DISTANCE PROTECTION PERFORMANCE ANALYSIS IN SHORT AND LONG TRANSMISSION LINES USING REAL TIME DIGITAL SIMULATION

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ABSTRACT

The purpose of this article is to present a performance analysis of the distance protection applied on short and long transmission lines of Companhia Energética de Minas Gerais – CEMIG (a Brazilian Electrical Company). The analysis was based on the simulations results of numeric protective relay on power transmission lines, in September 02 to 06, 2002, at SIEMENS AG's facilities (Erlangen – Germany), using Real Time Digital Simulator (RTDS™). Several types of faults simulations were accomplished, in several conditions of the electrical power system 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 system.

Key words: *Distance Protection, Teleprotection, Digital Simulation, Transmission Lines.*

INTRODUCTION

The CEMIG (Companhia Energética de Minas Gerais) is one of the most important energy utilities of Brazil, located in the Minas Gerais state, southeast region of the country. It is responsible for the operation of one of the biggest and most complex extra-high voltage transmission systems, occupying a critical position on the Brazilian National Integrated Energy System. A simplification of CEMIG Transmission System is presented on Figure 1.

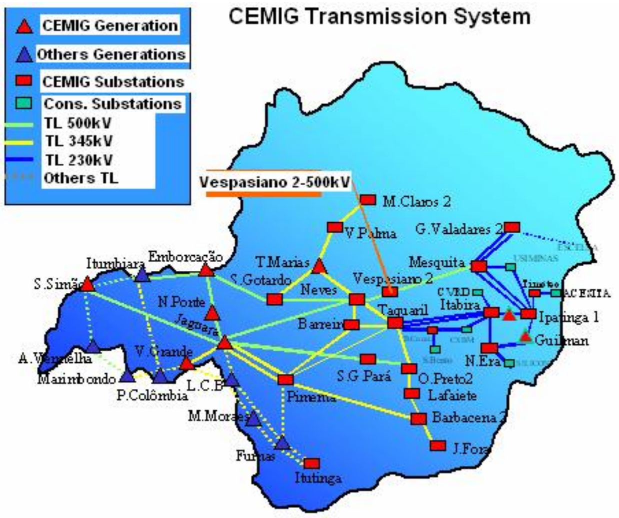

Figure 1 – CEMIG Transmission System

Nowadays, CEMIG has almost 21.000 km of transmission lines and more than 300 substations, with a transformation capacity of 28.000 MVA [1]. CEMIG has been worked on the expansion and modernization of the transmission system, building new transmission lines and big substations to add more security and reliability to one of the most organized power systems of Brazil.

One of these great endeavors was the Vespasiano 2 – 500kV/600MVA Substation, constructed around the city of Belo Horizonte (capital of the Minas Gerais state) that starts the operation in March 2003. This new substation parted the 500kV transmission line between the Mesquita and Neves 1 substations, resulting in two new transmission lines: one short (23,9km) and one long (148,6km).

The Neves 1 SS – Vespasiano 2 SS Short 500kV Transmission Line (23,9 km)

This Short 500kV Transmission Line is a single circuit line and has the length of 23,9km, with a normal loadflow of 1.150A, from the left strong source (Neves 1: 6,06GVA) to the right weak source (Vespasiano 2: 1,56GVA).

The Vespasiano 2 SS – Mesquita SS Long 500kV Transmission Line (148,6 km)

This Long 500kV Transmission Line is a single circuit line and has the length of 148,6km, with a normal loadflow of 1.050A, from the left strong source (Vespasiano 2: 5,20GVA) to the right weak source (Mesquita: 2,60GVA).

THE REAL TIME DIGITAL SIMULATION

The simulations were done in September 2002, at SIEMENS AG's facilities in Erlangen (Germany). CEMIG was responsible for supplying the necessary power transmission lines parameters and other elements of the electrical power system in which the new distance protection system were installed.

A Real Time Digital Simulator (RTDS) was used in a closed loop simulation. So the *tripping* and reclosing commands for the circuit breakers were sent directly to the simulator. The simulation system setup, using the given data provided great fidelity to the real power system for these tests and simulations.

