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On-site Repair of a HVDC Transformer

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ABSTRACT

This paper presents the setup and application of technology to on-site repair of a high voltage converter transformer.

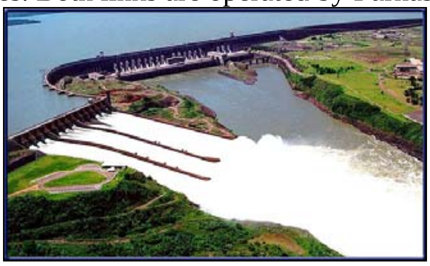
This technology has been applied successfully for many years in Brazil and South America to repair large HVAC power transformers. Based on this experience, this paper presents general aspects associated with the selection of this technology for repair of a large HVDC power transformer.

In short, this paper presents a general view of on-site repair steps of a HVDC converter transformer combined with the corresponding manufacturing steps at factory, including drying and on-site routine and high voltage electric test processes.

KEYWORDS: Transformer, Power Transformer, Converter Transformer, Repairs, On-Site Repairs

1. INTRODUCTION

The Itaipu Power Plant is located in the Paraná River at the border between Brazil (60Hz) and Paraguay (50Hz). It is the largest hydropower plant in the world today with 12600MW (plus 1400MW until 2004) of installed generation capacity. Two main transmission links connect the power plant to São Paulo and Rio de Janeiro heavy industrial load centers far more than 900km from the power plant. One HVDC 6300MW, ±600kV, 2-bipoles and another HVAC 765kV links are used for transmission purposes. Both links are operated by Furnas, the largest Brazilian utility.



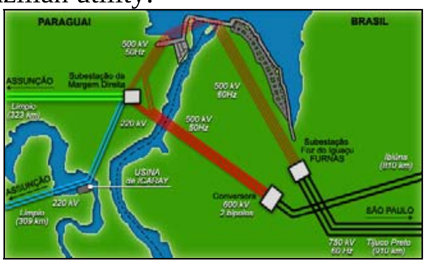


Figure 1 – Itaipu Power Plant and Transmission System

The HVDC transmission system has at the sending end a large converter station from 500kV AC to

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±600kV located near Foz do Iguaçu while at the receiving end the inverter station from ±600kV to kV345kVAC is located near to São Paulo. This HVDC system has been operating since 1984 and its reliability is very critical to the stability of the whole Brazilian interconnected power system. In each converter and inverter station there is a set of 24 large single-phase converter transformers connected to the valves.

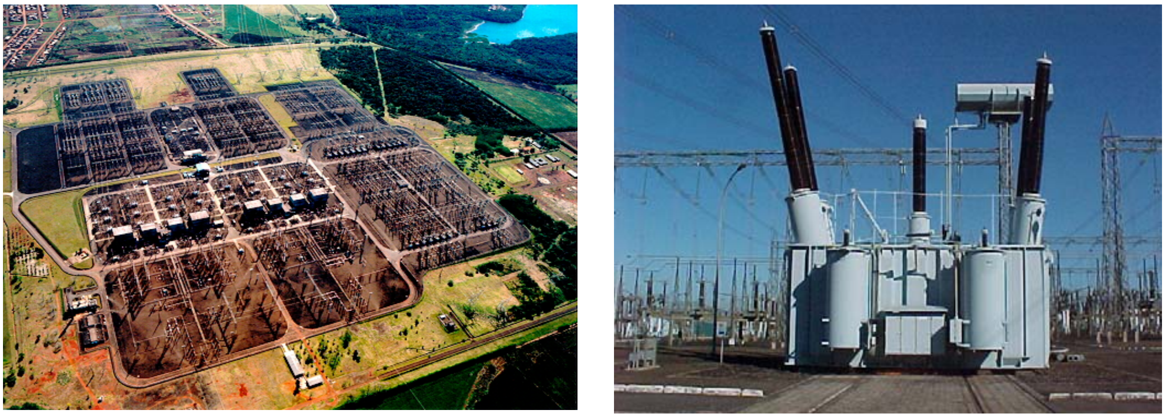

Figure 2 – Itaipu Electric Power System: Foz do Iguaçu Converter Station and the HVDC Converter Transformer Single-Phase, 314MVA, 600kV

