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“Garabi” the Argentina – Brazil 1000 MW Interconnection Commissioning and Early Operating Experience

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Abstract - **The commissioning of the Garabi back-to-back Converter Station was carried out from November 1999 through May 2000. This paper treats the organization and execution of the commissioning activities and describes some of the more important results in detail. Extensive Factory System Testing (FST) of the control and protection equipment was used to minimize site work. Being an international interconnection between Argentina and Brazil, regulating authorities in both countries were involved in the detailed planning of many of the commissioning tests. At the time of writing, about ten months of commercial operation have been experienced and data from this period was discussed.**

Index Terms - **Commissioning, Capacitor Commutated Converters, Contune filters, MACH 2, HVDC, Back-to-Back.**

I. INTRODUCTION

The Garabi 1 Converter Station is a 1100 MW (2x550 MW blocks) back-to-back located on the Brazilian side of the Argentinean / Brazilian border, in Rio Grande do Sul. The converter station, plus about 135 km of 500 kV line in Argentina and about 355 km of 525 kV line in Brazil, were constructed within a period of 25 months, to allow importation of 50 Hz power from Argentina into the 60 Hz Brazilian network. Included in the project were expansion of the Rincon de Santa Maria Substation in Argentina and the Itá Substation in Brazil.

Many technological innovations were included in the Garabi design, the more notable being the Capacitor Commutated Converters (CCC) required to permit operation with the low short circuit levels at the inverter, self tuning AC filters (Contune), a spare AC filter phase, modular out-door valve enclosures, a new PC based control system (MACH 2) and Compact AC breakers with optical CTs. Special damping resistors were also designed to damp out transients following AC line energization, and permitting fast restoration of an AC line following a line fault.

Figure 1 is a simplified view of the project, including those parts of the 50 Hz and 60 Hz AC networks electrically close to the converter station. More details of the project can be found in (1,2).

This paper describes the commissioning of the project and the more significant tests involving the interconnected AC systems. The large amount of new equipment, the short time schedule and the physical difficulties resulting from the remote location of the site, required a flexible test program that could be adapted to continually changing conditions.

II. COMMISSIONING ORGANIZATION AND PLANNING

Since the 1970’s, extensive Factory System Tests (FST) have been relied upon as a means of minimizing site-commissioning activities, specifically for control and protection equipment. In the FST the actual control and protection equipment was assembled as it would be on site, and connected to a simulator which represented the main HVDC and AC circuits.

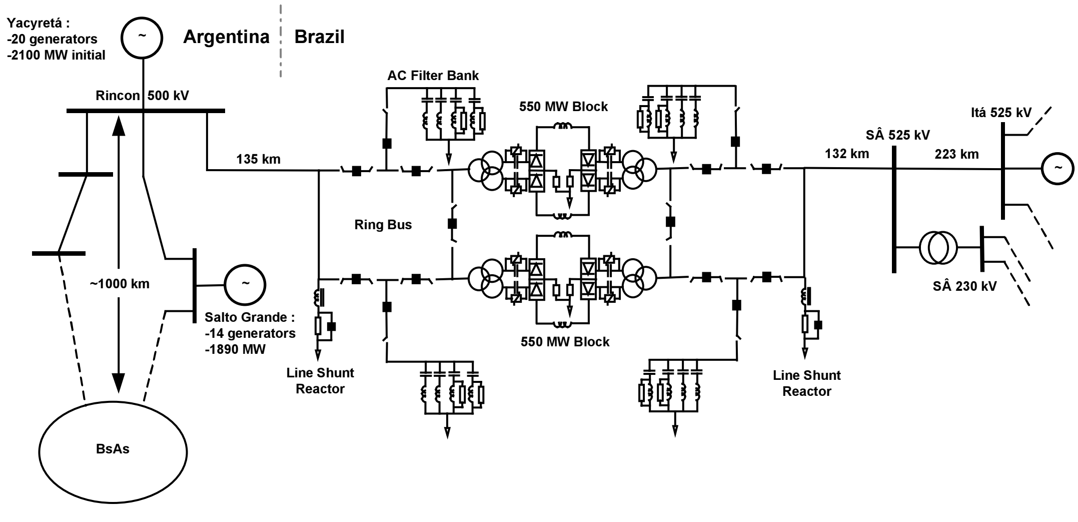

Fig. 1 Simplified single line diagram of the Garabi converter station and associated 50 and 60 Hz AC networks.

