THE USE OF REAL TIME DIGITAL SIMULATION FOR PERFORMANCE ANALYSIS OF BUSBAR DIFFERENTIAL PROTECTION

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ABSTRACT

The purpose of this article is to present a performance analysis of differential protection applied on Anhanguera 345/230/88 kV Gas Insulated Switchgear (GIS) Substation of ISA CTEEP (Companhia de Transmisão de Energia Elétrica Paulista), a Brazilian power transmission utility. The performance analysis was based on the digital simulations results of differential numeric protective relays on the GIS´s busbars and feeders, realized between July and August of 2006 at SIEMENS AG's facilities (Erlangen – Germany), using Real Time Digital Simulator (RTDS™). Several types of faults simulations were accomplished, in several configurations of the busbars and feeders of all the 03 (three) different voltage levels (345/230/88 kV) of the GIS Substation where the protective relays would be installed. The results are presented not only with the times of faults elimination, but also with all functionality and advantages that these modern devices make possible to the electrical power transmission and distribution systems.

Key words: *Differential Protection, Busbar Protection, Digital Simulation, Gas Insulated Switchgear (GIS).*

INTRODUCTION

The year 2007 constitutes a milestone in history: for the first time there are more people on the planet living and working in cities than in rural areas. The United Nations (UN) estimates that by 2030, the percentage of people concentrated in cities should reach 61%, increasing the current urban population from 3 to 5 billion. This accelerated process of urbanization and economic growth is creating a huge demand for infrastructure, especially in cities with more than 10 million inhabitants.

São Paulo is the largest city in South America (5th largest city in the World) and one of the largest metropolitan regions on the planet. It is also the largest industrial, economic and financial center in Latin America. Currently, more than 20 million inhabitants live in this megacity, equivalent to 10% of Brazil's population. This huge gathering of people, buildings, and streets is responsible for 15% of the total energy consumption in the country, a number that increases substantially each year.

To ensure adequate energy supply to keep pace with the growth of the city of São Paulo and to avoid the risk of energy shortages, ISA CTEEP *(Companhia de Transmisão de Energia Elétrica Paulista)* developed the Anhanguera Complex, consisting of the Guarulhos - Anhanguera 345 kV transmission line, the Guarulhos Substation expansion with two new 345 kV bays, and a Gas Insulated Switchgear (GIS), the Anhanguera 345/230/88 kV Substation, that is the most important project using the SF6 insulation technology in Brazil [1]. Figure 1 presents the location of the São Paulo State and the city on the Brazilian map.

Figure 1 – Location of the São Paulo State and the city of São Paulo on the Brazilian map

Located in the greater area of the city of São Paulo, the Anhanguera 345/230/88 kV GIS Substation was designed as a response to the growing demands for energy in the southeast region, as well as to create and guarantee the integration of the feeder system of the 230 kV Centro Substation and complete the 345 kV ring around São Paulo. The idea was to improve São Paulo's transmission system by increasing its flexibility, reliability and stability. Figure 2 presents the Anhanguera GIS 345/230/88 kV Substation.

Figure 2 – Anhanguera GIS 345/230/88 kV Substation

ISA CTEEP *(Companhia de Transmisão de Energia Elétrica Paulista)* is a Brazilian Energy Utility of the São Paulo State with a transformation capacity of 38.500 MVA, distributed in 11.780 km of transmission lines. It is responsible for 30% of Brazil's total power transmission [1]. The need for energy reliability and quality in power transmission and distribution resulted in the choice of multifunction numeric protective relays for this GIS substation that could assure the continuity and stability warranty for CTEEP's power system.
Simulations and tests were requested to analyze the busbar differential protection behaviors that were installed in the Anhanguera 345/230/88 kV GIS Substation. The digital simulations presented in this paper were accomplished in several configurations of the busbars and feeders of all the 03 (three) different voltage levels (345/230/88 kV) of the GIS Substation where the protective relays would be installed. The simulations results will be presented together, making possible a performance evaluation of all busbar differential protection.

REAL TIME DIGITAL SIMULATOR (RTDS™)

The *Real Time Digital Simulator (*RTDS™*)* is a digital TNA, flexible, accurate and with great Electrical Power System and components representation capacity. Figure 3 presents an example of a RTDS™`s rack (the simulation system uses more than one rack, depending on the system size that is being simulated in each case) [2].