Early in the year 2002, an electric failure damaged one of the converter transformers installed at Foz do Iguaçu converter station. The involved unit is single-phase, two wounded limbs, 50Hz, 314MVA rated power, ±600kV DC (550/√3-127/√3-127kV) rated voltage and 420tons of total mass. The repair requires complete replacement of the winding blocks.

2. TRANSFORMER ON-SITE REPAIR

The large transformers' factories in Brazil are also located near São Paulo. Road shipment, using large and heavy special trucks, is normally used for this transportation. Transformer mass for shipment is about 220tons. However, to cover one way almost 1200km of road routes to factory takes more than 60days due to complexity of the transportation operations. In addition, total transportation cost may amount to more than 1000000USD on both ways site-factory-site. Transportation risks are also relevant.

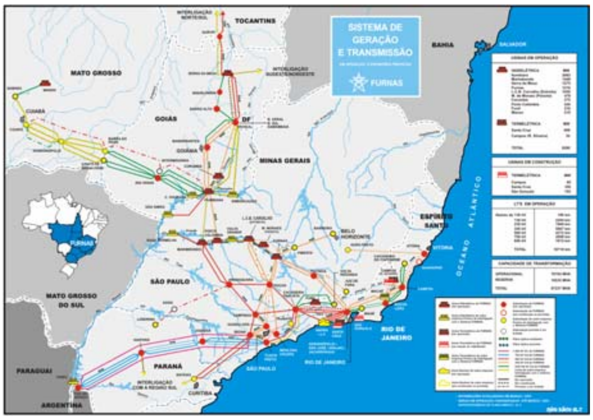

Figure 3 – São Paulo and Itaipu Locations

This and also based on advanced application of on-site repair technology in South America, especially in Brazil, where several large transformers have been completely repaired on site in the last 12 years [1], has motivated Furnas to proceed to on-site repair of this large HVDC converter transformer for the first time in Brazil.

3. ON-SITE REPAIR EXPERIENCE

Since 1992, complete on-site repair has been performed in more than 96 transformers for large electric power supply companies and industrial plants in South America. Transformers produced by different manufacturers and with different technologies, with rated power ranging from 30MVA to 440MVA and rated voltage ranging from 115kV to 765kV, have been repaired.

Figure 6 shows 96 transformers submitted to complete on-site repair (including winding replacement) in South America since 1992, stratified according to power levels.

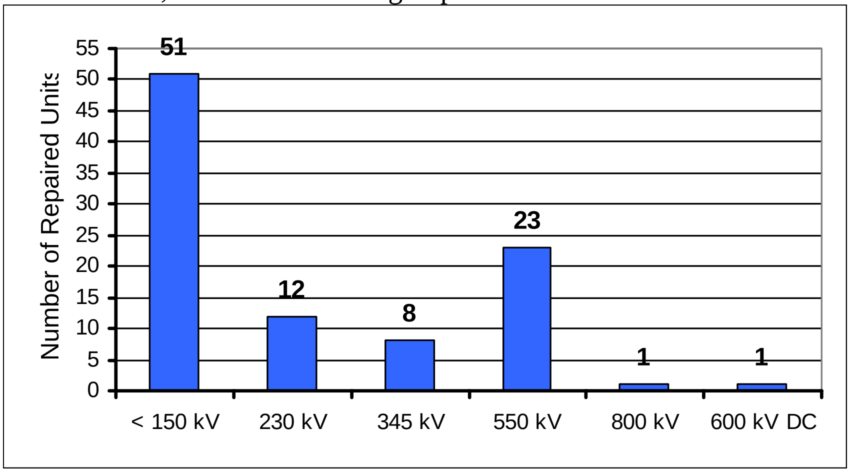

Figure 4 – On-Site Complete Repairs from 1992 to 2003

On-site repair results show that the transformers present reliable performance. Since 1992, it has accumulated more than 425 transformers x year operation after on-site repair. Additionally, long-term performance monitoring of transformers already repaired, under actual conditions of electric power systems, has also qualified the process used for on-site repair of HV power transformers.

