TUCURUI'S 500 kV SF_6 GAS-INSULATED SUBSTATION FAST TRANSIENTS - ANALYSIS, MODELING AND FIELD TEST COMPARISONS

J. F. de Lima Filho F. A. F. Pazo Blanco A. D'Ajuz L. F. A. Nascimento

Centrais Elétricas do Norte do Brasil - Eletronorte
70718-900, SCN, Quadra 06, Conj. A, Brasília-DF, BRAZIL

ABSTRACT

Since Eletronorte's Tucuruí 3600 MW power plant began to operate in 1984, disconnect switch operations into 500 kV gas-insulated substation (GIS) have caused problems in insulation and devices, sometimes resulting in personal risks.

These switching operations give rise to residual charge (trapped charge) and travelling wave surges within GIS and can subject its components to stresses from high frequency overvoltages caused by successive reflections at discontinuities [1,2,3].

In order to verify the actual stresses at Tucuruí, field tests were carried out in September, 1991. Special capacitive couplers developed by Cepel (Electrical Energy Research Center of Eletrobrás) were used to accomplish site test purposes.

Simulations on the Alternative Transients Program (ATP) were also performed in order to check the substation modeling and help the analysis.

This work presents and discusses field test results, comparing them with those generated by Tucuruí's GIS digital modeling for disconnect switch fast transients.

KEYWORDS
GIS, Gas-insulated substation, Fast transients, Disconnect switch surges, Measurement and Simulation.

1. INTRODUCTION

Since 1984, when Tucuruí's 300 MW generators began to operate in the North-Northeast Brazilian power system, some problems concerned 500 kV gas-insulated substation (GIS) switching actions have been observed like:

- CTs' support insulation flashover;
- governors' control circuit relays misoperation;
- internal flashover detections by photocaptor cells;
- measuring instruments oscillations, and
- transient ground potential rise (TGPR).

Based on disturbance analysis and operating experience, manufacturer and planning, operation and maintenance areas of Eletronorte provided solutions like:

- installation of metal oxide varistors on the CTs' support insulation;
- installation of low-pass filters on the governors' control circuit relays;
- replacement of control cables to provide better shielding;
- additional worker safety cautions during switching operations, and
- no voltage in both terminals during disconnector switch operations

Because of the Tucuruí's GIS configuration, this last operational restriction forces the disconnection of two generator units from the system.

In 1987, based on digital simulations [1], planning studies recommended field measurements in order to verify the actual surge levels compared to substation BIL (1550 kV).

2. FIELD TESTS AND RESULTS

As recommended by planning studies, measurements were made at PMA (phase B SF_6/air bushing) and PMC (phase B unit 4 disconnect switch) points showed in Figure 1.

Front wave recording and analysis were also necessary because the GIS was specified to withstand lightning surge rate of rise lower than switching one.

Transient ground potential rise (TGPR) measurements were carried out at phase B support structures of unit 4 disconnect switch (PT1) and SF_6/air bushing (PT2).

The field tests, assisted by Cepel [5] and Eletronorte's Central Laboratory, were made with unit 4 circuit breaker opened and unit 3 switchgear closed, according Figure 2.

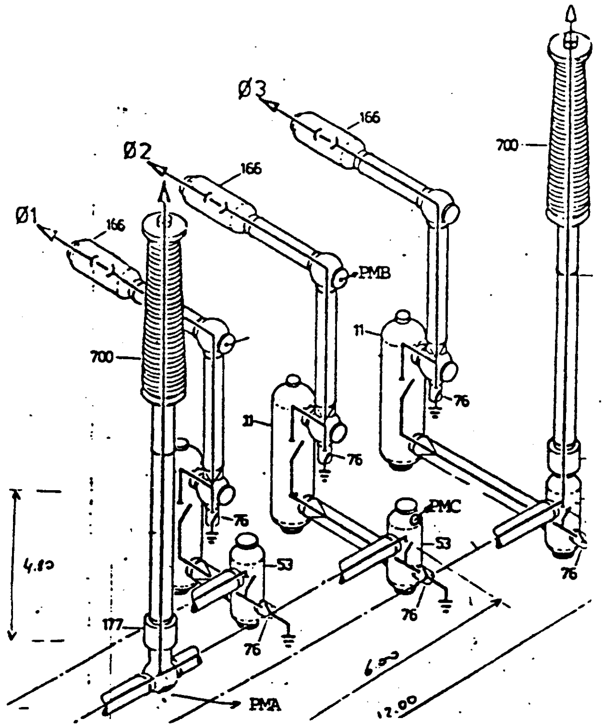


Figure 1 - Bay for study of disconnect switch surges at Tucuruí.