Due to the short time available for the FST and the requirements to ship the control and protection enclosures to not delay site work, a “replica” of the control and protection equipment was assembled in the factory and when the control equipment was shipped, the FST related activities continued. Additionally, the replica was used as a problem-solving tool for supporting site work.

Site commissioning activities were divided into 3 main areas:

- equipment tests (visual inspection, electrical and mechanical tests of individual equipment)
- subsystem tests (functional tests including as much individual equipment as practical);
- system tests (hv energization of the AC equipment and power transmission tests, acceptance tests).

Figure 2 illustrates the times taken for each of the above activities.

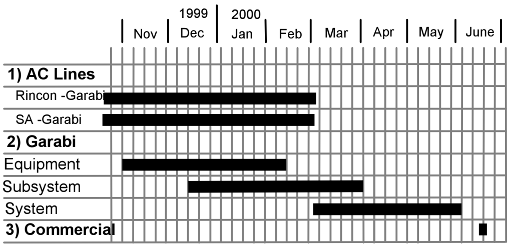

Fig. 2. Commissioning chronogram.

Prior to starting the hv energizations, a low voltage test was carried out on each side of each converter. Each converter was energized with a low (about 1 kV) AC voltage supplied by a portable diesel powered generator, connected to the incoming AC line busbars. This provided a simple way of confirming correct phasing.

Several weeks in advance of high voltage system tests, a description of the proposed test program was provided to the system operators (ONS in Brazil, CAMMESA in Argentina) for analyses. The description often included a “power profile”, a symbolic representation of equipment to be involved in the tests and power requirements expected. Figure 3 illustrates a typical power profile.

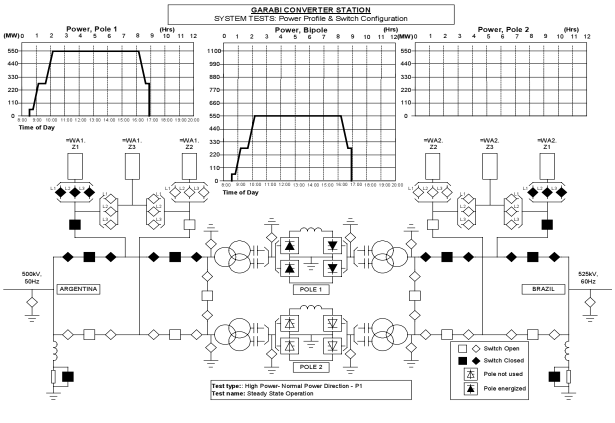

Fig. 3. Typical power profile.

As the energization of hv equipment, especially the first energization, involved the risk of equipment damage and human injury, pre-checks and trip tests (referred to as dry runs) were carried out as a last step just before energization. For example, the first energization of one of the AC lines involved the following steps:

- The line was handed over by the line constructor following his subsystem tests which was ready for energization;
- Subsystem tests for all involved equipment such as breakers, teleprotections, event recorders (Station Control and Monitoring – SCM) fault recorders (Transient Fault Recorders – TFR), the man-machine interface (Operator Work Station – OWS), etc. had been completed and the equipment was in service. Where appropriate, the involved equipment enclosures were then closed and marked “off limits”;
- Visual inspections were carried out in the substation bays where the line terminated and the areas that would be energized for the first time and the inspected areas were marked “off limits”;
- Disconnectors and breakers that connected the areas to be energized with other areas in the substation not to be energized were locked open;
- Arrestor counters on the line arrestors and line reactor oil temperatures were noted;
- The fire-fighting system (line reactor deluge system) was fully operational or a fire-fighting crew and fire-fighting vehicle were provided;
- Line protection trip testing was carried out in which the line breakers were closed at both ends (with disconnectors open) and faults were simulated by injection of voltages and currents into the line protections, using a “playback” system. The trip testing was carried out for all important protections;

When the above preparations had been carried out satisfactory, the line was considered to be ready for energization. Similar pre-checks and trip tests were carried out for all other hv equipment prior to its first energization. Even after the equipment had been successfully commissioned, the trip tests on selected equipment were often repeated, as a precaution, following outages involving modifications to this equipment.