4. ON-SITE REPAIR PROCESS

On-site repair of high voltage transformers requires a combined set of special processes supported by a group of transformer specialists. The repair process, involving replacement of winding and main insulation, basically includes the following main steps:

- setup of the site facility;
- hauling and transformer disassembly;
- untanking of the active part;
- active part disassembly;
- manufacturing steps;
- core repairs;
- active part assembly;
- on-site drying;
- final processes; and
- on-site routine and high voltage tests.

4.1. SITE REPAIR FACILITY

Due to transformer and active part weight and consequently a heavy foundations base, the repair facility is set up around a spare transformer base.

A temporary repair facility includes erection of a metallic house with an area up to 500 m² and 20 meters high (designed for 150km/hours wind speed and tight to heavy rain). Internally to the metal house, an internal extraclean room is assembled which has controlled environment for the active part assembly work. Figure 5 shows an external view of the metal house and hauling operation of the assembled transformer prior to active part untanking.

Figure 5 – Site Facility: Metal House

The transformer's active part is about 180tons. For active part untanking, mobile self-propelled lifting equipment is used with high load capacity (400 tons).

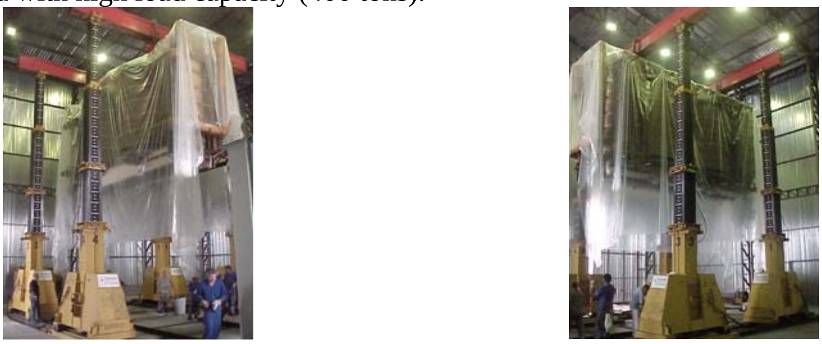

Figure 6 – Site Facility: Lifting Equipment

Auxiliary mobile lifting (crane) equipment with medium load capacity, devices for assembly and pressing of the active part are also used during the repair steps. In addition, the site facility includes:

- dry air generation stations (air dew point of <-30ºC and air outflow above 400m^3/h) in order to maintain the transformer’s active part and the extraclean room conditioned under a continuous and controlled dry air flow with positive pressure; and
- mobile facility with vacuum, drying and oil treatment equipment.

4.2. TRANSFORMER REPAIR

The transformer repair process started just after untanking of the active part. The following steps has been taken:

- opening of the upper core frame and disassembly of the core upper yoke;
- opening of all internal leads connections and disassembly of the HV winding connections and pressboard leads support structure;
- disassembly of windings, main insulation and core-winding insulation. Windings are removed from the core limbs through special lifting devices driven by a mobile auxiliary crane;
- core repair, including replacement of the complete core insulation from pressboard to fiberglass material and core retightening. Naturally, this operation requires that the core be in horizontal position. A mobile core stack table with capacity for 180tons has been used for this purpose;

Figure 7 – Core Repair (assembled core mass: 173tons)

