

# The FURNAS experience at Real Time Digital Simulation after 20 years of RTDS Simulator Commissioning



#### **FURNAS** Centrais Eletricas S.A.

- Mix private/state-owned company established on February 28, 1957
- 65 Substations (120.000MVA transformation capacity)
- 17 hydroelectric power plants, 2 conventional thermal power plants and 3 Wind farms (16.000 MW)
- 24.000 km of transmission lines
- 40% of Brazil energy pass through FURNAS system

#### **ITAIPU** transmission system:

#### 765kV

- 4 substations
- 3 circuits
- 800 km

#### **HVDC** system

- +/- 600kV
- 2 Bipoles (2 converters per pole)
  - 6300MW
    - 800km



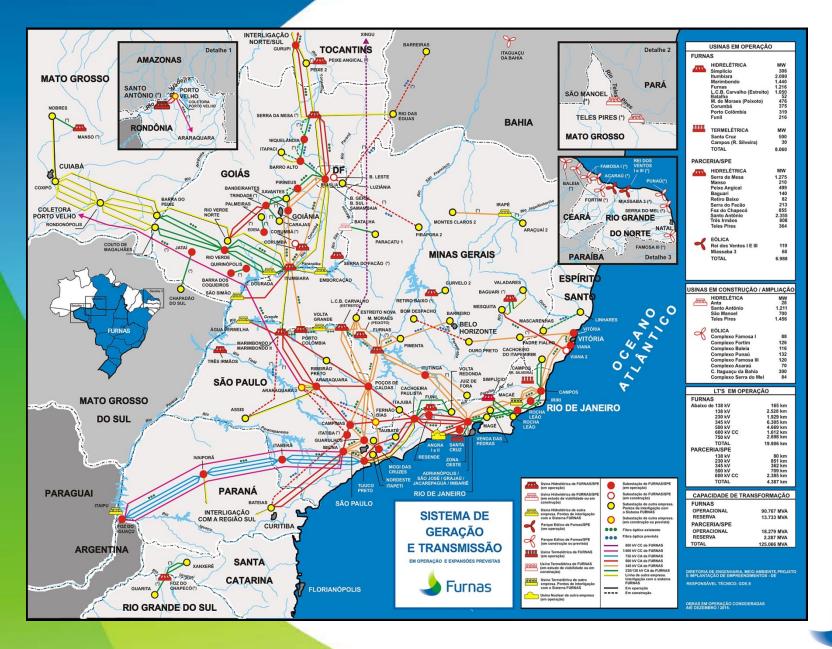
#### **FURNAS Centrais Eletricas S.A.**

#### **Examples of partnership:**

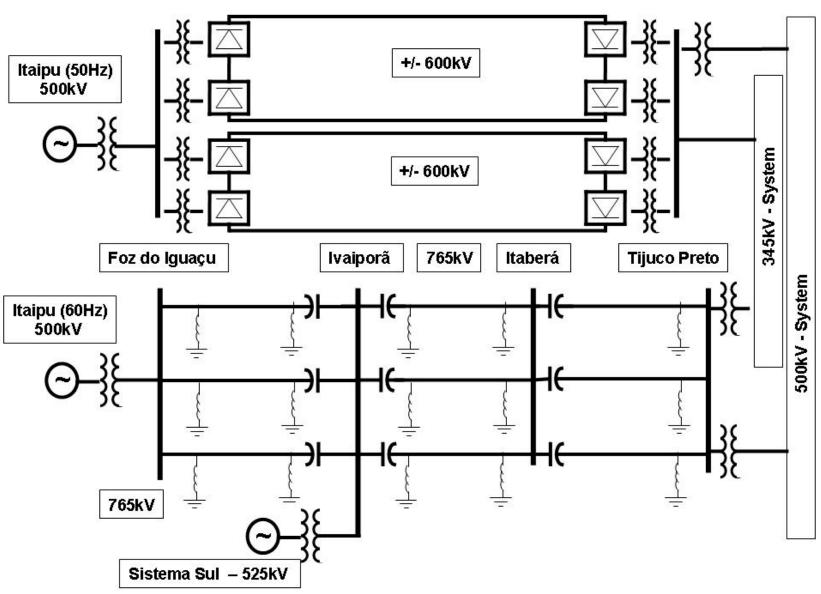
- UHE Santo Antonio (Rio Madeira) 3150 MW
- Rio Madeira Transmission system:
   Bipole 2 of the HVDC link (+/- 600kV, 3150 MW, 2400km)

Belo Monte Transmission system:
 Bipole 1 of the HVDC link (+/- 800kV, 4000MW, 2000km)











#### First Contact with Real Time Simulation:

TNA (scale down model of the FURNAS HVDC sytem) conected to real controls



FURNAS has considered the simulator an important tool for support the operation



Latter on FURNAS has realized that the AC representation at the inverter bus should be enhanced



#### **HVDC Studies Supporting System Operation**

#### **Hardware & Software Tests:**

Digitalization of Analog functions

FURNAS

- Redundancy scheme for the CCA (Current Control Amplifier)
- New Software versions

#### **System Performance:**

- Event modeling and analysis
- Comutation failure evaluation
- Paraguai 500kV system analysis



