TRANSIENT OVERVOLTAGE AND OVERCURRENT STUDIES USING EMTP TO EVALUATE THE FEASIBILITY OF SIMULTANEOUS ENERGIZATION OF TSC AND FILTERS OF FURNAS SVC LOCATED IN BANDEIRANTES SUBSTATION - A COMPARISON AND VALIDATION OF DIGITAL TRANSIENT SIMULATIONS BY MEANS OF SITE MEASUREMENTS

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ABSTRACT

Furnas Centrais Elétricas, a public owned company, is responsible for supplying, besides other regions, the central-western region of Brasil, where Brasília - Brasil's Federal Capital - is sited. Furnas' Bandeirantes substation is located in central-western region main transmission network, belonging to the 345 kv Brasília's supply system.

Furnas installed in Bandeirantes substation two SVC, planned to supply reactive power during and after transmission equipments outages or load impacts (load rejection), in order to keep voltage under control, avoiding or minimizing sustained under or overvoltages.

Due to Brasília's supply system VAr requirements, caused by a high growing of the local loads, we've been facing several voltage control problems, even under normal system operation conditions, during the last years.

Trying to mitigate these problems, and since the Bandeirantes' SVC could not operate up till now as they were planned to, Furnas evaluated the feasibility of using the Bandeirantes' SVC capacitor banks (including harmonic filters) in an emergencial and very special configuration, in order to aid the central-western electrical power system to supply the local loads within an acceptable level of quality and reliability.

In this sense, Furnas performed an electromagnetic transient study, using EMTP, to evaluate such possibility, determining the equipments energization requirements and operational procedures.

The studies performed demonstrated it was possible to use such SVC special configuration without risks of equipments damage.

We knew based upon a theoretical previous analysis that the proposed energization procedure would result in high transient overcurrent with low damping. To confirm so and to test the SVC overcurrent protection performance, we also made site measurements related to the energization procedures defined according digital simulation results. We could see the results obtained from site measurements were very similar to those obtained from digital EMTP simulations.

KEY-WORDS

Transformer - Capacitor bank - Energization - Electromagnetic Transients.

1.0 - INTRODUCTION

Furnas Centrais Elétricas, a public owned company, is responsible for supplying the central-western region of Brasil besides all the south-eastern region too. Brasília - Brasil's Federal Capital - is sited in the central-western region while the south-eastern is the most developed region of the country. So, they are the most important regions of the country, since in these areas are located the main industrial, financial, business and political centres.

Furnas' Bandeirantes substation, located in central-western region main transmission network, belongs to the 345 kv Brasília's supply system. This 345 kv system also supplies Goiás and Tocantins States, which have an important role with their agriculture, pecuary and mineral extraction enterprises.

In Bandeirantes substation, Furnas installed two SVC (+100/-50 MVAr range each one), planned to supply reactive power during and after transmission equipments outages or load disturbances (load rejection) in order to keep voltage under control, avoiding sustained under or overvoltages.

Unfortunately, due to several problems occurred during SVC comissioning (equipment malfunction, control system problems, valve failures, etc), these SVC are still out of operation as they were planned to.

On the other hand, due to VAr requirements in Brasília's supply system and due to a high growing of the local loads, we've been facing, since 1992, several voltage control problems, even under normal system operation condition.

These problems related to voltage control and system VAr requirements led sometimes the system operation to critical conditions. For several times in 1994, during heavy load period and under normal system operation condition, it was even necessary to use a local load shedding scheme in central-western region electrical system.

Trying to mitigate these problems, FURNAS performed a transient study to evaluate the feasibility of using the Bandeirantes' SVC in an emergencial configuration in order to aid the Brasília area system to supply the loads within an acceptable level of quality and reliability.

This energencial configuration of both Bandeirantes' SVC means that they should be able to operate with their filters plus TSC as a common fixed shunt capacitor bank (each one supplying approximately 100 MVAr of fixed capacitive reactive power).

It is important to emphasize that the manufacturer's warranty on the equipment should not be affected in any way. So it was necessary to obtain the manufacturer's agreement regarding the studies performed, their results and the criteria adopted by FURNAS.