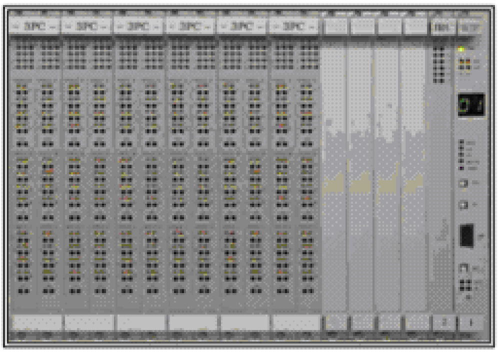


Figure 3 – Example of a *Real Time Digital Simulator (*RTDS™*)*'s rack

The numeric protective differential relays are connected to the *Real Time Digital Simulator (*RTDS™*)* via current amplifiers (5, 20 or 40 Arms) and voltage amplifiers (0 to 130 Vrms). The *tripping* commands were realized by segregated phase, allowing the test of single pole auto-reclosure.
The Real Time Digital Simulations documentation (presented in Figure 4) contains all the faults and alarms registers, also the numeric relays commands and reactions through the process of sending and receiving signals to the system. Besides current and voltage analogical signs were registered together with the numeric protective relays binary inputs and outputs, supplying the fault detection and *tripping* commands times.

DIGSI V4.30 ...siano 2 / 7SA612 V4.2 left/7SA612 V04.22.03 09/04/2002 11:53:19

Trip Log - 000088 / 04.09.02 11:55:11.315 - CEMIG / Vespasiano 2 / 7SA612 V4.2 left/7SA612 V04.22.03

Number	Indication	Value	Date and time	Cause	State
00301	Power System fault	88 - ON	04.09.2002 11:55:11.315		
00302	Fault Event	104 - ON	04.09.2002 11:55:11.315		
03682	21 Pickup AG	ON	0 ms		
03701	21 Selected Loop AG forward	ON	0 ms		
04056	85-21 Carrier SEND signal	ON	0 ms		
03802	21 TRIP command - Only Phase A	ON	0 ms		
02844	79 1st cycle running	ON	1 ms		
02801	79 - in progress	ON	1 ms		
00533	Primary fault current Ia	6,11 kA	2 ms		
01332	50N / 51N Ground O/C is BLOCKED	ON	10 ms		
04006	>85-21 Carrier RECEPTION, Channel 1	ON	29 ms		
01318	>85-67N Carrier RECEPTION, Channel 1	ON	29 ms		

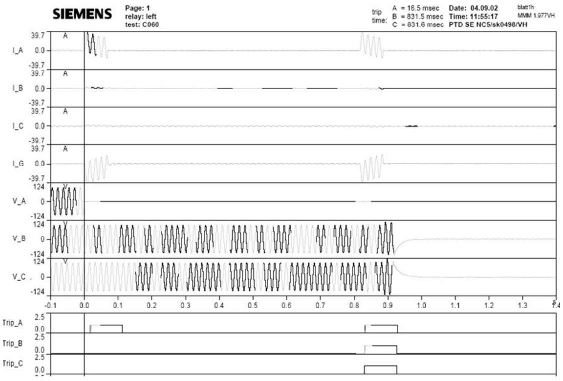


Figure 4 – Events Sequence and Oscillograph example of a fault simulation on the RTDS™

THE SIMULATION CONFIGURATION

The simulations were realized through the definition of 03 (three) possible busbar configurations, this means 03 (three) different configurations of the bay units of the differential protection on the busbar feeders (double busbar), in a total of 04 (four) remote units (Bay Units), supplying information to the central unit of the busbar differential protection. Figure 5 to 7 presents the 03 (three) possible busbar configurations.

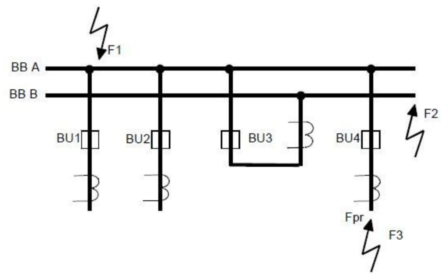


Figure 5 – Busbar Configuration 1 (all Feeders on Busbar A)

In these configurations were applied short-circuits using resistance values that cannot be annulled due to numeric reasons, so the value of 0.04 Ω was used, being realized internal and external faults tests. The fault types simulated were: single phase fault (AG/BG/CG), double phase fault (AB/AC/BC), double phase fault with ground (ABG/ACG BCG), three phase (ABC) and three phase fault with ground (ABCG), internal and external to the protection zone.