#### **Protection System Testing**

FURNAS



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- Outage Analysis
- Pre and Post FAT Real Time Tests
- New Setup evaluation
- I Time Tests

  RTDS and Computer Workstation

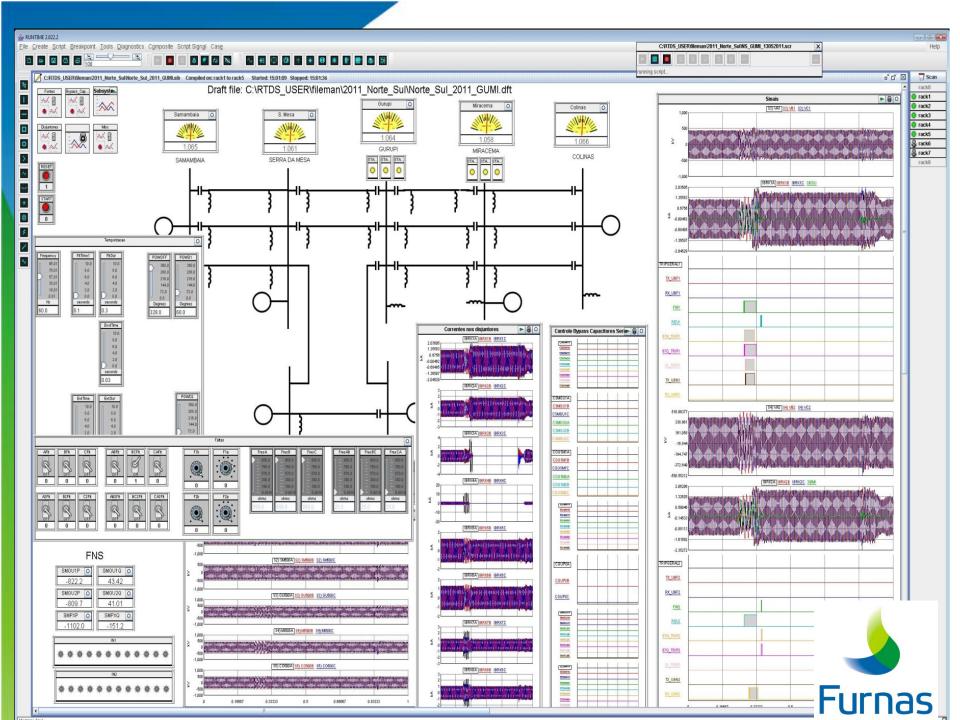
  RELAY(S)

  Interfacing Protective Relays to the RTDS

breaker trip and re-close signals

- Outsorcing testing (FURNAS hired to perform Real Time Test)
- Protection compatibility and Firmware upgrade analysis