2.0 - SVC ORIGINAL ENERGIZATION LAY-OUT AND OPERATING START-UP PROCEDURE

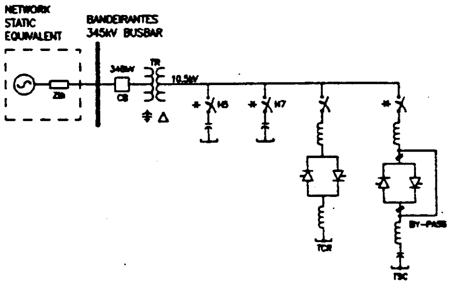
The original SVC energization lay-out stablishes the SVC be energized just with its transformer plus harmonic filters. During start-up procedure the TCR and TSC thyristor valves are blocked in their non-conducting state. The SVC control system is also blocked until the substation operator changes the SVC control from manual mode to automatic mode. From now on, according to system VAr requirements and depending on the voltage reference set, the SVC will deliver indutive or capacitive reactive power by energizing the TCR (-75 MVAr at thyristor valves full conduction) or TSC (+75 MVAr) by means of control system action on thyristor valves.

3.0 - SPECIAL PROPOSED SVC LAYOUT

The figure 1, shown bellow, presents the special proposed SVC lay-out. Thus, the filters and TSC should be all the time connected to the low side of SVC's transformer, with the TSC thyristor valves by-passed and TCR thyristor valves blocked.

In this way each SVC would supply approximately 100 MVAr of fixed capacitive reactive power (25 MVAr delivered from filters at 60 hz frequency plus 75 MVAr from TSC).

This SVC configuration would be possible since the control system and thyristor valves of TSC are the SVC components that still keep on having the commissioning problems reported above.



* ==> SVC's equipments previously connected before energization procedure.

SVC main components description :

CB ==> Circuit Breaker
TR ==> SVC Transformer (345 / 10.5 kV - 100 MVA)
H5 ==> Fifth Harmonic Filter
H7 ==> Seventh Harmonic Filter
TCR ==> Thyristor Controlled Reactor
TSC ==> Thyristor Switched Capacitor

FIGURE 1

4.0- RESULTS OBTAINED FROM DIGITAL SIMULATIONS WITH EMTP

A detailed analysis of SVC's energization conditions, with TSC plus filters previously connected at SVC transformer low side, was performed using EMTP.

Among the several curves obtained from digital simulations in this energization study, we selected some we found more representative, presented below, in order to give an idea of the tipical magnitude and wave-shape of voltages, currents and energies obtained during Bandeirantes SVC energization in such special configuration.

The graphic of Figure 2 shows the wave-shape of transient overcurrent in one phase of SVC transformer low side after its energization in the special proposed configuration (TSC + harmonic filters previously connected).

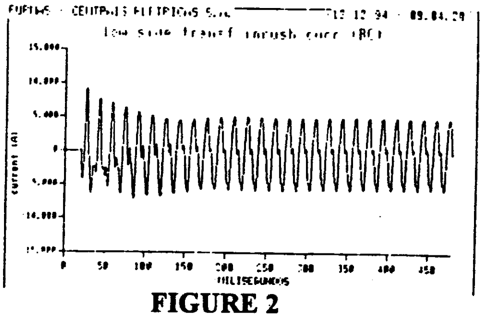


FIGURE 2

The graphic of Figure 3 shows the wave-shape of transient current between the harmonic filters neutral points after SVC energization in the special proposed configuration.

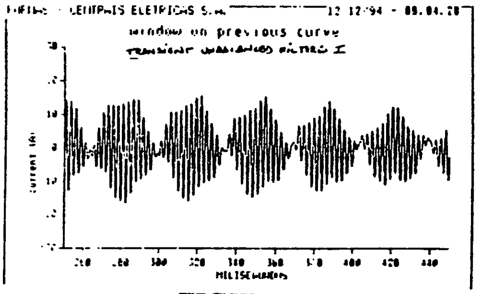


FIGURE 3

The graphic of Figure 4 shows the wave-shape of one 345 kV arrester current during SVC energization in the special proposed configuration.

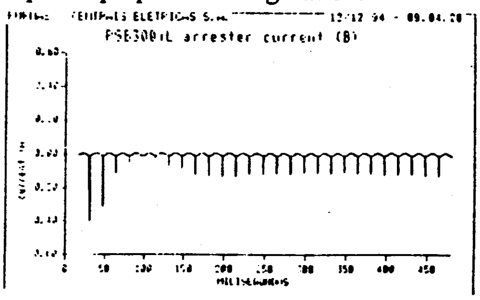


FIGURE 4

The graphic of Figure 5 shows the energy strain of one 345 kV arrester during SVC energization in the special proposed configuration.