The Fault Simulation System

The modeling of the fault simulation system is presented in Figure 2, which presents the transmission lines real conditions where the numeric protective relays were installed: single-circuit with high voltage circuit breakers on the line ends, with one of the substations as a strong source and other as weak source.

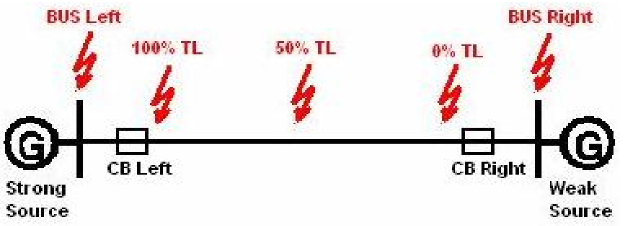

Figure 2 – Faults Simulation System modeling with the faults simulations positions

The faults (short-circuits) were simulated using resistor values that could be changed from a very high to a low value. Since zero fault resistance is not possible due to numeric reasons, the value of 0,04Ω was used [2, 3]. The internal and external (susbstations busbar) fault types and nomenclature were:

- Single Pole Fault (SPF)
- Double Pole Fault (DPF)
- Double Pole Fault with Ground (DPFG)
- Three Pole Fault (TPF)
- Three Pole Fault with Ground (TPFG)

In these faults simulations, power transmission lines conditions with or without load, high impedance faults, circuit breaker switch onto faults and behavior on evolving faults were analyzed.

The 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 [2]. Figure 3 presents an example of one RTDS™`s rack (the simulation system uses more than one rack, depending of the system size that is been simulated in each case).

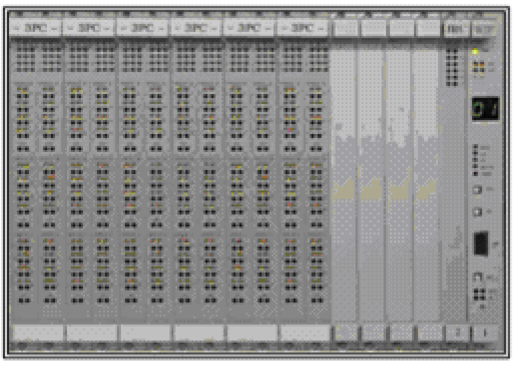

Figure3 – Example of one Real Time Digital Simulator (RTDS™)'s rack

The numeric protective distance relays are connected to the Real Time Digital Simulator (RTDS™) via current amplifiers (5, 20 or 40Arms) and voltage amplifiers (0 to 130Vrms). The tripping commands were realized by segregated phase, alowing the test of single pole auto-reclosure.

The 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. Also 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.

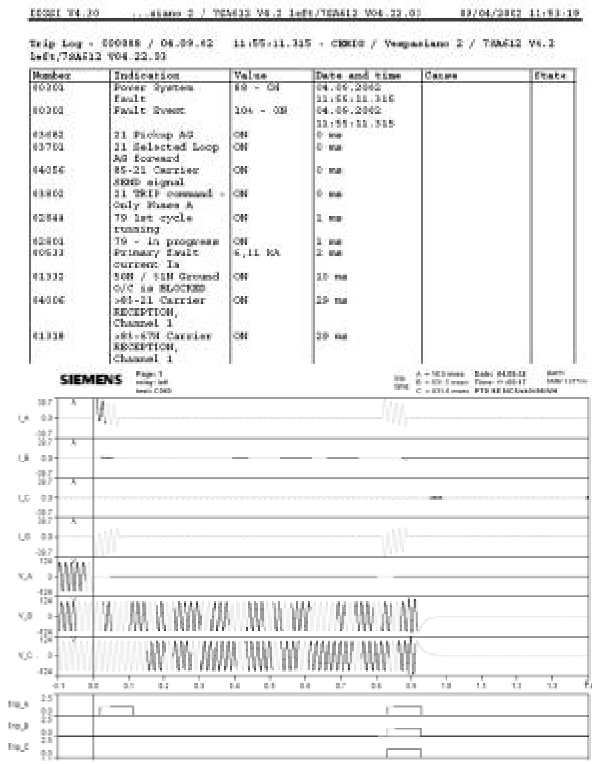

Figure 4 – Events Sequence and Oscillograph example of a fault simulation on the RTDS™

The Numeric Distance Protective Relay 7SA612

The protection systems to be installed in the Brazilian Electrical Power System should follow the Minimum Requirements of Protection, Supervision/Control and Telecommunications Systems of the National Operator of the Electrical System – ONS [4]. Besides, CEMIG elaborated a rigorous technical specification.