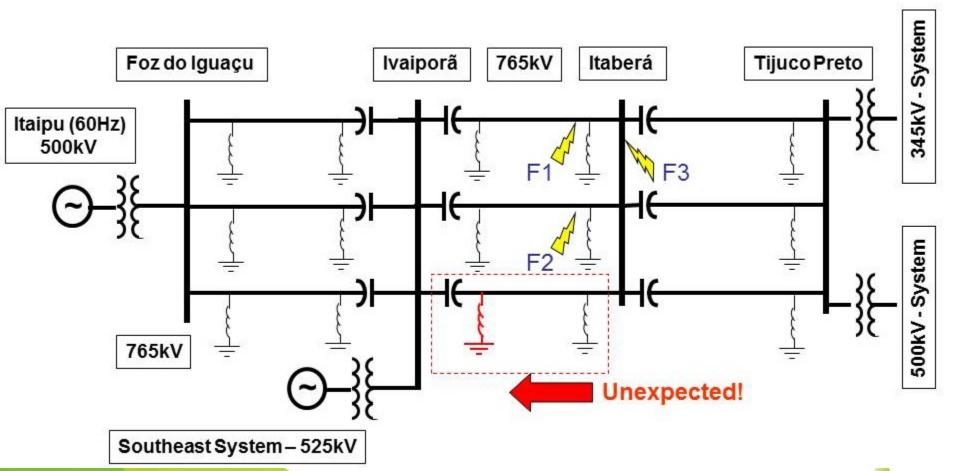


#### **Protection System Testing**

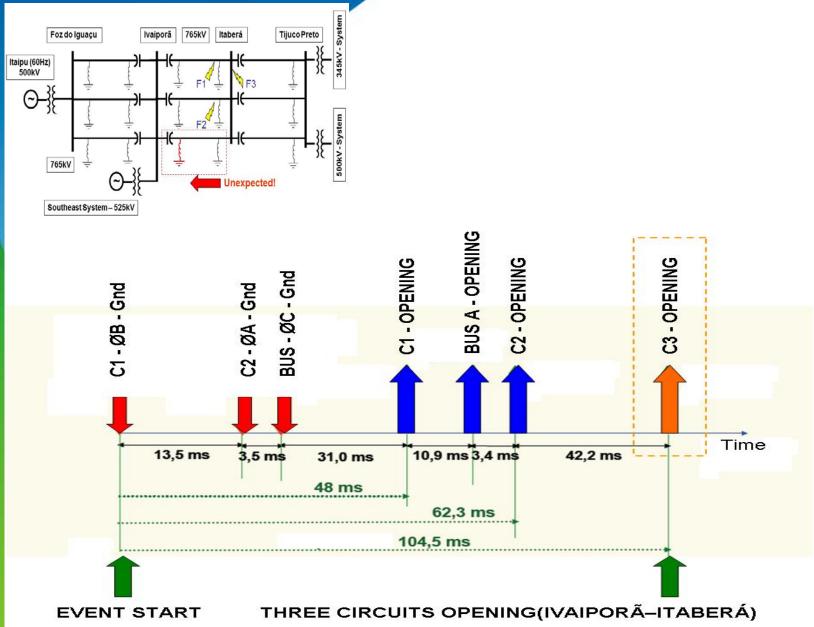
#### Script Files: Batch Mode and Automatic Testing Result

