Analysis of Large-System Fault with Phasor Measurements

I. C. Decker, S. L. Zimath, D. Dotta, M. N. Agostini, *and* A. S. e Silva.

Abstract-- **This paper describes results of the MedFasee project aiming at the development and performance testing of a Synchronized Phasor Measurement System (SPMS) prototype and its applications for monitoring of power system operation. The prototype consists of a Phasor Data Concentrator (PDC) and nine Phasor Measurement Units (PMUs) installed in the main cities in Brazil. Results from monitoring system frequency and voltage under disturbance conditions are presented. This present paper will show analysis of faults that occurred in the transmission corridor from Itaipu Power Plant (14,000MW) when two 765kV lines are simultaneously unavailable at the same time, imposing significant restrictions on the transmission from the north to the southeast of Brazil.**

***Index Terms*—Phasor Measurements, PMU, power system monitoring, wide-area monitoring, SPMS, WAMS.**

I. Introduction

LARGE integrated power systems usually have generation and transmission restrictions due power system stability [1]. Special protection schemas (SPS) can be implemented to improve the power system stability margins and consequently providing a power system operation safety and economic viable. Special protection schemes are those designed to detect one or more predetermined system conditions that have a high probability of causing unusual stress on the power system, and for which preplanned remedial action is considered necessary. The failure of these schemes to accurately detect the defined conditions, or their failure to carry out the required preplanned remedial action, can lead to very serious and costly system disturbances [2].

This present paper will show analysis of faults that occurred in the transmission corridor (3 x 765 kV AC, 1 x +-600 kV DC) from Itaipu Power Plant (14,000MW) when two or more line are simultaneously unavailable at the same time, imposing significant restrictions on the transmission from the north to the southeast of Brazil.

On July 4th, 2009, a rainy day with severe thunderstorms, the protection of 2 of the 765 kV circuits from Itaipu set the lines out of service, imposing an overload onto the remaining transmission system from Itaipu to the load center. A special protection schema dropped 4 generators from Itaipu to reduce the overload on those lines, but on the other hand, it caused an overload in the transmission system from the north to the southeast of Brazil.

This behavior had been predicted in simulations and thus, a command was sent to Tucurui Hydroelectric power plant (8,340MW) in the north of Brazil, turning off 2 generators and reestablishing the balance after a spinning reserve from several power plants in the south immediately got the load. The special protection schema was responsible for allowing an additional 900 MW from the north to the south of Brazil, generated from hydro sources and reducing the same amount of thermal generation with cost and environmental benefits.

The Itaipu and Tucurui hydroelectric plants are 2200 miles away from each other and the command sent to Tucuruí passed by 40 substations and reached the final destination within 33 milliseconds, a time short enough to maintain the integrity of the electrical power system. Just a few months after its installation, the special protection schema has already been used twice due to the fact that the 765 kV lines are very long and located in a region which is very susceptible to thunderstorms.

Synchronized measurements from 9 regions were bused to analyze the excited oscillation modes in order to check if the SPS had a good behavior and if the oscillations detected during simulations actually happened.

The paper is organized as follows. In Section 2, the MedFasee project is presented and the main software and hardware components of the SPMS prototype are described. In Section 4, the performance of the SPMS prototype in monitoring the power system under abnormal conditions is presented. Finally, in Section 5, the main conclusions are presented.

II. MedFasee Project

The MedFasee project was started in 2003 aiming at the development of a phasor measurement system prototype and applications for power systems monitoring and control. The first prototype was installed in the end of 2004 and since then several disturbances, in Brazilian power system, have been monitored[4].

A. SPMS Prototype

The SPMS prototype is composed by one PDC and nine PMUs. The PMUs were installed in laboratories of nine universities in Brazil covering all the geo-eletric regions. The

Work supported of the Brazillian Government Research Agency (CNPQ) Grant 554847/2006-0.

I. C. Decker, D. Dotta, M. N. Agostini , and A. S. e Silva are with Federal University of Santa Catarina, Florianópolis, SC 88.040-900 Brazil (e-mail: decker@labplan.ufsc.br,daniel@labplan.ufsc.br,agostini@labplan.ufsc.br,aguinald@labspot.ufsc.br).

S. L. Zimath is with Reason Technology S. A., Florianópolis, SC 88.025-500 Brazil (e-mail: sergio.zimath@reason.com.br).

PMUs measure the instantaneous three-phase distribution voltage and frequency. Each PMU is connected to the Internet through an ethernet network interface and sends the phasors to the PDC located in the Electrical Systems Planning Research Laboratory (LabPlan) at UFSC. In Figure 1 the geographical location of the PDC and PMUs in Brazil is shown.

