was presented. The maximum active power oscillation was 200.6MW, and occurred at 00:11:43h.

Among the system oscillations occurring up to the 26th December, till the date under analysis, the



Data	#Regs	#Mant	DPmax	Hora
26/12/2001	294	8	200.6	0:11:43
25/12/2001	190	5	327.1	0:56:29
24/12/2001	268	3	108.3	6:58:00
23/12/2001	388	8	147.6	9:06:31
22/12/2001	389	11	129.1	22:37:21
21/12/2001	448	14	378.1	13:14:09
20/12/2001	570	20	140.6	23:39:22
19/12/2001	493	10	152.2	14:41:28
18/12/2001	498	14	442.7	21:13:03
17/12/2001	620	17	138.3	22:16:48
16/12/2001	735	24	230.5	11:37:10
15/12/2001	627	12	537.1	2:56:06
14/12/2001	575	11	172.9	21:09:40
13/12/2001	471	10	428.8	19:27:26
12/12/2001	378	10	149.8	7:59:44
11/12/2001	637	12	168.3	7:36:32
10/12/2001	766	28	228.3	10:55:25
09/12/2001	352	13	486.4	21:22:51
08/12/2001	363	10	468	12:53:20
07/12/2001	605	7	539.5	14:31:24
06/12/2001	651	12	163.7	15:17:42
05/12/2001	735	24	273.2	16:30:07
04/12/2001	554	13	193.7	0:07:09
03/12/2001	582	16	1042	7:32:04
02/12/2001	1066	56	1687.2	14:00:24
01/12/2001	803	5	154.5	0:04:08

Data	Hora	Dur	Freq	Pmed	DPmax	Zrmax	Zrmin	Zmmax	Imin
26/12/2001	0:11:43	40.1	0.251	431.7	200.6	39.37	13.01	39.72	322.7
26/12/2001	7:46:30	35.2	0.227	356.4	124.5	29.07	13.15	30.07	327.5
26/12/2001	8:00:05	21.2	0.238	383.8	101.4	26.04	13.18	26.98	350.2
26/12/2001	9:10:09	21.7	0.223	244.5	106	31.19	13.13	32.99	234.6
26/12/2001	9:30:48	30.3	0.246	198.7	126.8	38.99	13.13	39.72	196
26/12/2001	11:14:14	24.1	0.207	206.6	101.5	30.61	13.1	31.94	179.3
26/12/2001	12:10:01	27.8	0.261	184.1	131.4	28.74	13.14	29.68	168.3
26/12/2001	14:15:58	22	0.18	157.6	129	40.38	12.96	39.72	179.5
8 registros mantidos em 26/12/2001									

FIGURE 8

maximum ones varied between 108.3MW on the December 24th, and 1687.2MW on the December 2nd. The active power and the TCSC impedance for each of these are presented in Figures 9 and 10 respectively, with the same scale, to facilitate comparisons. The sudden power variation on December 2nd was due to loss of the North-Northeast interconnection, after the loss of 310MW in Xingó, a Northeast System Power Plant. This caused the inter-area mode of oscillation frequency to increase from 0.23Hz to 0.44Hz.

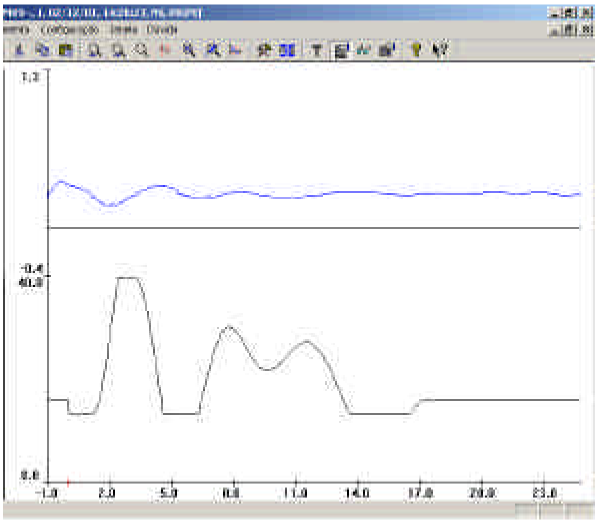


FIGURE 9

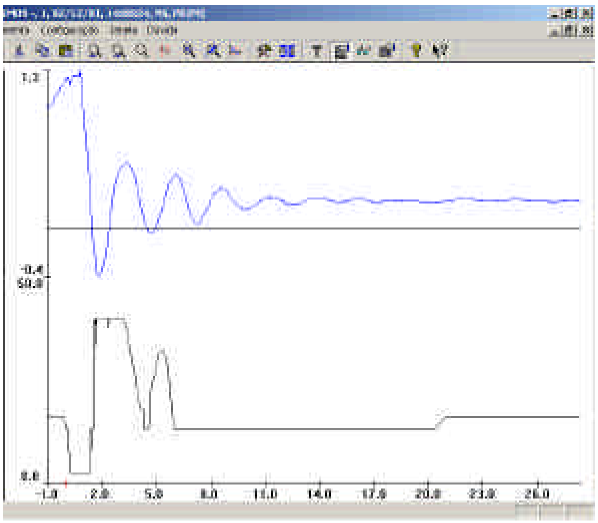


FIGURE 10

Figure 11 shows an event of December 18th at 21:13:03h, with 442.7MW, where the TSR mode was activated three times. Since the TSR mode produces a fast active power variation, as can be observed in the digital simulation of Figure 6, it is possible to conclude that it also operated at Imperatriz. The analyses of the selected events are performed with the program SINAPE, a tool developed by CEPEL [Electric Research Center, in Brazil].