F			CHINAS	FURNAS	
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		ITAC	ACAUNAS	CARAJAS	
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		8 8 8 8 8 <del>8</del> 8	A A B C C C E L	8 8 8 8 4 4	1
		* 8 8 8 8 8 8 8	ARTHUR NO.	A B O D B W W W W W W W W W W W W W W W W W W	N   N   L   N   L   N   N   N   N   N
2		*   BE   BE   BE   TY   CG   TY	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		N 6 6 6 8 8 8 8 8 9 8 9 8 8 9 8 9 8 9 8 9
		F 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2			
8 8	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	F 8 8 8 8 8 8	8 8 8 2 2 2 2 2 2 2	F 2 8 8 8 8 8 8 8	8 1 2 2 2 2 2 <u>9</u> <u>9</u>
2366 EXTERNA 2367 EXTERNA	NA 4 10:28:30 58:2008 BN F7 999 0 60 5:00 - 20:00 S NA 4 10:27:44 58:2008 CN F7 999 0 60 5:00 20:00 S	No Trip	- 2739 1741 - 1920 - - 2739 1958 - 2125 -	No Trip	- 1856 22,40 On On BOS By-Passed: - 21,25 28,62 On On BOS By-Passed:
2368 EXTERNA	NA 4 10:28:57 55:2008 AS F7 999 0 80 - 5:00 5:00 - S	422.27 422.40 422.27 422.27 - 20.88 420.88	8 - 20,35 22,40 -	No_Trip 15,87 -	- 1843 2829 Of On BCS By-Passed:
2369 EXTERNA 2370 EXTERNA		421,25 421,76 421,25 421,89 - 20,22 421,50	90 - 21,63 21,76 - - 20,48 20,99 - 20,48 -	No_Trip 18,05 No_Trip 18,00 -	- 21,76 25,34 Of On BCS By-Naxxet - 18,30 28,11 On On BCS By-Naxxet
2371 EXTERNA	84A 4 10:32:43 55:2008 ABC F7 989 0 60 - 5,00 5,00 5,00 - 5	223,10 223,10 223,23 223,74 - 17,92 -	- 17.15 19.33 222.59	274,82 274,94 276,10 274,82 15,36 -	27597 2086 219.66 22.86 Of OF BCS By-Passed:
2372 EXTERNA 2373 EXTERNA	NA 4 10:36:14 56/2008 NN F7 990 - 90 60 - 500 - 20:00 S	No Trin	- 2580 1536 - 1728 - - 2586 2022 - 2176 -	No Trip	- 2074 20,26 On On BCS By-Nasset
2374 EXTERNA	NA 4 10:36:29 55:2006 CN F7 999 90 60 5:00 20:00 S	No Trip	- 2419 1856 - 2022 -	No Trip	- 23,17 25,34 On On BOS By-Passed:
2375 EXTERNA 2376 EXTERNA	PNA 4 10:37-42 55:2008 R6 F7 929 90 55 - 5,00 5,00 5 PNA 4 10:39:00 55:2008 BC H F7 929 90 55 - 5,00 5,00 - 5 PNA 4 10:42:14 55:2008 BC H F7 929 90 55 - 5,00 - 5,00 20,00 S	418,30 418,56 416,30 418,43 17,15 416,30 418,18 418,30 418,18 418,69 17,15 418,43	30 - 18,43 458,50 - 18,69 - 18,56 - 18,56 -	No Trip 15,38 -	- 2202 2330 Of On BCS By-Passet
2377 EXTERNA 2378 EXTERNA		No Trip 16,64 - 18,06 - 18,06 -	- 1779 2048 - 17.92 - - 1741 19.48 222.86	No_Trip 14,98 -	- 1690 2125 On On BCS By-Passed:
2379 EXTERNA	NA 4 10:42:50 55:2008 BN F11 999 0 60 5,00 - 20,00 S	No_Trip		No Trip	- 2253 On On BCS By-Passed:
2380 EXTERNA 2381 EXTERNA	NA 4 10-44-00 5552006 CN F11 999 0 60 5,00 20,00 5	No Trip	2227	No Trip	- 23,30 On On BCS By-Naxaet - 1889 On On BCS By-Naxaet
23 82 EXTERNA	NA 4 10-48-24 5/52/008 BC F11 999 0 60 5,00 5,00 - 5	No Trip	- 2227		- 2081 On On BCS By-Passed:
2383 EXTERNA 2384 EXTERNA	NA 4 10:47:34 5/52/208 CAN F11 989 0 60 - 5,00 - 5,00 20,00 5 NA 4 10:48:5/52/208 ABC F11 989 0 60 - 5,00 5,00 5,00 - 5	No Trip	2189	No Trip	- 1869 On On BCS By-Passed: - 1856 On On BCS By-Passed:
2385 EXTERNA	NA 4 10-49:57 5/52:008 AN F11 989 90 80 - 5,00 20,00 S	No_Trip		No_Trip	21/8 On On BOS By Passed:
2386 EXTERNA 2387 EXTERNA	NA 4 10.51:10 5/52/2008 BN F11 999 90 80 5,00 - 20,00 S NA 4 10.52:21 5/52/2008 CN F11 999 90 80 5,00 20,00 S	No Trip	<del>                                      </del>	No Trip	- 2394 On On BCS By-Naxaet - 2150 On On BCS By-Naxaet
2388 EXTERNA 2389 EXTERNA	NA 4 10:51:31 5/52:008 AB F11 999 90 60 - 5,00 5,00 S	No_Trip	- 2355	No Trip	- 2202 On On BOS By-Passed: - 2176 On On BOS By-Passed:
23 90 EXTERNA	NA 4 10-55-52 5/52006 CAN F11 999 - 90 80 - 500 - 500 20:00 S	No Trio	23,17	No Trip	- 1792 On On BCS By-Passed:
2391 EXTERNA 2392 EXTERNA	NA 4 10.57.02 5/52/008 ABC F11 989 90 80 - 5,00 5,00 5,00 - 5 NA 4 10.52.16 5/52/008 AN F8 989 0 80 - 5,00 20,00 S	No Trip	- 2176	No Trip	- 18,18 On On BCS By-Passed:
23 93 EXTERNA	NA 4 10:59:23 5:52:008 EN F8 999 0 80 5,00 - 20,00 S	No Trip		No Trip	On On BCS By-Paxxed: 48 58
2394 EXTERNA 2395 EXTERNA	NA 4 11-01-42 NISCORR AR ER 999 - 0 80 - 500 500 - 5	No. Trin	<del> : : : : : : : : :</del>	No Trip	On On BCS By-Passed: 4C 5C
2396 EXTERNA 2397 EXTERNA	NA 4 11:02:51 5/52:008 BC F8 999 0 60 5:00 5:00 - 5	No Trip		No Trp	On On BCS By-Passed: 48 4C 58 5C
23.98 EXTERNA	NA 4 11:06:13 552:008 ABC F8 999 0 60 - 5:00 5:00 5:00 - 5	No Trip	<del>                                      </del>	No_Trip	On On BCS By-Naxxet 4A 4C 5A 5C
23 99 EXTERNA 24 00 EXTERNA	NA 4 11:02:25 5:52:008 AN F9 929 90 80 - 5,00 20,00 S NA 4 11:07:34 5:52:008 BN F9 929 90 80 5,00 20,00 S	No Trip		No Trip	On On BCS By-Nasset
2401 EXTERNA	NA	No Trip		No Trip	On On BCS By-Passed:
2402 EXTERNA 2403 EXTERNA		No Trip	<del> : : : : : : : : : :</del>	No Trip	
2404 EXTERNA	NA 4 11:12:08 552:008 CAN F9 999 90 60 - 5,00 - 5,00 20,00 5	No Trip		No_Trip	- On On BCS By-Passed: 6A 6C
2405 EXTERNA 2406 EXTERNA	NA 4 11:13:17 5:52:008 AN F10 999 0 60 - 5,00 5,00 5,00 - 5 NA 4 11:14:30 5:52:008 AN F10 999 0 60 - 5,00 20,00 5	No Trip	526,90	No Trip	On On BCS By-Paxxed: 6A 68 6C
2407 EXTERNA 2408 EXTERNA		No Trip		No Trip	On On BCS By-Nasset
2409 EXTERNA	NA 4 11:17:59 5/52/008 AB F10 989 0 80 - 5,00 5,00 5	No_Trip	<del>                                      </del>	No_Trip	- On On BCS By-Naxset BA 88
2410 EXTERNA 2411 EXTERNA	NA 4 11:12:11 552008 BC F10 999 0 80 5,00 5,00 - 5	No Trip		No Trip	On On BCS By-Nasset 88 BC
2412 EXTERNA	NA 4 11:21:28 5%2008 ABC F10 989 0 60 - 5,00 5,00 - 5	No_Trip		No Trip	On On BCS By-Passed: 8A 8B 8C
2413 EXTERNA 2414 EXTERNA			30,59	No Trip	On On BCS By-Passed: 10A
2415 EXTERNA	NA 4 11:24:57 5/52/008 CN F12 999 0 60 5,00 20,00 S	No Trip	31,74	No_Trip	On On BCS By-Paxxed: 10C
2416 EXTERNA 2417 EXTERNA	NA 4 11:27:22 5/52008 BC F12 999 0 60 - 5,00 5,00 - 5	No_Trip	21,50	No Trip	On On BCS By-Passed: 10A 10B
