I. INTRODUCTION

**ITAIPU DAM** is currently the world’s largest hydroelectric plant in terms of power generation. With 20 generator units and 14,000 MW of installed capacity, it provides approximately 17% of the energy consumed in Brazil and 75% of consumption in Paraguay. Itaipu produced in 2013 a total of 98,630,035 megawatt-hours (98.6 million MWh), breaking its own world record for energy production, which occurred in 2012, with the generation of 98,287,128 megawatt-hours (MWh). The previous record was in 2008 when Itaipu generated 94,684,781 MWh. [1]

Itaipu is responsible for delivering the electricity generated by the power plant to the connection points with the Interconnected System. On the Brazilian side the connection is located at the Foz do Iguazu substation owned by Furnas, and on the Paraguayan side, the connection is made at the Right Bank substation, situated within the area of the Itaipu power plant. Power transmission to the load centers is the responsibility of Furnas Centrais Elétricas, in Brazil, and ANDE (Administración Nacional de Electricidad), in Paraguay.

Itaipu Gas Insulated Switchgear are in the same building, one for 50Hz, a double busbar receiving energy from 10 Generators, 700 MW each, and switching to 4 output transmission lines and the other for 60Hz, with the same configuration, receiving energy from 10 Generators, 700 MW each, and switching to 4 output transmission lines. The main components are 54 Circuit Breakers (4000Amps/63kA), 128 Disconnecting Switches, 154 Earthing Switches, 414 CT’s, 24 PT’s, 132 Metal Oxide Surge Arrestors, More than 7500 meter of busbars and 110 tons of SF6 gas.

The installation was carried out in seven stages over the period from 1984 to 1990, With 91 failures from 1984 to 2013 the statistics results as per **Table 1** below raise the concern of finding a way to prevent such failures. [4]

**Table 1**

The initial failures mostly had common causes and the GIS supplier responded immediately to solve the problems. At the present moment there are no known common mode failures without corrective actions already implemented. Since 1984 Itaipu had chosen a portable acoustic PD equipment to detect and amplify vibrations at the range from 36kHz to 44kHz. When it was evident that this monitoring method was not capable of detecting and preventing all the possible failure modes, Itaipu began researching for a complementary method to increase detection of the total range of failures at their initial stage.

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**Abstract— This paper endorses the UHF method to monitor partial discharges (PD) in Gas Insulated Switchgear Systems (GIS). This paper highlights the experiences of Itaipu - the world’s largest hydroelectric power plant in terms of power generation – in detecting and eliminating PD’s considers a risk in its GIS system.**

Before deciding to use the UHF method, Itaipu formed a research group to analyze available methods to decide which would best inform the presence of all possible kinds of PD in GIS. The lead-time of material and also total cost of repairing a GIS is much higher then an AIS, not to mention that repairing GIS takes time and must be carefully inspected and reassembled. Having said that, Itaipu’s goal as described throughout this paper is to reduce the probability of failure through removal of the Partial Discharge source identified by the use of a PDM intelligent monitoring device, with alarms capabilities integrated. This paper is sharing cases of prevention provided by José Guilherme Rodrigues Filho, Electrical Engineer responsible in Itaipu for the GIS equipment, it also inform how Itaipu acted upon the information of the PD signal and how they proceeded to eliminated the dielectric partial breakdown.

**Index Terms—**Partial Discharge, UHF, Gas Insulated Switchgear, Expert System, Alarms

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Itaipu’s main goals and restrictions were: (1) To find a system that increases the range of detectable failures at their initial stage. (2) A solution that must be compatible with the Switchgear already in operation. (3) The relative cost-benefit ration has to be compatible with the expenses to repair one failure/year over the plant life.

Experts who monitor equipment insulated by SF6 [2] conducted a study in 1996 to investigate the efficiency and state of the art monitoring systems available: IEC-60270 (capacitive divider connected directly to potential), Acoustic Method (piezoelectric sensor), Chemistry method (Ion Mobility Spectrometer), Optical method (applies to UV photodiodes) and VHF and UHF Method (Electromagnetic Waves reflected inside the enclosure).