In spite of having experienced some transfer problems during the year, less than 1% of all events

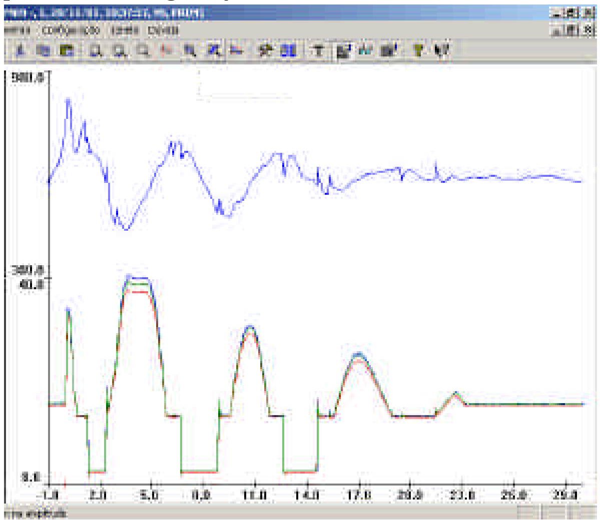


FIGURE 11

were lost. Since an average of only 2% are kept for analysis, it can be stated that none of the significant events were really lost. Data loss problems, whose description and analysis are not included this article, are under analysis, and will probably be eliminated during the next year.

5.0 – RESULTS OF THE ANALYSIS

Events analyzed during 2001 allows one to safely state:

- The POD has been acting more than 500 times a day, damping inter-area oscillations due to small system disturbances, through small TCSC impedance variations.
- In the face of major disturbances, occurring on average once a day, the control acts to vary the TCSC impedance, over the whole variation range, i.e. 13 to 40 ohm capacitive. The TCSC control also entered the TSR mode several times, where 2.5 ohm inductive impedance is set, in a discontinuous way.
- There was no loss of the North-South interconnection due to the inter-area mode of oscillation.

Analysis of the recorded events also made it feasible to identify a Serra da Mesa TCSC control limitation. Thyristor firing is inhibited when the line current is below 100A, due to low firing voltage. This makes its performance poor for power oscillations around zero due to loss of control while the current is below 100A. No situation can be identified in which the control causes any instability problem. This could be due to either inherent system stability, or efficient actuation of the TCSC control at Imperatriz. If a similar monitoring system existed in Imperatriz, it would be possible to safely reach a conclusion about this subject.

Also, the monitoring system showed that the time delay imposed on the AWC function was incorrectly restarting every time the thyristor firing pulses were inhibited, due to low line current. This caused the AWC function to be active during the POD action, thus nullifying the benefits from its own time delay. The recorded events were sent to the manufacturer, who implemented the necessary corrections.

6.0 - CONCLUSIONS

This article presented a synthesis of extensive work made to check the operation of equipment whose importance has two distinct aspects:

1. Use of a relatively new technology [TCSC] to damp inter-area power oscillations, the only one in the world till now for this purpose,
2. Interconnection of two big Brazilian electrical subsystems, namely North-Northeast and South-southeast, bringing about a significant strategic advance toward meeting the Brazilian national demand for energy

The analysis performed, either with the real plant, or with digital models, allowed changes to be made in the Serra da Mesa TCSC control, which in turn made the control performance more adequate to the system needs.

The monitoring system has allowed not only the control system performance follow-up, but also the effectiveness of the implemented changes.

7.0 ACKNOWLEDGEMENT

I wish to acknowledge Dr. James Giesbrecht for his help in preparing the paper.

8.0 - BIBLIOGRAPHY

[01]- G.Sarcinelli, C.Gama, et all, “Avaliação do Desempenho dos Amortecedores de Oscilação de Potência das Compensações Série Controladas a Tiristores da Interligação Norte/Sul” - VII SEPOPE, 21 a 26 de Maio de 2000, Curitiba, Brasil

[02]- G.Sarcinelli, N.J.P.Macedo, V.R.Oliveira - “Validação do Modelo do Controle do TCSC de Serra da Mesa no Programa ANATEM utilizando-se o Modelo do RTDS” - IX ERLAC, 27 a 31 de Maio de 2001, Foz do Iguaçu, Brasil

[03]- G.Sarcinelli, N.J.P.Macedo, V.R.Oliveira - “Análise do Desempenho do TCSC de Serra da Mesa no Programa ANATEM a partir de Resultados de Comissionamento” - XVI SNPTEE, 21 a 26 de Outubro de 2001, Campinas,SP, Brasil

[04]- G.Sarcinelli, N.J.P.Macedo, V.R.Oliveira - “FURNAS TCSC - An example of using different simulation tools for performance analysis” - Proceedings of the 2001 International Power System Transients, June 24-28, Rio de Janeiro, Brazil