Aiming to reach all the power system protection requirements, SIEMENS presented the distance protection 7SA612 (Software Version V4.22.03), a numeric protective relay (presented in Figure 5) of digital microprocessor technology with multifunction, oscillograph routines, internal time synchronization by GPS satellite sign, local and remote settings, self diagnostic, self tests and serial/optical outputs for communication with microcomputers. Besides the non-switched distance protection with 6 measuring systems (21/21N), this protective relay also has directional overcurrent function for the three phases and neutral (67/67N), additional complementary protection functions (overcurrent backup (50/51 and 50/51N), circuit breaker failure (50BF), power swing blocking (68), undervoltage (27)/overvoltage (59), synchronization check(25)) and selection of single pole/three pole auto-reclosure. It has also logics that permit the application of several protection schemes like: Permissive Overreaching Transfer Trip (POTT), Permissive Underreaching Transfer Trip (PUTT), Unblocking/Blocking, Weak Infeed Protection, etc. [5].

Figure 5 – Numeric Distance Protective Relay 7SA612

Training

The network simulations are also perfect training for the customers that will work with the protective relays. The fault analysis gives deep understanding of the behaviour of the network and the relays. This improved capability helps the customer to study and find suitable settings for future projects and the correct solution in case of real network faults.

DISTANCE PROTECTION PERFORMANCE ANALYSIS

The main purpose of the analysis of numeric distance protection performance is to validate the relay that will be used in the transmission lines protection project, also proving the effectiveness of the schemes and protection settings. The 7SA612 numeric protective relays settings and the protection schemes were defined together with SIEMENS and CEMIG.
The results analysis was 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 both transmission lines (short and long). A total of 134 simulations were realized, all present in a specific report [3]. Some of the most important results will be presented, with Internal Transmission Lines (TL Position (%): from the Weak Source/Right Side to the Strong Source/Left Side) and Busbar Right (B-R) and Busbar Left (B-L) faults, validating all the remaining work realized. The triping times are presented for each protective relays: (Neves 1 = NEV, Vespasiano 2 = VES and Mesquita = MES).

Metallic Faults with Load

● Conditions: Load 100% / Metallic Faults (0,04Ω).
● To Observe: Distance Protection, Phase Selection, Zone Selection and Trip Times.

TABLE I
Simulations Results: Metallic Faults with Load

FAULTS Phases, TL Position (%), R (Ω)/Ang (°)	Trip [ms] (Short Line)		Trip [ms] (Long Line)	
	NEV	VES	VES	MES
A-G/100%/0,04Ω/0°	16,5	31,9	16,3	41,1
A-B/100%/0,04Ω/30°	13,8	38,5	14,1	43,4
B-G/50%/0,04Ω/60°	16,6	16,7	16,3	16,5
A-B-C/50%/0,04Ω/30°	16,3	16,2	17,8	17,8
B-C-G/0%/0,04Ω/60°	38,3	15,8	40,4	15,8
A-B-C/0%/0,04Ω/90°	42,8	20,2	40,1	16,6
A-G/B-L/0,04Ω/0°	------	317,3	------	318,4
A-B-C/B R/0,04Ω/90°	317,4	------	322,3	------

High Resistive Faults with Load

● Conditions: Load 100% / High Resistive Faults (5 to 20Ω).
● To Observe: Distance Protection, Phase Selection, Zone Selection and Trip Times.

TABLE II
Simulations Results: High Resistive Faults with Load

FAULTS Phases, TL Position (%), R (Ω)/Ang (°)	Trip [ms] (Short Line)		Trip [ms] (Long Line)	
	NEV	VES	VES	MES
A-G/100%/5,0Ω/0°	18,5	42,3	17,6	43,7
A-G/100%/20,0Ω/0°	16,2	39,3	18,2	43,4
B-C-G/50%/10,0Ω/60°	16,5	18,1	19,0	18,6
B-C-G/50%/20,0Ω/60°	16,2	16,4	18,3	18,5

Close onto Faults

● Conditions: Without Load / Metallic Faults (0,04Ω) / CB Right is open and CB Left closes onto fault.
● To Observe: Close onto fault detection and Trip Times.