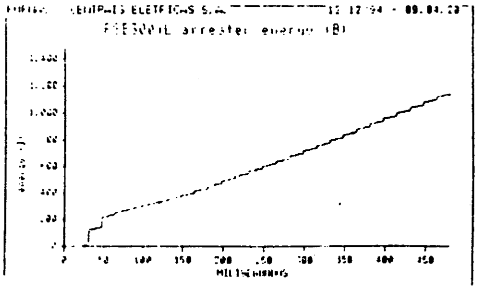


FIGURE 5

The graphic of Figure 6 shows the wave-shape of transient overvoltage in the SVC transformer low side after SVC energization in the special proposed configuration.

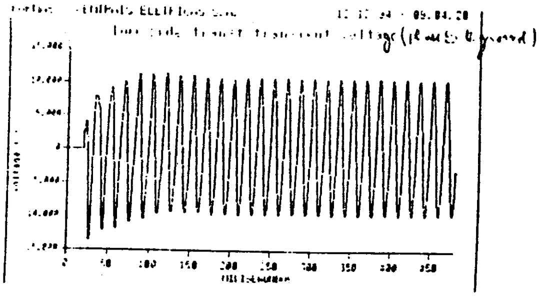


FIGURE 6

The graphic of Figure 7 shows the wave-shape of transient overvoltage in the TSC capacitor cells after SVC energization in the special proposed configuration.

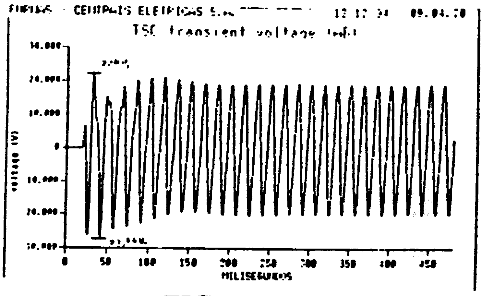


FIGURE 7

The graphic of Figure 8 shows the wave-shape of energy strain in one TSC capacitor cells arrester during SVC energization in the special proposed configuration.

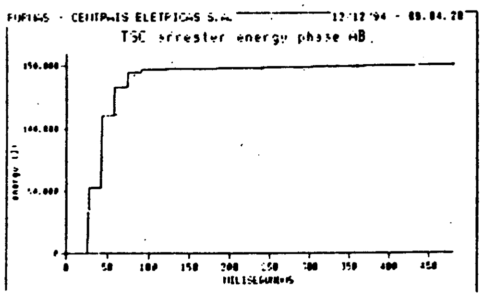


FIGURE 8

5.0 - SVC PROTECTION PROJECT MODIFICATIONS TO PERFORM SITE MEASUREMENTS

Since we knew we would simulate a transient phenomenum associated with simultaneous energization of iron-core windings (SVC transformer) and capacitors elements (TSC and harmonic filters), this could result in high transient overcurrents with very low damping.

That is the main reason the SVC equipments and the network models should consider, as precisely as possible, the existing damping elements of interest of both in the simulations performed with EMTP.

Thus, it would be possible to evaluate the performance and the possibility of operation of existing SVC overcurrent protections during energization procedures.

Since we confirmed the presence of high transient overcurrents in the simulations performed, regarding energization procedure of SVC's special configuration, and as far as the behaviour of overcurrent protection would be very hard to evaluate by means of digital simulations, due to strongly non-sinusoidal overcurrents wave-shape, we also made site measurements to help us in this evaluation.

As far as the simulations results showed preliminarly the possibility of some overcurrent protection operation, what could make this SVC special configuration not feasible, during site measurements we tested both the performance of original settings of the SVC protection system and also new proposed settings.

It was accorded with SVC's manufacturer that site measurements would begin with the original settings of SVC protection system, without any change. In case of some overcurrent protection operation, as previously foresecm by digital simulations, it should be studied each especific case and necessary modifications negociated with SVC's manufacturer.

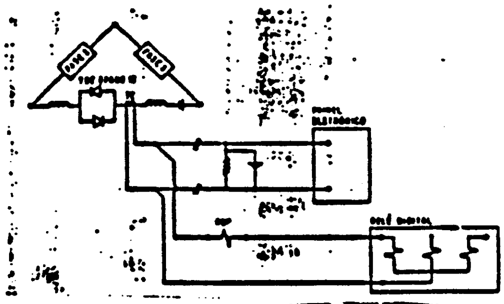
Basically, during site measurements, the monitored voltages and currents were those already considered during protection project, such as 345 kV and 10.5 kV voltages and the currents in all SVC branches. They were easily monitored using a digital monitoring equipment called RDP-100, installed in SVC control room at Bandeirantes substation. This equipment is a dedicated micro-computer that holds in electronic midia the digitalized wave-form and instantaneous values of voltages and currents of interest.