2418 EXTERNA 2419 EXTERNA				No Trip	27,39 - 29,44 - On On BCS By-Passed: 10A 10C On On BCS By-Passed: 10A 10C On On BCS By-Passed: 10A 10B 10C
2420 EVOLUTIV	TMA 5 15.52.18 5/52.008 AN F1 33,33 AB F1 0 80 - 5,00 5,00 - 20,00 5	No Trip 29,44 29,44 43,90 44,42 515,07 17,28 13,44	14,98 108,82 15,49 15,10 29,31	80,28 80,28 208,90 207,67 - 79,62 78,85 74,5	0 28,11 - 28,03 18,05 On OY BCS By-Passet
2421 EVOLUTIV 2422 EVOLUTIV	TNA 5 15:52:40 5:52:008 AN F1 33:23 AB F1 90 60 - 5,00 5,00 - 20,00 S	33,68 33,68 60,67 61,18 531,71 13,18 9,34 - 24,63 24,63 47,62 47,87 518,66 27,01 19,20 -	- 14,98 15,36 - 10,88 33,41 - 20,48 1690 - 18,56 23,30	44,42 44,42 229,83 234,88 - 83,58 82,94 78,9 20,48 20,48 44,67 44,67 - 26,88 19,58 21,6	
2423 EVOLUTIV	TWA 5 16:02:19 5/52:008 AN F3 33:23 AB F3 90 60 - 5:00 5:00 - 20:00 S	20.74 20.74 60.16 60.42 536.42 25.09 15.23 -	16.51 - 17.02 - 16.77 20.48	20.22 20.22 63.62 63.62 705.28 24.83 13.70 - 17.6	8 - 17.15 - 16.77 21.89 On On BCS By-Passed:
2424 EVOLUTIV 2425 EVOLUTIV	TMA 5 18:03:37 552:008 AN F5 33:33 AB F5 0 80 - 5:00 5:00 - 20:00 5 TMA 5 18:04:54 552:008 AN F5 33:33 AB F5 90 80 - 5:00 5:00 - 20:00 5	38,48 38,48 67,58 67,71 544,64 - 45,31 - 30,92 30,92 89,38 67,58 546,69 - 68,10 -	- 28,03 18,05 - 19,84 17,41 - 25,86 15,74 - 17,86 16,00	21,76 21,76 59,28 58,82 731,78 20,22 10,75 19,0 20,36 20,36 57,73 58,70 717,96 15,10 8,70 14,9	7 - 794,13 - 18,69 - 14,21 22,78 On On BCS By-Passed: 6 16,64 - 11,78 20,66 On On BCS By-Passed:
2428 EVOLUTIV 2427 EVOLUTIV	TMA 5 16:06:11 5/52:008 AN F6 23,23 AB F6 0 60 - 5,00 5,00 - 20,00 S	No_Trip	22,91 30,98	No Trip	28,50 - 28,42 - On On BCS By-Passed:
2428 EVOLUTIV	TVA 5 16:14:03 5/52/006 AN F7 33:33 AB F7 0 60 - 5:00 5:00 - 20:00 5	No Trip 46.08 -	- 19,58 31,87 - 28,80 18,82 - 20,81	No.Trip - 44.29 -	- 28,54 - 30,21 - On On BCS By-Passet: - 19,84 28,60 On On BCS By-Passet:
2429 EVOLUTIV 2430 SOTF1	TMA 5 16:14:59 5/52008 AN F7 33,33 AB F7 90 60 - 5,00 5,00 - 20,00 5	No Trip 60,29	- 24,32 16,38 - 18,18 - 18	No Trip 42,37 -	- 1805
2431 50171	1 8 16:12:33 5/52:008 AN F1 999 90 80 - 5,00 0,01 S	8,70 8,83 8,70 9,34 - 17,54 17,92 -	- 15,10 15,62 8,32 17,28 57,47 - 15,38 15,67 8,58 17,41 81,70	No Trip	
2432 SOTF1 2433 SOTF1	E1	870 896 870 896 - 32.13 15.74 -	- 15.10 858 17.28 - - 14.46 755 18.77 56.70	No Trip	
2434 SOTF1	F1   6   16:23:10   552:006   AN   F5   929   -   -   0   60   -   5,00   -   -   0,01   5	65,15 65,41 65,15 65,79 - 32,51 26,62 -	- 23,81 22,02 - 23,94 65,28	No Trip	
2435 SOTF1 2436 SOTF1	1 5 15:24:11 515:2008 AN F5 999 - 90 50 - 5,00 - 0,01 5 1 8 16:25:28 55:2008 ABC F5 999 - 0 50 - 5,00 10,00 15,00 - 5	8,70 8,70 8,83 9,34 - 45,44 32,51 - 9,86 10,11 9,86 10,50 31,62 -	- 32,00 - 19,46 - 32,38 8,45 31,23 - 18,56 9,86	No Trip	<del> : : : : : </del>
2437 SOTF1	1 6 16:26:20 5/52:008 ABC F5 989 90 60 - 5,00 10,00 15,00 - 5	9,34 9,34 9,60 9,73 31,23 -	- 30,48 - 17,92 9,09	No_Trip	