The main hardware components and the prototype functionalities are described as follows:

1) PMU

The PMUs currently used are simplified versions of the Reason RPV304 Digital Fault Recorder, with PMU functions. For the implementation of the main PMU functions, phasor calculation and transmission to the PDC, the voltage three-phase samples acquired synchronously with the GPS reference, are processed, and formatted in data frames, using the IEEE Std. C37.118 format [17]. Each PMU has a GPS receiver to synchronize the samples, so that the phasors measured by all PMUs in the power system are in the same time reference. The PMUs have nine phasor channels, and currently three of them measure the three-phase outlet voltage. The phasors are continuously sent to the PDC, at a rate of 60 data frames per second, using an Ethernet link (UDP/IP protocol).

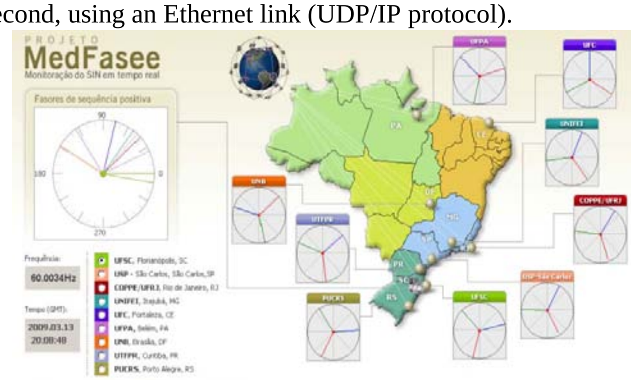

Fig. 1. PMUs and PDC geographical location.

2) PDC

The PDC receives and correlates time-tagged phasor data sent by all the PMUs. Two parallel computational platforms are used to perform these functions.

A homegrown PDC were designed and implemented in computing routines using the Object Oriented Modeling paradigm and C++ programming language. As the PDC needs to support real time applications it is necessary to rank the routines priorities. The PDC was built using the GNU/Linux operating system that does not have native real time support. The real time support is enabled in GNU/Linux applying a patch to the GNU/Linux kernel.

Recently, the TVA OpenPDC has been also used for this function and tests of performance are developed.

3) Network

The PMUs and the PDC are connected by Ethernet using the Internet network. The Internet connection was chosen due to its availability and the facilities provided to manage the PMUs remotely. There is a firewall installed at the PMU, that sets a VPN (Virtual Private Network) tunnel with the server installed at UFSC. All communication packets between PMUs and PDC are transmitted securely through the VPN tunnel. The phasors are sent by the PMUs using the UDP/IP protocol, with IEEE Std. C37.118 data frames.

B. Environment for Monitoring Application

An integrated software with facilities for monitoring and analysis applications using the PDC phasors were developed and implemented using a C++ platform. These facilities are divided in tree modules [15]:

1) Geographical Module

This module presents the geographical and technical information of the PMUs. In the technical information is included the PMU idcode, number of measurement channels and voltage and current base.

2) Real Time Module

This module supports the monitoring of real time data provided by the PDC. The application shows the real-time phasors arriving in the PDC.

3) *Off-Line Module*

This module allows the monitoring of the phasors kept in the PDC database. The main screen allows access to the database and graphics plotting. This screen enables the user to choose which phasors he wants to observe. One of the phasors can be chosen as the system reference. The user can still choose which measurements to observe: voltage magnitude, voltage angle or frequency. This environment facilitates the development of graphical applications and the mathematical treatment. Additionally, a fault location tools was developed and included in this module

The integrated system is presented in the Figure 2.

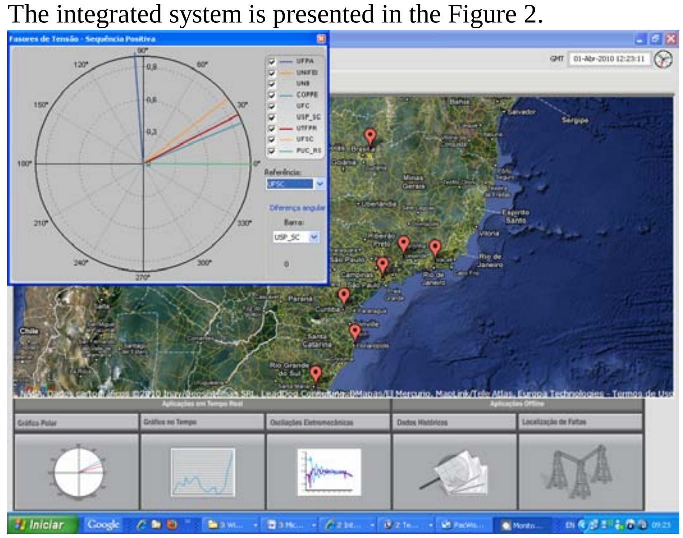

Fig. 2. Application of monitoring and analysis

III. SPMS Prototype Performance

This section describes the SPMS prototype performance under abnormal operating conditions using the software applications developed in the MedFasee project.