The main protection project modification we would like to point out was the insertion of a digital overcurrent relay in all phases of TSC (usually used in capacitor banks of high rating power to protect them against overloads and short-circuits).

The original TSC overcurrent protection system was out of operation, since as the thyristor valves were by-passed and disconnected, the valve electronic and interface panels were also out of operation. These panels have, besides several other control functions, a TSC protection function. They have a set of protection functions (performed by specific electronic cards) including TSC instantaneous (IOC) and temporized (TOC) overcurrent protections.

The adopted adjustments, used with the described TSC protection modification (pick-up and temporizations), were the same of IOC and TOC electronic protections described, in order to avoid risks of equipment damages and taking into account manufacturer's warranty.

The described TSC overcurrent relay was installed in each TSC phase as shown in figure 9 presented below.



TSC protection project modification to implement a new TSC overcurrent relay

FIGURE 9

Another current protection it was necessary to monitore during site measurements was inside the delta connection of SVC's transformer low side. We made so since we noted, by meams of the results obtained from EMTP simulations, that the transient overcurrents in SVC's transformer delta winding were also very high and could operate such protection.

Regarding the aresters currents and energies, of course, it was not possible to monitore them. In this case we only could believe in EMTP simulations results, wich showed us there were no problems of dangerous arresters stresses due to this energization procedure.

The table 1 shows the complete results of protection study developed based upon EMTP simulation results

6.0 - SITE MEASUREMENT RESULTS - COMPARISON WITH SIMULATION RESULTS

Performing the SVC energization procedure at site with the proposed special configuration and the original protection system settings, of 5 energization trials, all were unsuccessful due to overcurrent protection operation (protection 6 of table 1), as we have foreseen based upon EMTP digital simulation results.

In the oscillograms of figures 10 and 11, related to one of the tentative energizations, we can see the transient overcurrents in all phases of SVC transformer delta winding (10.5 kV), responsible for protection 6 opertion (figure 10), and the filters unbalanced neutral current (figure 11).

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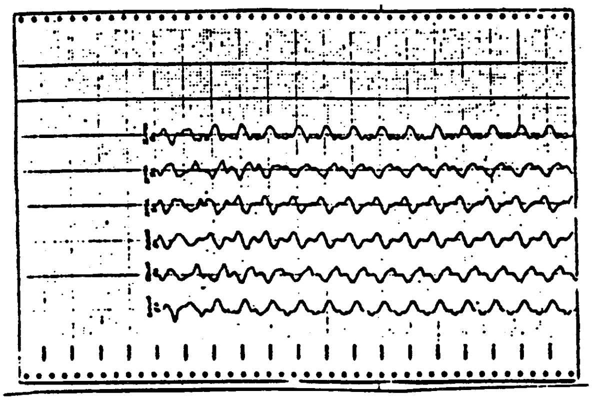
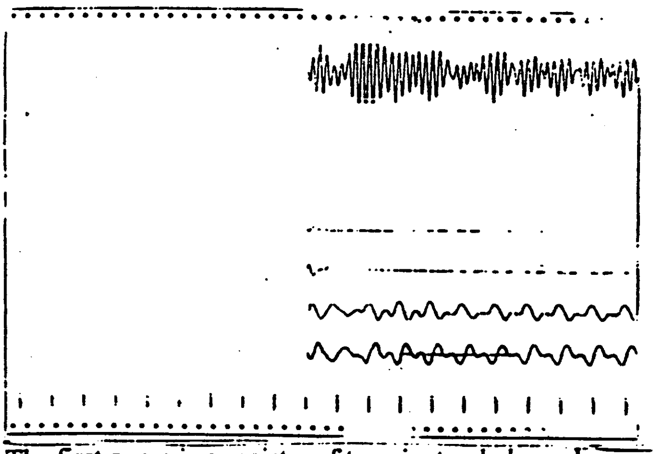


The first three curves are TSC transient inrush currents (inside delta)
The others are transformer delta winding inrush currents

FIGURE 10



The first curve is a register of transient unbalanced filters current

FIGURE 11

After about 30 cycles, the transformer delta winding transient current comes to a value below protection 6 pick-up setting, not enough, however, to reset the relay. To avoid protection 6 operation in this case, it would be necessary a reasonable growing of its pick-up adjustment.