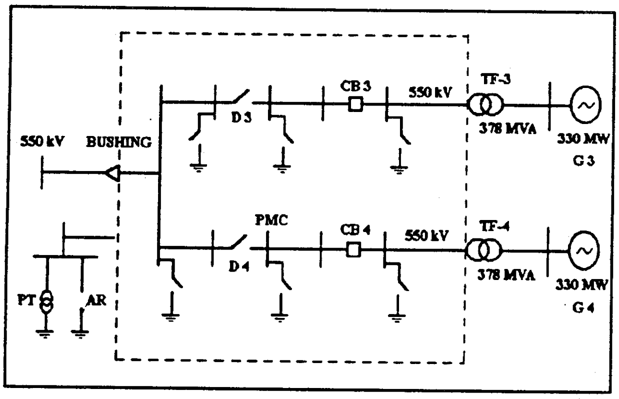


Figure 2 - Single-phase diagram.

The tests associated with closing and opening of unit 4 disconnect switch were named as follow:

M1 - opening for residual voltage measurement;

M1.1 - closing with unit 4 off;

M2.1 - closing in opposite phase with unit 4 50% excited;

M2.2 - opening with unit 4 off.

M2.3 - closing in opposite phase with unit 4 70% excited.

M2.4 - opening in phase shift of 90° with unit 4 70% excited.

M2.5 - opening in opposite phase with unit 4 70% excited.

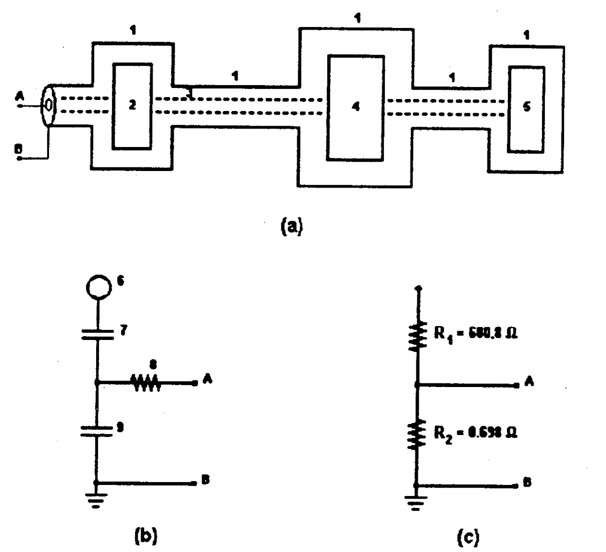
M2.6 - closing in opposite phase with unit 4 100% excited.

M2.7 - opening in phase shift of 90° with unit 4 100% excited.

M2.8 - opening in opposite phase with unit 4 100% excited.

M2.9 - closing with unit 4 100% excited.

The PMA, PMC, PT1 and PT2 voltages were obtained from the measuring system showed in Figure 3.



(a) components arrangement
1 - electromagnectic shielding
2 - buffer
3 - measuring cable
4 - oscilloscope
5 - source
6 - conductor
7 - high voltage capacitor
8 - matching resistence
9 - low voltage capacitor

(b) capacitive voltage divider

(c) resistive voltage divider for TGPR measurements ($R_1 = 600.8\ \Omega$ and $R_2 = 0{,}698\ \Omega$)

Figure 3 - Measuring system

Seven disconnect switch openings (M1) were made in order to obtain voltages caused by residual charge left on the floating point. The maximum magnitudes observed were -0.07, +0.04, +0.18, -0.03, +0.03, +0.11 and +0.15 pu in $500.\sqrt{2}/\sqrt{3}$ kV basis.

Sixteen tests were carried out in order to measure disconnect switch closing transients. The greatest overvoltages obtained are shown in Table 1.

Table 1 - Disconnect switch closing tests

Test	Resid V (pu)	Gen # 4	Overvolt (pu) Measu	Simul	Re-mark
M1.1	-0.08	off	1.20	1.56	—
M1.1	+0.04	off	1.23	1.51	—
M1.1	+0.20	off	1.46	1.61	—
M1.1	-0.03	off	1.17	1.54	—
M1.1	+0.03	off	1.29	1.51	—
M1.1	+0.12	off	1.10	1.48	—
M2.1	—	50% Vn	1.29	1.53	oppos. phase
M2.3	—	70% Vn	1.48	1.53	oppos. phase
M2.6	—	100% Vn	1.40	1.53	oppos. phase
M2.7	—	100% Vn	1.29	1.52	oppos. phase

Twenty one site tests were made for disconnect switch opening transient measurements. The highest overvoltages obtained are in Table 2.