#### 765kV Outage Analysis:







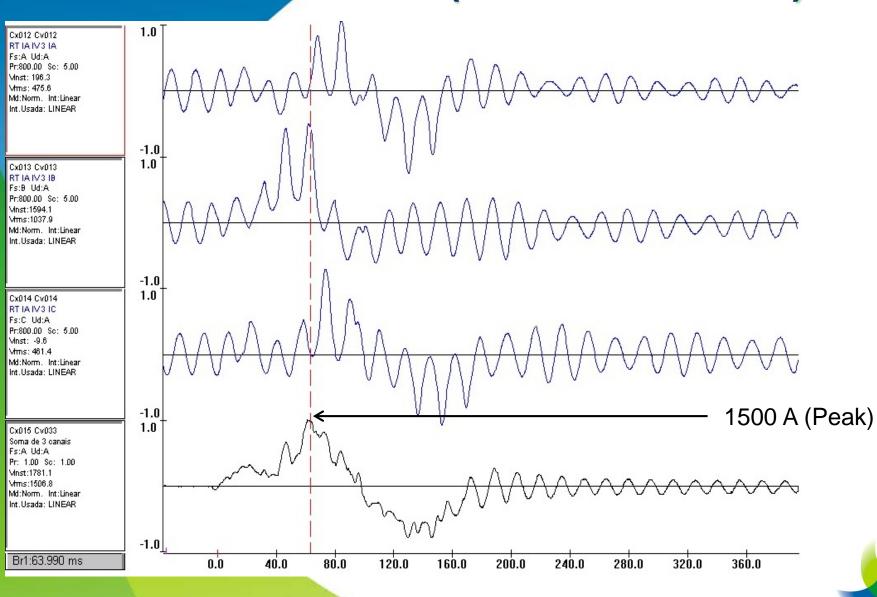


#### **Power Outage:**

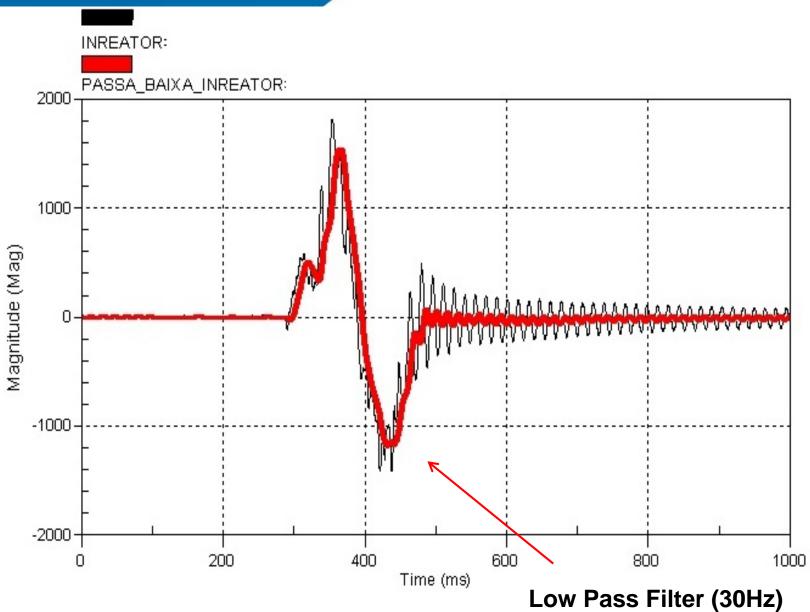
- 765kV: 5.564 MW
- HVDC System: 5.329 MW (Blocking of 2 Bipoles)
- Total Power outage: 24.400MW (40% of the Brazilian Transmission System)



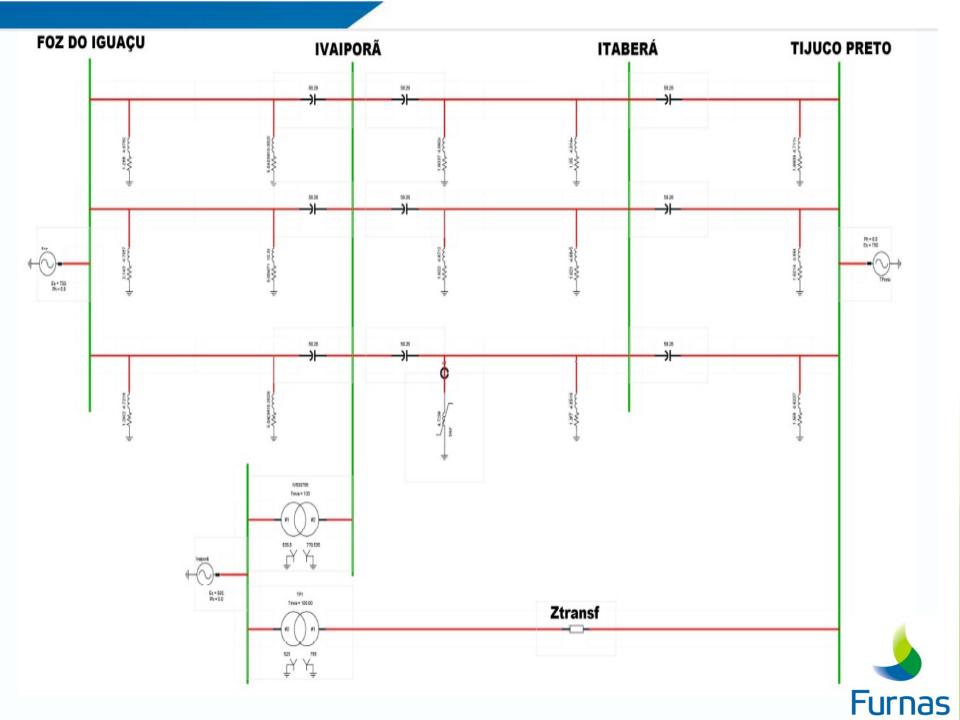
#### Reactor C3 currents (COMTRADE File)