The table 2, shown below, presents a comparison abstract among the currents monitored with RDP-100 and the currents digitally obtained with EMTP. We can see the good match among the site measurements and simulation results.

7.0 - CONCLUSION

7.1 - The digital simulation to determine the electromagnetic transients, during the proposed SVC energization procedure, showed precise results, since the electrical equipments involved have a good modelling. This allowed us to take a reliable decision concerning the feasibility of this special use of Bandeirantes'SVC.

7.2 - In similar cases is desirable a digital simulation of the electromagnetic transients involved in the energization of SVC equipments in such special configurations. These simulations will permit to anticipate possible problems of risks of equipment damage or protection malfunction.

7.3 - The use of EMTP seemed to be in this case suitable to fit the desired aims, allowing us to obtain confident results to make a reliable evaluation of the problem.

7.4 - It is important in such cases, whenever possible, to perform site measurements in order to get a confirmation concerning the results obtained from digital simulation. This will allow a better validation of used equipments modelling in digital simulations.

7.5 - Taking into account all the results of the simulations performed, i.e., the transient overvoltages, overcurrents and energy strain in SVC arresters, the proposed SVC energization procedure, with such emergencial configuration, is feasible.

7.6 - We could verify, by means of digital simulations using EMTP, that the energization of Bandeirantes' SVC, with the proposed special configuration, would cause overcurrent protection operation, when using the original protection system settings. This was confirmed by site measurements afterwards performed. In this way, the SVC overcurrent protection system setting must be changed to values that not cause the protection mis-operation.

7.7 - The recorded wave-shapes and peak values of transient overvoltages and overcurrents, obtained from site measurements, were very similar to those obtained from digital EMTP simulations.

8.0 - BIBLIOGRAPHY

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LOCALIZATION	TRANSF HIGH SIDE (345 KV)			TRANSF LOW SIDE (345 KV)			TRANSF NEUTRAL TRANSIENT OVERCUR
PROTECTION	RESIDUAL OVERCUR 1	OVER-LOAD 1 2	OVER-LOAD 2 3	INST OVERCUR 4	OVERCUR TEMP 1 5	OVERCUR TEMP 2 6	OVERCUR TEMP 7
CURRENT ADJUST IPEAK (AMP)	40	192	206	8,960	3,840	4,160	120
TIME ADJUST (SECONDS)	1,0	9,6	2,0	-	9,6	0,9	0.8
I (EMTP) MAXPEAK (AMP)	354	354	354	8,485	8,485	8,485	170
90-200 mS ESTABILIZED I(EMTP) (AMP-RMS)	237	237	237	4,596	4,596	4,596	106
DISTORTION REDUCTION FACTOR (%)	20	20	20	10	10	10	-
ESTABILIZED I(EMTP) WITH REDUCTION FACTOR	197	197	197	4,180	4,180	4,180	-
POSSIBILITY OF PROTECTION OPERATION	NO	NO	NO	NO	YES	YES	NO
POSSIBILITY OF ADJUSTMENT MODIFICATION	NO	YES	YES	NO	YES	YES	NO
OBS	-	-	-	-	1	1	-

Observations

1 - These were the protection with more possibility of operation during SVC energization procedure.

General Observation - It is not expected any influence of SVC energization transients in other protections than listed above.

TABLE 2

I (AMPPEAK) LOCALIZATION	EMTP	SITE MEASUREMENTS				
345 kV (RATING=167)						
MAXPEAK	354	350	380	300	270	-
10 CYCLES	237	250	280	250	240	-
50 CYCLES	-	240	250	230	220	-
10.5 kV (RATING=3,180)						
MAXPEAK	8,485	-	-	-	7,200	8,000
10 CYCLES	4,596	-	-	-	5,000	5,000
50 CYCLES	-	-	-	-	4,400	5,000
TSC (RATING=2,460)						
MAXPEAK	5,560	5,700	6,000	5,250	4,500	4,800
10 CYCLES	3,460	4,200	4,050	3,900	3,750	3,750
50 CYCLES	-	3,450	3.450	3,450	3,450	3,450
H5 + H7 (RATING= 1,375)						
MAXPEAK	4,737	3,675	3,500	3,938	-	-
10 CYCLES	849	2,363	2,625	2,625	-	-
50 CYCLES	-	2,363	2,625	2,450	-	-