Table 2 - Disconnect switch opening tests

Test	Gen # 4	Measured overvolt (pu)	Remark
M2.4	70% Vn	1.47	90° shift
M2.4	70% Vn	1.60	90° shift
M2.5	70% Vn	1.63	oppos. phase
M2.8	100% Vn	1.63	oppos. phase

For TGPR measurements, three disconnect switch closings and two switch openings were done. The results are in Table 3.

Table 3 - TGPR measurements

Test	TGPR levels (kVpeak)		Frequency
	PT1	PT2	(Mhz)
M1.1	0.516	—	67
M2.8	—	0.602	6.7
M2.6	—	≥ 3.44	—
M2.8	—	10.33	7.1
M2.13	—	≥ 32.3	7.7

3. FIELD TEST ANALYSIS

The highest residual potential observed was 0.20 pu (81.6 kVp). Although seeming low, it is in agreement with Ontario Hidro measurements [2].

Succesive restrikes were observed when disconnect switch was closing as well as it was opening, the latter lasting up to 1.25 seconds.

During switch closing tests (Table 1) with unit 4 circuit breaker opened and pre-switching rms line-to-line voltage of 1.09 pu (545 kV), the highest measured overvoltage was 1.52 pu with unit 4 off and without recording of the residual voltage. In the closing tests that residual charges were recorded, the highest overvoltage obtained (1.46 pu) was concerned with the highest residual voltage measured (0.20 pu). Figure 4 shows the oscillogram of M1.1 closing test with residual voltage of 0.04 pu resulting in 1.23 pu overvoltage after 150 nanoseconds and rate of rise about 3 kV/ns.

During disconect switch opening tests (Table 2) the highest overvoltage obtained was 1.63 pu in opposite phase condition and unit 4 70% excited (M2.5 test). Figure 5 shows the respective oscilloscope record.

The TGPR tests detected a maximum peak voltage about 32.3 kV. Although the assessment of personal risks is a difficult task even regarding the high frequencies (7.7 Mhz) and the short term (≈ 2μs) envolved this value seem to be high. According reference [4], that mention biomedical aspects of short term high frequency electric shocks, this transient energy level causes pain without danger for workers although accidents would be caused by instantaneous reactions.

4. SIMULATION TESTS AND RESULTS

Since the results of disconnect switch operations are innately statistical, the accomplished measurements probably do not reflect the highest feasible overvoltages. Therefore, in order to help the dielectric stress analysis and the discussion with the manufacturer, digital simulations become necessary.

The closing tests were reproduced in the ATP from the basic configuration showed in Figure 6. The parameters were obtained from trial reports, manufacturer informations and design features.

As known, disconnect switch poles do not move simultaneously due to pole spread (few miliseconds), hence quite slower than fast transient duration caused by disconnect switch operation (few microseconds). For this reason there is not necessary to represent the GIS in a three phase way. Lumped capacitance and surge impedance single-phase modeling is suitable to reproduce the analysed phennomena.

The unit 4 disconnect switch was operated forty times throughout field test. This seems to be much but different configurations were used, each with insufficient test sampling for statistical analysis.

In order to check the substation modeling as for front wave, damping, rate of rise and frequencies involved the closing time of M1.1 simulation test with 0.04 pu residual voltage was changed so that the same 1.23 pu measured overvoltage could be achieved. This brought out the voltage wave form showed in Figure 7.
The switching tests of Table 1 were simulated closing the disconnect switch at the system voltage peak value with the same residual voltage polarity and level, resulting in higher overvoltages than measured ones.

These simulation tests in the most severe pre-switching conditions confirmed swithing surges with higher rate of rise than lightning ones although overvoltage levels did not reach the substation BIL.

Due to steepness of the resultant front waves, operational restriction of only switch disconnect switch without system voltage in both terminals was maintained. Furnas and Itaipu brazilian utilities have imposed switching restrictions on 500 kV GIS' disconnect switches.

The aleatory nature of disconnect switch opening field tests and the difficulty on obtaining initial conditions to reproduce the effect of successive restrikes did not alow a detailed comparison through digital simulations. Analysis with different pre-switching conditions were carried out and indicated that opening overvoltages are more critical than closing ones due to more critical initial conditions.

Regarding TGPR modeling, it depends on several datailed influent parameter investigations for its synthesis. Then, it was left to a future work.