TABLE III
Simulations Results: Close onto Faults

FAULTS Phases, TL Position (%), R (Ω)/Ang (°)	Trip [ms] (Short Line)		Trip [ms] (Long Line)	
	NEV	VES	VES	MES
A-G/100%/0,04Ω/0°	14,9	------	13,9	------
B-C-G/100%/0,04Ω/0°	14,4	------	14,2	------
A-G/0%/0,04Ω/30°	19,5	------	18,3	------
B-C-G/0%/0,04Ω/0°	18,5	------	18,8	------

Echo Function

● Conditions: Without Load / Metallic Faults (0,04Ω) / CB Right is open and an internal fault occour.
● To Observe: Echo Function and Trip Times.

TABLE IV
Simulations Results: Echo Function

FAULTS Phases, TL Position (%), R (Ω)/Ang (˚)	Trip [ms] (Short Line)		Trip [ms] (Long Line)	
	NEV	VES	VES	MES
A-G/100%/0,04Ω/0˚	14,3	------	15,2	------
A-C-G/0%/0,04Ω/60˚	20,5	------	21,2	------
A-B-C/0%/0,04Ω/90˚	20,8	------	21,8	------

Evolving Faults

● Conditions: Load 100% / Metallic Faults (0,04Ω) at 100% of TL / One fault evolve to another after XX ms (5 or 25ms).
● To Observe: Distance Protection, Phase Selection, Zone Selection and Trip Times.

TABLE V
Simulations Results: Evolving Faults

FAULTS Phases+ XXms = New Fault	Trip [ms] (Short Line)		Trip [ms] (Long Line)	
	NEV	VES	VES	MES
A-G +5ms= A-B-G	19,5	43,1	20,0	44,6
B-G +5ms= A-B-C-G	19,8	43,8	20,4	45,7
A-G +25ms= A-B-G	15,1	38,5	18,7	42,4
B-G +25ms= A-B-C-G	16,5	39,5	16,1	41,7

The simulations results were all satisfactory. The *trip* times were effective even whem the relay operates as a backup protection (busbar faults). The same simulations were accomplished for the short and long lines and were not found significant differences on the protective relay selected for the project, demonstrating the equipment's versatility.

CONCLUSIONS

Real Time Digital Simulation (with the use of RTDS™) to analyze the performance of distance protection applied to short and long transmission lines demonstrates to be a very powerful tool. It is possible to simulate infinite situations that can happen in the electrical power system and to obtain the best performance of the numeric protective relay that is being analyzed for future installation in the electrical power system. Also permits the protective relays training together with specialists.
The choice of the faults to be simulated was made through sampling, with the purpose to cover the most common cases that occur in the power transmission lines of Brazilian Electrical Power System. Real time digital simulation is recommended for performance analysis of numeric protective relays to be used in power transmission lines.

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BIOGRAPHIES

André Luiz Pereira de Oliveira was born in 1978 (Brazil). He received his BSEE degree in electrical engineering from the Itajubá Federal School of Engineering (EFEI), Brazil, in 2001. Obtained Specialist's title in Power Systems Protection and MSc in electrical engineering, in 2004 and 2006, respectively, from Itajubá Federal University (UNIFEI), Brazil. Project Management Professional (PMP®) certified by the Project Management Institute® - PMI® (USA) since 2004. He works at SIEMENS Ltda. as a Project Manager (PM) since 2001 at PTD H (Power Transmission and Distribution - High Voltage Department). Responsible for the supplying of "turn-key" High Voltage Substations and Power Compensation Systems, managing contracts with industrial sector and Brazilian Electrical Power System utilities.

Volker Henn, born 1959 in Germany, received his Dipl.-Ing. degree from the University of Karlsruhe in 1985. From 1985 to 1990 he worked at Siemens AG, Power Transmission and Distribution, Protection Department. In 1991 he joined the System Planning Department, were he is working in the field of real time simulation and protection testing.