III. COMMISSIONING AND TEST PROGRAM

A. Energization of the AC lines.

The 50 Hz Rincon-Garabi line was first energized on March 2, 2000 at 10:24 while the 60Hz Garabi-Santo Ângelo line was first energized on March 3. Verifications of voltages, currents, line shunt reactor temperatures and position indications were performed.

B. 3 50 / 60 Hz AC Filter Energizations

In Garabi, as shown in Figure 3, an 85 MVAr filter bank is provided for each converter (i.e. 2x50 AC filters and 2x60

Hz AC filters). On each side a complete spare phase is provided that can be connected via disconnects to either filter. The 50 and 60 Hz AC filters and the spare phases were energized in early March, 2000. Initially, many trips occurred due to the filter's capacitor unbalance protection, which needed to be trimmed to compensate for the initial unbalance and "aliasing" problems in the measurements made this adjustment difficult. Once the aliasing problems were resolved, the unbalance protection functioned correctly. Measured filter currents in the ACPs were also verified.

C. AC Switchyard and Converter Energizations

During operation of the AC breakers on the line side of the ring bus, the busbar differential protection tripped occasionally. It was found that a spurious current measurement could occur due to interference at the hv level on the optical current transducer (OCT) installed in each breaker. Improved noise rejection techniques eliminated this problem.

On one of the first converter transformer energizations, the "AC Conductor Ground Fault Protection" tripped the transformer. This protection is intended to detect faults on the bus connections between the valves and the transformer, before the converters are deblocked. A modification was introduced to correct this. Further energizations of the converter transformers and valve modules were performed without difficulty.

D. System (transmission) tests

E. System test objectives.

System tests were subdivided into the following sub-items;

- Steady state operation;
  This involved starting the converter at minimum load (55 MW) and verifying measurements, parameters and indications.
- Protective blocking;
  Different protective blocking sequences are used for different types of faults. Faults were simulated, often by injections of voltages or currents in a protection, and the correct blocking action verified. This was done first at minimum load then at higher loads.
- Current and power control;
  Here the stability of the current control regulator was verified by applying ramp and step changes in current order. Mode shifts from rectifier current control to inverter current control and back were checked. The tests were repeated in power control.
- AC filter phase switching;
  When a fault in a filter is detected the filter bank is tripped, the faulty phase is disconnected and replaced by the spare phase and the filter bank is re-energized automatically. This sequence requires about 20 seconds and was tested with the converter in operation.at various loads
- Auxiliary power disturbances;
  Auxiliary supplies were switched off and on to verify that no interruption in power transmission occurred.
- Biblock tests;
  In Biblock operation the ability of one block to compensate for power changes in the other block was verified.
- Heat run;
  A 72-hour heat run at power levels determined by AC system requirements was performed. This also served as a type of reliability test.
- Response to disturbances;
  A variety of AC system disturbances involving simulated and real AC line faults, line and transformer switching in nearby substations were planned.
- Reverse power
  The Converter Station was dimensioned to transmit 1000 MW in the reverse power direction, from Brazil to Argentina. At the moment, AC network limitations do not permit significant reverse power transmission and little reverse power testing has been carried out.
- Harmonic Measurements
  AC harmonic measurements have been carried out at Rincon, on both the 50 and 60 Hz side of the converter station and at Itá.

F. Problems encountered during System Tests

Transmission tests began in Pole 1 on March 11, 2000 when the converter was first deblocked at 55 MW. Parameter verifications were carried out to ensure that the converter controls and protections received correct analog values and indications. Upon blocking the converter, the Thyristor Fault Monitor incorrectly indicated failed thyristors and tripped the converter transformer. This was investigated in conjunction with site and factory staff and corrected. During early transmission trials, the transformer Restricted Earth Fault Protection also produced a trip. An incorrect input polarity was discovered and corrected. Additionally the AC Filter Reactor Overload Protection produced trips due to incorrect programming. The thyristor valve cooling also produced trips due to power supply problems to the pump motors and incorrect hydraulic valve position indications.