A. Disturbance Detection

1) Outage of a 765kV Transmission Line

An important disturbance was registered by the SPMS prototype in July 04, 2009. At 18h36min, two of the three circuits of the 765 kV transmission line Itaipu/Ivaiporã (shown in Figure 3) was tripped. Soon after, the Special Protection Scheme (SPS) actuated at Itaipu powerplant, removing four 60 Hz generators, and at Tucuruí powerplant, in Northern Brazil, removing two generators. This SPS is designed to avoid the loss of synchronism between the North-Northeastern and the South-Sotheastern sub-systems. The total generation shedding was 2300 MW at Itaipu and 576 MW at Tucuruí powerplants. Generators operating as synchronous compensators reverted to real power generation in eight power-plants in Southern and Southeast/Center-Western regions. Figure 3 depicts the Brazilian Interconnected Power System and indicates three main events of this disturbance.

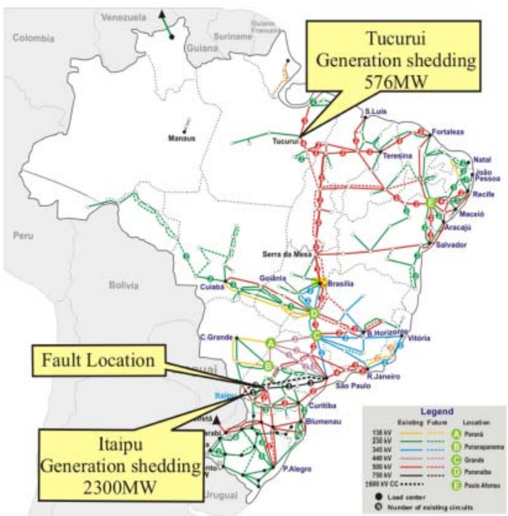

Fig. 3. Brazilian Interconnected Power System.

Figure 4 shows the frequency behavior during the disturbance in the five measurement points. These points represents each geo-eletrical region of the Brazilian Interconnected Power System.

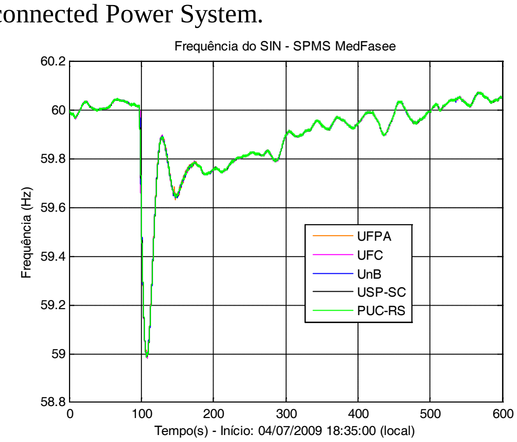

Fig. 4. Voltage frequency at five locations.

Figure 5 shows frequency behavior exactly during the disturbance. The system frequency reach a minimum of 59 Hz.

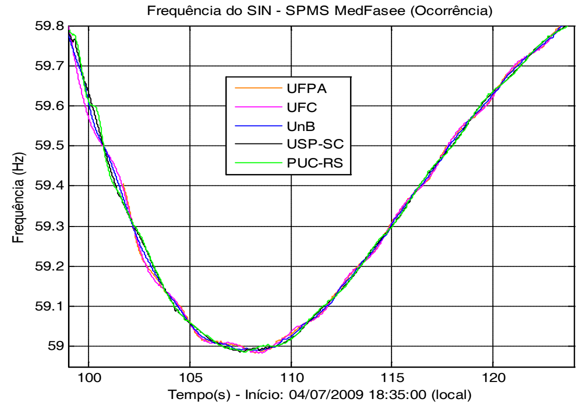

Fig. 5. Voltage frequencies zoom.

Electromechanicall oscillations between different regions of Brazilian Interconnected Power System are shown in the Figure 6.