5. SIMULATION VERSUS FIELD TEST RESULTS

Table 1 and Figure 7 show the results of ten closing simulations accomplished for comparing with field records, making possible to verify the consistence of the fast transient model used. A detailed comparison was performed between Figures 4 and 7. The latter shows that the greatest overvoltage of 1.23 pu happened 141 ns after disconnect switch closing, with 4 kV/ns rate of rise. The corresponding measured magnitudes were 150 ns and 3 kV/ns. After 300 ns the overvoltages came at 1.18 pu (simulation) and 1.19 pu (field). The highest observed frequencies, corresponding to the smallest oscillatory amplitudes of Figures 4 and 7, remained around 160 Mhz (simulation) and 150 Mhz (field), highlighting the little precision on achieving it through field record.

The comparative analysis between simulation and field test results suggests the consistence of the GIS modeling for fast transients used on ATP.

6. CONCLUSION

The highest disconnect switch overvoltages are considerably influenced by residual charge and pre-switching voltage. The use of 1.0 pu as residual voltage in disconnect switch closing simulations leads to very conservative results seeing that field tests indicated maximum value of 0.20 pu.

The overvoltage wave form is considerably influenced by the open circuit breaker capacitance and GIS bus surge impedance.

The reduced number of disconnect switch opening field tests, its aleatory nature and the difficult on obtaining initial conditions to reproduce the effect of successive restrikes did not allow a detailed comparison between simulations and field tests. Supposing that the resultant overvoltages are mainly caused by the last restrike ("last closing") and since field tests with unit 4 excited indicated that opening overvoltages are more critical than closing ones, simulations indicated that the initial conditions are more critical too.

The TGPR modeling depends on detailed influent parameter investigations for its definition and check. The recorded TPGR of 32.3 kV seems to be very high but in principal it doesn't cause damage due to its short term (2μs).

The measured and simulated overvoltages, even if the residual voltage of 1.0 pu is used and the disconnect switch is closed at system peak voltage in the simulations, always remained below the substation BIL (3.8 pu).

The measured and simulated switching front waves (1.5 ns) are quite harder than lightning ones (1.5 μs). For this reason the operational restriction of do not switch disconnect switches under system voltage was maintained.

7. REFERENCES

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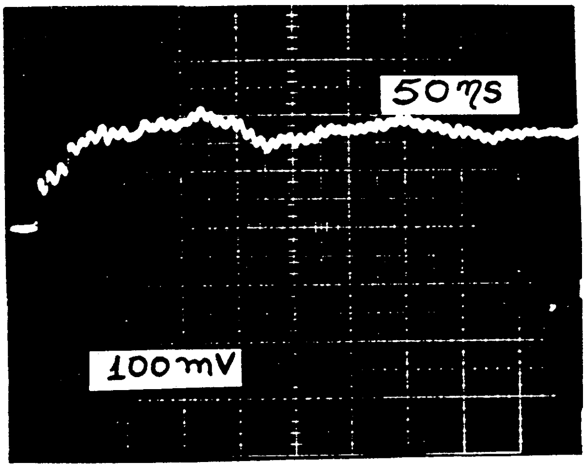