Some more complex problems surfaced as the test program proceeded. Incorrectly designed interlocking and human error permitted the 60 Hz Santo Ângelo-Garabi line to be energized with no active AC protection and control (ACP1 and ACP2) at Garabi. A result of this was that the bypass breaker used to short circuit the line damping resistors failed to close following the line energization and the resistors were destroyed. The interlocking was corrected and the bypass breaker upgraded. Additionally, improvements were made to the change over logic between the duplicated ACPs.

In a similar incident involving changeovers between redundant equipment, an unsuccessful changeover between redundant control equipment, initiated by a power supply failure, resulted in the loss of measured current response in the current control regulator, producing high currents through the commutating capacitors. The capacitors are protected by zinc-oxide varistors, which failed in this case. Corrections were made.

During operation at high load, higher than expected currents were found to be circulating in the ground mat in the region between the converter transformers and the valve enclosures. Additional conductors were added to the ground grid in this area increasing its cross sectional area. Inside the valve enclosures hot spots around the AC bushings resulted in burn marks appearing on the internal enclosure painting near the bushing. This was solved by cutting a slot in the internal enclosure wall, just under the bushing, to increase the flux path, reducing induced currents in the enclosure walls.

Perhaps the most serious difficulty encountered during the transmission test was due to the ConTune filters. Late changes in the design of the DC power supply that feeds the ConTune reactor's control winding, required a major upgrade to be carried out. Long delivery times for some components and difficulties to plan the outages to install the required modifications, resulted in the ConTune filters going into commercial operation without adequate redundancy greatly increasing the risk of forced outages. During preparation of this paper the ConTune upgrade was being carried out.

Most of the difficulties encountered during the execution of the system tests occurred in equipment or protections that could not be tested in the FST program and were considered as typical considering the amount of new equipment involved. Joint efforts involving experts from the factory along with the commissioning staff permitted successful solutions to be implemented and tested during the test program.

G. *Test results*

Some typical test results have been selected for presentation herein.

Figure 4 shows a protective trip of one block from near full load, (495 MW) during biblock operation. The second block was at minimum load (55 MW) and was able to compensate completely for the loss of the first block. This was a very severe, but short, disturbance and did not have a notable impact on the AC networks. Within about 70 ms Block 2 had compensated for the loss of Block 1.

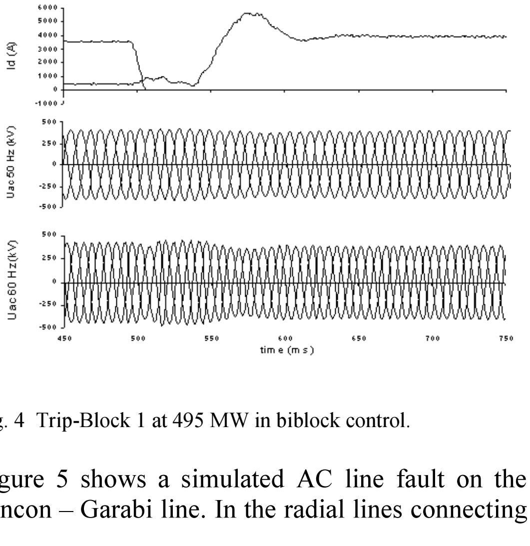

Fig. 4 Trip-Block 1 at 495 MW in biblock control.

Figure 5 shows a simulated AC line fault on the 50 Hz Rincon – Garabi line. In the radial lines connecting Garabi to the adjacent AC networks, single phase reclosing is not used as blocking of the converter is required to interrupt the secondary arc current. Once the converter has been blocked, a three-phase trip with its shorter dead time, allows for a faster restoration of power. In Figure 5 the line protection trips the 50 Hz line at t = 1000 ms. The protective sequence also trips the converter transformer on the 50 Hz side and AC filters on both sides. The complete sequence from initiation of the fault to restoration of full power required about 1.4 seconds.