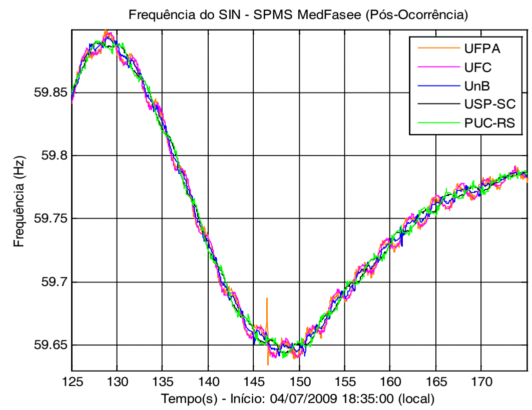

Fig. 6. Eletromechanical oscillations

IV. Conclusions

This paper described the performance of a SPMS prototype developed by the MedFasee project. The PMUs were installed in geographically distant cities covering the main geo-eletrical regions in Brazil. Performance results of SPMS under Internet have shown its capability in providing network connection for SPMS.

A large system disturbance is presented and show the applicability of the SPMS prototype to understand the dynamical phenomena at the power system despite the conection on the low-voltage.

V. Acknowledgment

The authors gratefully acknowledge the contributions of Thiago Jeremias and Pedro Cordeiro for their cooperation to support the applications development.

VI. References

[1] J Karlsson, D. Hemmingsson, M. and Lindahl, S., "Wide Area System Monitoring and Control," *IEEE Power and Energy Magazine*, Vol. 2, pp. 68-76, Sep. 2004.

[2] P. M. Anderson and B. K. LeReverend, “Industry Experience with Spectial Protection Schemes” IEEE Transactions on Power Systems, Vol. 11, n 3, pp. 1166-1179, Aug. 1996.

[3] R. Klump, R. E. Wilson, and K. E. Martin, "Visualizing Real-Time Security Threats Using hybrid SCADA/PMU Measurement Displays" *Proceedings of the 38th Hawaii International Conference on System Sciences*, Hawaii, U.S.A. 2005.

[4] I. C. Decker, et al.: "Performance of a Synchronized Phasor Measurement System in the Brazilian Power System," *IEEE General Meeting 2006*, Montreal, Canadá, June, 2006.

[5] *IEEE Standard for Synchrophasors for Power Systems*, IEEE Standard PC37.118-2005, Jun. 2005. (under revision)

VII. Biographies

Ildemar Cassana Decker received his B. Sc. from the Catholic University of Pelotas, RS., Brazil. He obtained his M.Sc. (1984) and D.Sc. (1993) degrees in Electrical Engineering from Federal University of Santa Catarina and Rio de Janeiro, Brazil, respectively. From 1980 to 1985 he worked in Federal University of Santa Maria, RS. Since 1985 he has been Associate Professor of the Federal University of Santa Catarina, in Department of Electrical Engineering. His general research interest is in the area of computer methods for power systems analysis and control and high performance scientific computing.

Sergio Luiz Zimath received his degree in Automation and Control Engineering from Federal University of Santa Catarina in 1997. Since 1995, he has been with Reason Technology where he was responsible for the development of the Digital Fault Recorder model RPIV, GPS Based time references among other products. Since 2005 he is in charge of the Research Projects Department, involved in the study of new technologies.

Daniel Dotta received his B. Sc. and M.Sc. degrees in Electrical Engineering from the Federal University of Santa Catarina, SC., Brazil. Since 2004 he has been developing his Ph.D. in Federal University of Santa Catarina, in Department of Electrical Engineering. His general research interest is in the area of modeling and object-oriented programming for power systems analysis and control and high performance scientific computing.

Marcelo Neujhar Agostini received his degree in Electrical Engineering from Federal University of Santa Maria in 1996. He worked as a research engineer at the same institution before starting postgraduate studies. He obtained his D.Eng. degree in Electrical Engineering from the Federal University of Santa Catarina in 2002. Currently he works at this university as a researcher engineer. His general research interest are phasor measurements, software engineering applied to Electric Power Systems, Object-Oriented Modeling, Electric Power Systems Modeling, Electric Power Systems Dynamics and High Performance Scientific Computing.

Aguinaldo Silveira e Silva received his degree in Electrical Engineering from Federal University of Parana in 1977, and the M.Sc. and Ph.D degrees in Electrical Engineering from Federal University of Santa Catarina, in 1982 and UMIST, UK, in 1990, respectively. Since 1980, he has been with Federal University of Santa Catarina. His main research interests are in the area of power systems dynamics and control applications.