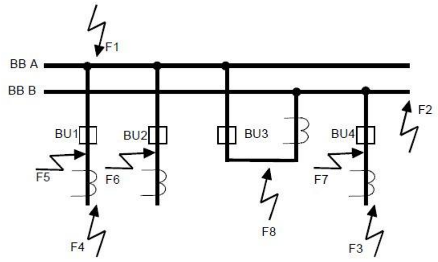


Figure 6 – Busbar Configuration 2
(Feeder 4 on Busbar B)

The conditions of the 03 (three) busbar configurations (and all voltage levels) were analyzed through the application of the following faults: Internal faults on Busbar A and B; External faults and Evolving faults (external to internal).

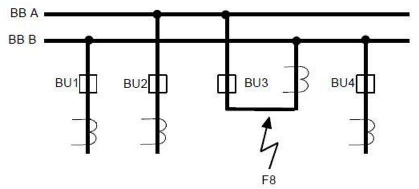


Figure 7 – Busbar Configuration 3
(Feeders 1 and 4 on Busbar B)

BUSBAR DIFFERENTIAL PROTECTION PERFORMANCE ANALYSIS

The protection systems to be installed in the Brazilian Electrical Power System should follow the Minimum Requirements of Protection, Supervision/Control and Telecommunications Systems defined by the National Operator of the Electrical System – ONS [3]. Besides, ISA CTEEP elaborated a rigorous technical specification. Aiming to reach all the power system protection requirements, SIEMENS presented the busbar protection and bay units 7SS52, presented in Figure 8 [4].

Figure 8 – Busbar Protection and Bay Unit 7SS52

The main purpose of the performance analysis of a numeric protection is to validate the relay that will be used in the busbar protection project, also proving the effectiveness of the schemes and protection settings. The 7SS52 numeric protective relays settings and the protection schemes were defined together with SIEMENS and ISA CTEEP.
The results of the performance analysis were accomplished with oscillographic fault recording, the sequence of the events and the defects elimination times. All the situations here presented were chosen for the tests and simulations in all the 3 (three) voltage busbars levels 345/230/88 kV of the GIS Substation. A total of 350 simulations were realized, all present in a specific simulations report [5]. Some of the most important results will be presented, with the simulation description, the busbar configuration (C1, C2 and C3), fault location (F1, F2, F3, F4, F5, F6, F7 and F8), and Bay Units (BU1, BU2, BU3 and BU4) *tripping* times, validating all the remaining work realized.

Internal Faults on Busbars A and B

- Configuration 1 (all Feeders on Busbar A);
- Fault Location 1 (Fault on Busbar A).

TABLE I
Simulations Results: Internal Faults on Busbar A (F1)

Internal Fault		**7SS52 – Bay Units**			
Busbar [kV]	**Fault Phases**	**BU1 [ms]**	**BU2 [ms]**	**BU3 [ms]**	**BU4 [ms]**
345 kV	AG	13.8	13.8	13.6	13.6
345 kV	ABG	12.7	12.8	12.6	12.6
345 kV	ABC	12.4	12.5	12.3	12.4
88 kV	AG	13.9	13.9	14.0	14.0
88 kV	ABG	12.8	13.0	12.7	12.7
88 kV	ABC	13.1	13.2	12.9	13.1
230 kV	AG	13.8	13.9	13.7	13.8
230 kV	ABG	13.0	13.0	12.8	12.7
230 kV	ABC	12.4	12.4	12.2	12.3

- Configuration 1 (all Feeders on Busbar A);
- Fault Location 2 (Fault on Busbar B).