In order to correctly evaluate the performance of all of these methods per Itaipu field conditions equipment, Itaipu assembled a test installation cell using spare parts and started a systematic research program to verify the performance of all available methods. The tests had the support from the experience and cooperation of Itaipu employers in laboratory tests, factory and field acceptance tests, maintenance tests, in addition to supplier demonstrations, the results and conclusions could be summarized as follows:

- **IEC-60270**: (Capacitor divider directly connected to potential): Not applicable to field conditions because it was very sensitive to field noise and also has high cost of capacitor dividers and adapting to existing equipment.

- **Acoustic Method**: already used by Itaipu through a monthly scan in more than 200 designated points. The method proved unable to detect all the possible modes of detectable failures at their initial stage under field conditions.

- **Chemistry Method** (collect sample of the SF6): Incapable of meeting the requirements of detection of failures at their initial stage.

- **Chemistry Method** (Ion Mobility Spectrometer): Tested under Itaipu field conditions twice without success.

- **Optical Method**: Not tested because of its limits in detecting discharges internally in insulators and other structures that don’t allow light to pass through.

- **VHF and UHF** (Electromagnetic Waves inside the enclosure): Tested with success with equipment from two different suppliers that differ in performance due to the technology they use for signal acquisition and processing.

III. THE CHOICE

The UHF Monitoring System was selected because of better technical performance and lower cost in the Itaipu field conditions. The chosen UHF Partial Discharge Monitoring out of the two systems also had an expert system using Artificial Neural Networks (ANNs) as part of a hybrid modular expert system with a database consisting of over 2 ½ million exemplars from real live substation data, in addition to providing a classification of the PD type the output from the expert system is used to generate PD alarms such that only signals considered to be PD contribute towards PD alarms.

The UHF method has gained wider acceptance all over the world, and has now been installed on hundreds of substation worldwide. The expert system with PD analyses carried still by only one supplier has high degree of accuracy considering the increasing of exemplars from real live substation data. The PD analyses given are used to provide technical advice and reporting to customers with such solutions.

IV. IMPLEMENTATION

In 2001 Itaipu installed an initial set with 24 points PDM system. As it demonstrated the expected performance, in 2004 the system was expanded to more than 420 points. As mentioned before there are 154 Earthing-Switches available in Itaipu. Considering that it’s a single phase GIS installed, there are 462 sensors available. (See Fig. 1 below)

This specific GIS design has in its earth switch a corona shield internally around the ground conductor connected to an external BNC female connector (Fig. 2). This shield is able to receive the UHF signal when partial discharge occurs. The other reason for this BNC output is to verify the absence of VAC prior to grounding the busbar.

![Fig. 1 - Itaipu GIS Installation](image-url)
In 2006 the supplier developed a UHV sensor that could be installed externally to the busbar insulator (Barrier Couplers), and Itaipu acquired more than 60 sensors. Today in Itaipu there are 480 sensors installed at their GIS. Because of significant UHF sensitivity there is no need to install antennas in every gas compartment. The electromagnetic waves are capable of passing through barriers insulators and continue to travel along the way, and there is attenuation of the signal that must be considered. According to CIGRE Joint TK 15/33.03.05 [3] the sensitivity test can be verified and couplers/antennas can be designated accordingly. The UHF PDM system has to be capable of detecting discharges in the range of 5pC above, as the GIS has to be designed to allow the installation of a sufficient number of antennas to measure such lower discharges rates.

V. DETECTED CASES

More than 10 cases of detection/prevention were documented from the day of Itaipu's GIS installation, after crossing 6 cases prevented the system has already paid itself. It was determined the average cost to repair a GIS in case of failure times the number of cases prevented, when subtracting the cost of the PDM system it clearly shows the benefit of using the PDM system on a Condition Base Maintenance Strategy. All cases in Itaipu were announced/detected by the Partial Discharge Monitoring (PDM) system via its alarms capabilities. Because of that Itaipu could track the PD development and make a decision on whether to take or not the system out of service to be repaired. Without a plan to efficiently react in those times, failure will continue to occur.

In order to maintain a minimum number of pages accepted in conferences, only three cases out of 10 were selected.