- at factory it is provided manufacture of new components specified for the transformer, such as windings and main insulation. Windings are mounted as a single-phase block.
  Before delivery for drying, windings are submitted at delivery to the following ***on-factory tests***: measurements of winding ohmic resistance; voltage ratio (with auxiliary test core); measurements of leakage magnetic flux and applied voltage between parallel conductors.
  Winding blocks and other insulating components are processed in a Vapor Phase type oven and impregnated with insulating oil. Packaging is performed in metal tanks pressurized with dry air;
- on-site assembly of the active part, final pressing, tank active part assembly and external assembly;
- controlled drying process, using the combination of cycles of full vacuum and hot oil circulation with continuous monitoring of temperature, internal and surface moisture of solid insulation and water concentration in the oil;
- final external assembly, vacuum, oil filling and oil circulation; and
- routine and dielectric tests.

Each phase of the process is fully controlled. The quality control of the processes is recorded according to internal procedures certified in compliance with ISO 9001 and ISO14001.

4.3. ON-SITE DRYING

Initially, phase winding blocks and the remaining insulating components internal to the transformer are submitted, while in factory, to Vapor Phase drying and oil impregnation processes.

On site, the drying process is initiated after the assembly and tanking of the transformer’s active part. The on-site drying process is performed by a combination of successive cycles of vacuum and hot oil circulation.

Control parameters of each drying cycle are: vacuum time, vacuum pressure, core temperature, insulation and oil temperature.

In addition, the control parameter of the drying process quality is the internal moisture of the insulation measured in Laboratory, by using the Karl Fisher method applied to adequate test models (sized pressboard material) extracted from the transformer after each drying cycle. Drying is complete when the internal moisture of test models is below or equal to 0.5%.

As an example, table 1 shows, step by step, the amount of surface and internal moisture of the test models used in on-site drying control of a typical large 550kV power transformer submitted to the above described drying process on site.

Table 1 – On-Site Drying Performance

Step	Process	Moisture %
1	after factory drying	0.30
2	during on-site assembly	0.40
3	after active part tanking	0.62
4	final	0.46

Thus, the repair process used, including on-site drying, ensures low final moisture and high-quality insulation of the transformer, compatible with advanced on-factory drying processes.

4.4. ON-SITE ELECTRIC TESTS

After the final processes have been completed, final acceptance electric tests are performed, including high voltage dielectric tests.

To perform these tests, a complete set of mobile testing equipment is shipped to the repair site, including variable frequency motor-generator group, step-up and regulating transformers, reactive power compensating capacitors and reactors as well as measuring and partial discharge electro-acoustic monitoring system.

The following ***on-site tests*** are performed:

- routine tests: insulation resistance (core and structure-core); polarity, phase angle displacement and phase sequence; voltage ratio; measurements of winding ohmic resistance; insulation resistance measurements (Megger), insulation power factor measurements (Doble) and insulation capacitances of windings and condensing bushings; verification of accessories, functional tests and thermometer calibration;
- loss measurements: no-load losses and excitation current at 90%, 100% and 110% of rated voltage; load losses with reduced current and short-circuit impedances;
- dielectric tests: applied voltage, long-term induced voltage (1 hour) with monitoring of partial discharges and voltage level up to 150% of rated voltage; no-load energization with rated voltage during 24 hours with monitoring of partial discharges;
- special tests: frequency response (FRA), in some cases.

Electric tests are also monitored by means of oil sampling and corresponding analysis of dissolved gases.

Due to high costs and limited availability of testing equipment, lightning, switching impulse and HVDC tests are not performed.

Results of on-site repairs performed since 1992 and reliable operating performance of transformers after repair certify the established repair processes, even when impulse standardized tests cannot be performed.

5. CONCLUSIONS

Through right high-quality application of on-site transformer repair technology, it has been possible to optimize the whole HVDC converter transformer repair process. The whole repair process has proven to be inexpensive and reliable.

In addition, the main achievements of the utility are: overall cost reduction, significant reduction of the mean time to repair and consequential unavailability of the transformer, elimination of transportation risks and promptness of the whole structure for future repairs.

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