TABLE II
Simulations Results: Internal Faults on Busbar A (F2)

Internal Fault		**7SS52 – Bay Units**			
Busbar [kV]	**Fault Phases**	**BU1 [ms]**	**BU2 [ms]**	**BU3 [ms]**	**BU4 [ms]**
345 kV	AG	----	----	13.5	----
345 kV	ABG	----	----	12.4	----
345 kV	ABC	----	----	12.3	----
88 kV	AG	----	----	14.0	----
88 kV	ABG	----	----	12.9	----
88 kV	ABC	----	----	12.4	----
230 kV	AG	----	----	12.8	----
230 kV	ABG	----	----	12.7	----
230 kV	ABC	----	----	12.1	----

External Faults

- Configuration 2 (Feeder 4 connected to Busbar B);
- Fault Location 4 (external fault on Feeder 1);
- Breaker Failure start by external signal.

TABLE III
Simulations Results: External Faults on Feeder 1 (F4)

Internal Fault		7SS52 – Bay Units			
Busbar [kV]	**Fault Phases**	**BU1 [ms]**	**BU2 [ms]**	**BU3 [ms]**	**BU4 [ms]**
345 kV	AG	148.1	287.2	287.0	----
345 kV	AB	150.3	289.4	289.3	----
88 kV	AG	148.2	287.2	287.0	----
88 kV	ABG	148.3	287.4	287.1	----
230 kV	AB	150.8	162.6	162.5	----
230 kV	ABC	148.2	158.3	158,0	----

Evolving Faults

- Configuration 2 (Feeder 4 connected to Busbar B);
- Fault Location 4 to 1 (after 100 ms).

TABLE IV
Simulations Results: Evolving Faults (F4 to F1)

Internal Fault		7SS52 – Bay Units			
Busbar [kV]	**Fault Phases**	**BU1 [ms]**	**BU2 [ms]**	**BU3 [ms]**	**BU4 [ms]**
345 kV	AG to AG	25.8	25.9	25.8	----
345 kV	AG to ABG	26.2	26.3	26.0	----
88 kV	AG to AG	29.9	29.9	29.7	----
88 kV	AG to ABG	23.3	23.4	23.2	----
230 kV	AG to AG	28.0	28.2	27.9	----
230 kV	AG to ABG	23.3	23.4	23.2	----

- Configuration 2 (Feeder 4 connected to Busbar B);
- Fault Location 3 to 2 (after 100 ms).

TABLE V
Simulations Results: Evolving Faults (F3 to F2)

Internal Fault		7SS52 – Bay Units			
Busbar [kV]	**Fault Phases**	**BU1 [ms]**	**BU2 [ms]**	**BU3 [ms]**	**BU4 [ms]**
345 kV	AG to BG	----	----	18.7	18.7
345 kV	AG to ABG	----	----	18.6	18.6
88 kV	AG to BG	----	----	21.9	22.0
230 kV	AG to ABG	----	----	18.3	18.4

CONCLUSIONS

Differential protection was one of the first protection functions to be used. The faults are detected through the comparison of the electrical currents that enters in the protected element with the electrical currents that leaves the same element in the system. As a result of this quality command of fast trip with absolute selectivity, the differential protection is used to protect the main components of the power systems as generators, transformers, busbars, as cables and transmission lines.
For all the accomplished simulations the *tripping* times were satisfactory and significant differences were not found on the protections performances for the 03 (three) different voltage levels (345/230/88 kV) of the Anhanguera GIS SS.
The great and constantly growing concern with the power systems protections theme will stimulate the utilities to use Real Time Digital Simulation (with the RTDS™) to obtain better performances of the protections that will be installed in their power transmission and distributions systems.

REFERENCES

[1] ISA CTEEP (*Companhia de Transmisão de Energia Elétrica Paulista*): www.cteep.com.br.

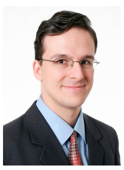
[2] A. L. P. de Oliveira, 2003, *Transmission Lines Numerical Distance Protection Performance Analysis using Real Time Digital Simulation (in Portuguese)*, Power Systems Protection Specialization Course – CEPSE monograph, Federal University of Itajubá - UNIFEI, Itajubá, MG, Brazil.

[3] National Operator of the Electrical System – ONS, 2002, *Minimum Requirements of Protection, Supervision/Control and Telecommunications Systems-Submodule 2.5 –Rev.1*, Brazil.

[4] G. Ziegler, 2005, *Numerical Differential Protection – Principles and Applications*, Publicis MCD (Munich and Erlangen): Siemens AG.

[5] V. Henn, 2006, *System Planning CTEEP TNA Test*, Erlangen – Germany.

BIOGRAPHY



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