A. Breaker CB 05U09 Phase R – Particles (August 04, 2005)

On August 2005 the presence of “particles” (Fig.3) on the PDM system via the Artificial Neural Networks (ANNs) were detected. Itaipu decided to take action and open the breaker for further investigation as per information provided by the PDM system. As per the following Fig.4 and Fig.5 Itaipu could continue to validate the performance of the PDM system:

Action: SF₆ Gas Analyses, Gas Handling and Vacuum Cleaner were performed to eliminate particles; the breaker was resealed with new O-rings and desiccant, Vacuum, SF₆ was refilled to nominal pressure and gas analyses was conducted (result above limit expected); approved to be reenergized.

B. Surge-arrester A34-T1 phase T (May 05, 2006) - Particles

At the same time (09:01AM) the presence of PD was detected in two different channels: channel a6A03T2 B (Fig.6) and channel 76U11T B (Fig.7). As per picture Fig.7 it is clear that the amplitude of the signal is higher on channel 76U11T B (right side) where the position of the Surge Arrestor is at A34-T1 phase T as Fig.8. This is an excellent case to demonstrate that the PDM system can also help obtain an approximated localization of the failure, which can effectively reduce the time in finding the PD source as preventing to open the wrong gas compartment.
The Artificial Neural Networks (ANNs) indicate a higher percentage of chance (69%) to be particles. The ANNs is a continuous diagnosing brain, collecting the PD occurring in the cycle in real time and comparing it with the data bank to inform the results out of the 100% sampling collected at that moment. As the PD continues to develop the ANNs will collect other samples and inform higher probability. Below Fig.8 shows Itaipu lowering the surge arrestor to remove particles.

Figs.9 and 10 show the PRPD (Phase Resolved Partial Discharge) before and after the repair.

Action: As action taken on case “A”

C. Support Insulator DS 55U9A (30, April 2006) - Void

This case shows that between 1984 and 2006 this support insulator as shown in the following Fig.12/13 never presented partial discharging, until after April 30th, 2006. The PD doesn’t have time and place to start to develop. Due to a variety of reasons PD can become active and start to discharge until it possibly could find a complete way through the dielectric insulation. Figs.12/13 shows a void opening at the support insulator and Fig.11 shows the discharge pattern and also its classification “Void/Contamination 98%”.

Below on Fig.13 is a radiography from the support insulator indicating an opening of 6mm internally.

Action: As action taken on case “A” plus replacing the support insulator with a new one.

VI. CONCLUSION:

This paper discusses how the expert system (ANNs) can be useful in identifying the PD source. Partial Discharge (PD) can develop in a matter of minutes, hours, days even years, without key software intelligence 24-hour supervision would be needed. The practical response to those alarms is vital to preventing failures. Installing a PDM system alone is insufficient; the data collected and the alarms generated by the system must be assessed and acted upon. It’s important to take a balanced and objective approach when reacting to the presence of PD activity within switchgear.

Itaipu has many successfully stories because behind an efficient PDM system there is a plan taking place to act upon the information provided by the PDM, helping to save millions of dollars to be invested in other priorities.
REFERENCES:

[2] CIGRE-WG15.03 – Studies accomplished in 1996 (references)
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José Guilherme Rodrigues Filho (1958) is from Santos Dumont, MG, Brazil. He graduated with a B.S. in Electrical Engineering from the Federal University of Minas Gerais in 1981. He started as a maintenance engineer in 1982 at the State Utility in Minas Gerais (CEMIG) and has worked for the Itaipu Hydroelectric Power Plant since 1988. In 1996 he obtained his Masters in Computer Science, followed by a postgraduate degree in Software Engineering in 1998. In 2002 he earned a Masters of Science in Electrical Power Systems and is about to conclude a PhD at the Federal University of Itajubá. Since 2004, in parallel with Itaipu maintenance activities, Mr. Filho teaches Grounding Systems and Substation Electrical Equipment courses at the State University of West Parana. At Itaipu he is responsible for maintenance engineering of the 500kV GIS. Besides the routine maintenance, Mr. Filho always works to provide the Itaipu GIS, 1980 design, with the updated technologies in the monitoring systems that justify their cost benefit to increase the reliability of the GIS. Also the UHF monitoring System, has already implemented a 54 Circuit Breakers monitoring system and now is concluding a SF6 Humidity, Density and Temperature monitoring system to 670 points. Phone contact +55 45 3520 2696, jgrfilho@itaipu.gov.br.

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