Figure 4 - Closing field record

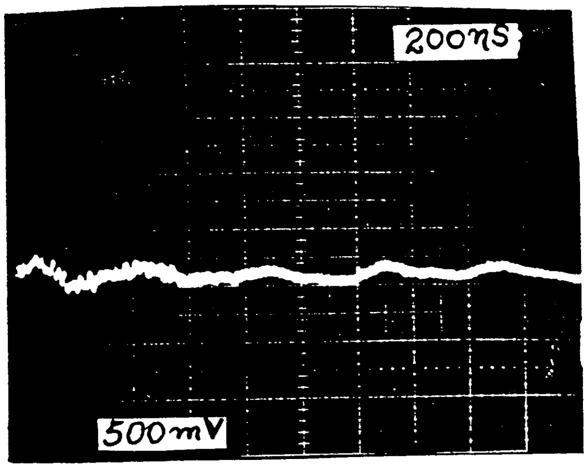

Figure 5 - Opening field record

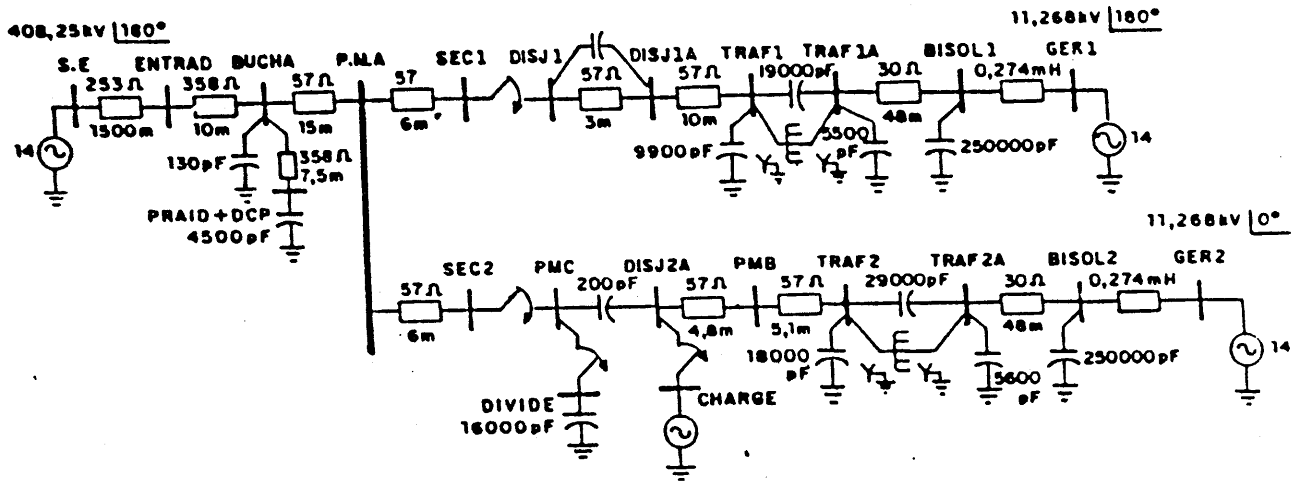

Figure 6 - Basic configuration modeling

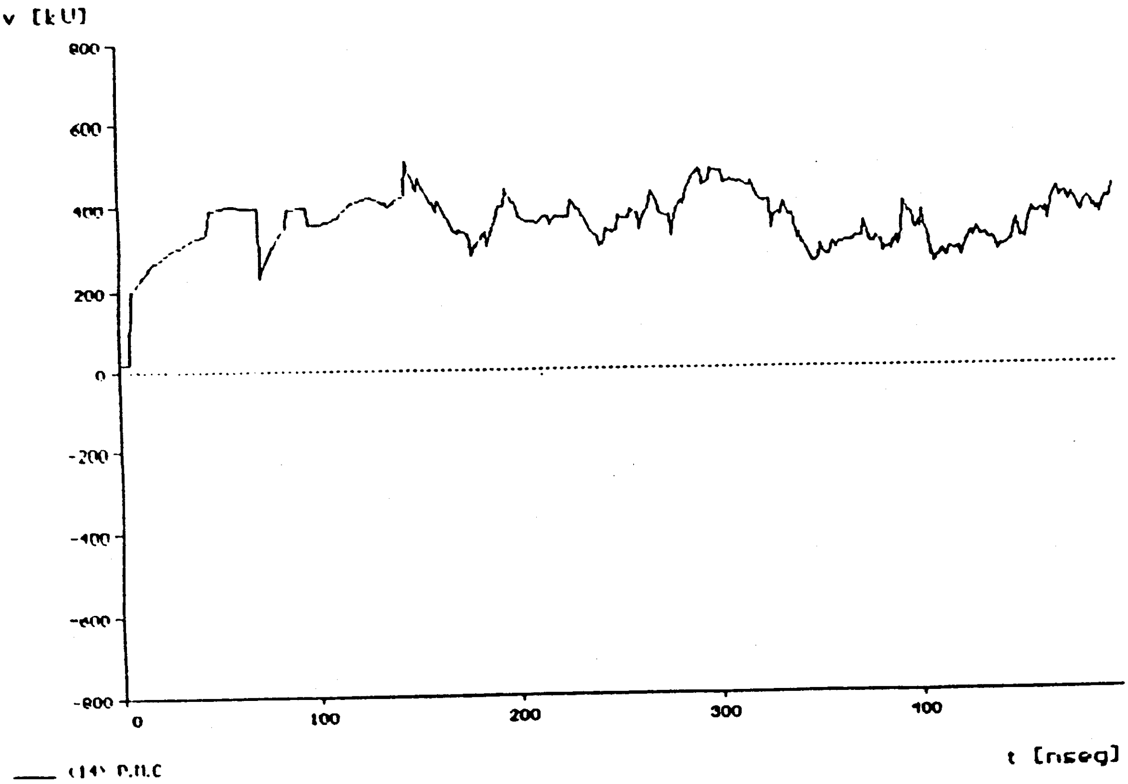

Figure 7 - Closing simulation