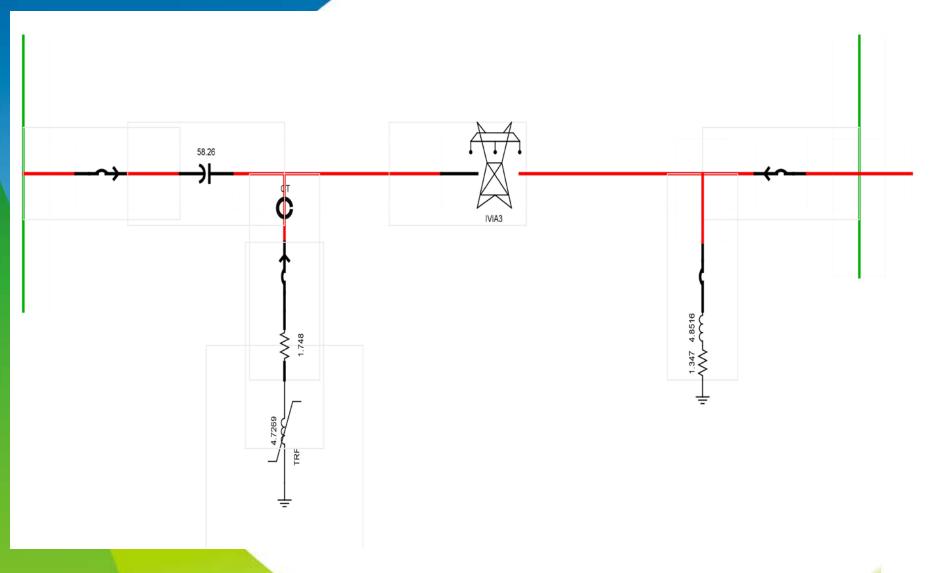


**Furnas** 

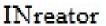


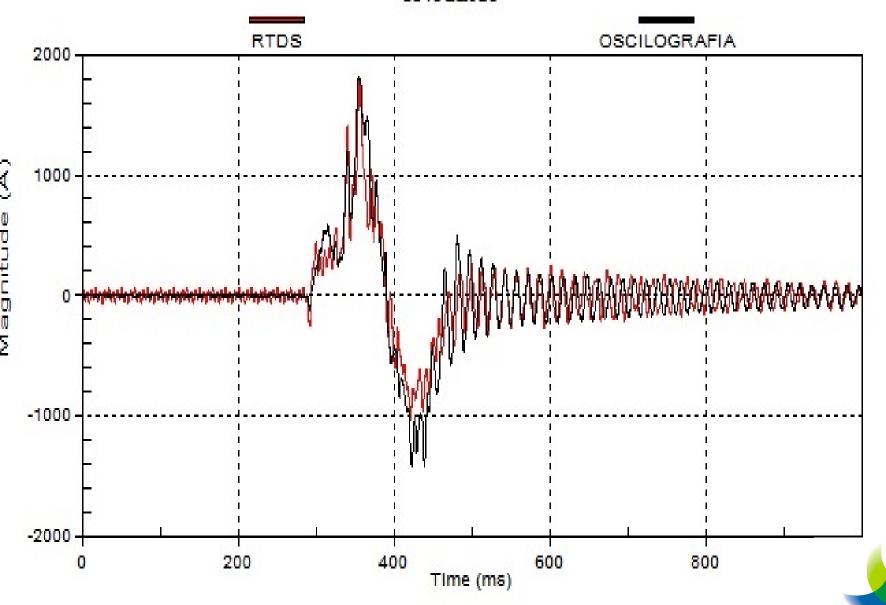




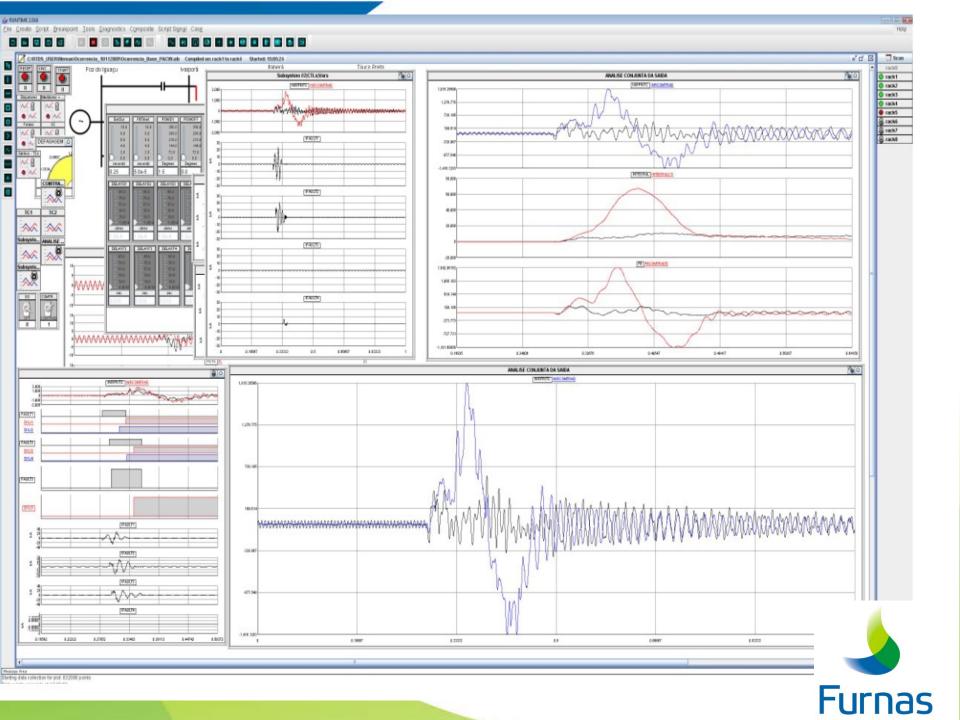








**Furnas** 



#### Real Protection Testing using the RTDS

Real Current of the event applied to the protection (COMTRADE)



#### **Protection TRIP**

RTDS Reactor current applied to the protection



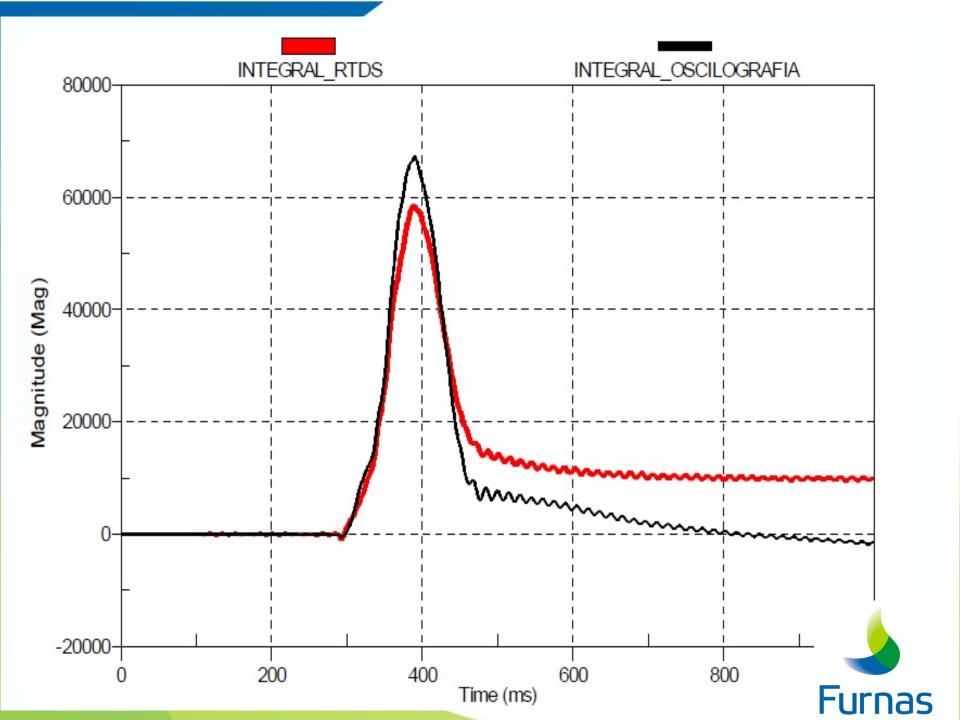
**Protection DID NOT TRIP!** 

RTDS Reactor current + 3% gain



**Protection TRIP!** 





#### **New Digital Protection Testing using the RTDS**

**COMTRADE** current of the event applied to the protection



**Protection DID NOT TRIP** 

RTDS Reactor current applied to the protection



**Protection DID NOT TRIP** 

Protection TRIP only after a 200% gain applied!



### Report of the Studies were presented to the National Agency of Electrical Energy

**Recommendations of the Agency:** 



Instalation of Booster Shed to enhanced the insulation



The Brazilian ISO must increase the priority for the upgrade of the 765kV protections



#### Conclusion:

- Real Time tests are useful for support system operation
- Hardware Replicas for controllers and Protection Spares has a important role for system operation analysis

More realistic analysis



**Operators training on real situations** 



Aditional Spare Set for emergency

 FURNAS Operation Staff realize that is important to include the supply of hardware replicas for FACTS devices (HVDC and SVC)

## Thank you for your Attention!