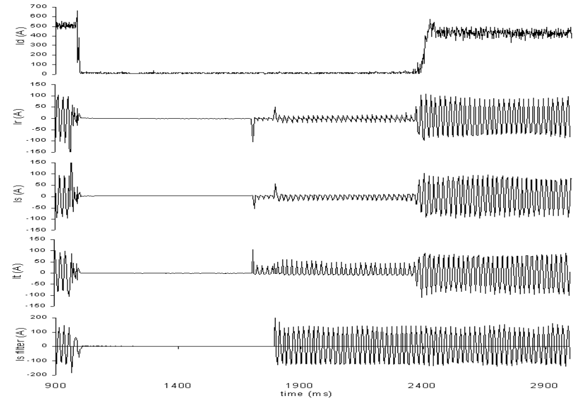

Fig. 5 50 Hz AC line fault protective sequence.

Harmonic measurements have been carried out at both sides of the Garabi station, at Rincon and at Itá. Figure 6 shows typical measurements taken on the Garabi 60 Hz side at full power. As may be noted, the dominating harmonics are the 2nd (at D= 0.69%), the 3rd (at D=0.35%) and the 5th (at D=0.46%). Total D including all harmonics is Deff=0.94%. The maximum permitted value from the customers specification is 1.5%.

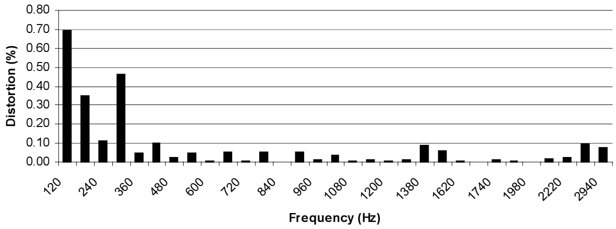

Fig. 6 Harmonic measurements at Garabi 60 Hz with Pd=1100 MW.

Similar results were obtained on the Garabi 50 Hz side.

IV.EARLY OPERATIONAL PERFORMANCE

The converter station was handed over for commercial operation on the 21st of June' 2000 and regularly been dispatched to import power to Brazil. As mentioned above the system test program was not 100% completed at commercial operation and this has impacted the availability upto the time of writing as some activities were carried out during scheduled outages. In fact some tests still remain::

Staged and simulated AC faults and other AC network disturbances are to be performed upon completion of the above activities;

Tests to confirm the satisfactory operation of the ConTune reactor DC power supply are to be performed upon completion of the supply upgrade. Also additional reverse power testing remains to be carried out.

Table 1 summarizes the availability performance of the converter station over this ten month period, using the format of the CIGRÉ Protocol 14-97 (WG 04).

TABLE 1. Energy Unavailability

Forced Outages:	Events	Equivalent Duration	FEU
AC and Auxiliaries	23	45.62hs	0.63%
Valves	0	0	0
Control and Protection	23	09.31hs	0.13%
DC Equipment	0	0	0
Other causes	1	0.02hs	0
Total	**47**		**0.76%**

Scheduled Outages	Events	Equivalent Duration	SEU
Single Block	4	04.5hs	0.06%
Station (2 blocks)	4	24.45hs	0.34%
Tests (100%)	4	16.32hs	0.23%
Total	**12**		**0.63%**

It can be seen that the availability has been good over this short period, although the number of trips could be considered rather high. For the forced outages, the number attributed to control and protection has dropped significantly over this initial operaring period as control modifications have been carried out, much as usual with HVDC projects. The forced outages due to AC and auxiliaries have been mainly due to the ConTune issue discussed in 3.5.2 above. As this modification, involving changes to the power supply feeding the ConTune control winding, is now being carried out at site, we expect this to be resolved shortly.

The HVDC equipment has performed well and the capacitor commutated converter (CCC) gave no surprises, behaving as required and ensuring satisfactory system performance under all conditions.

In general the interconnection has transmitted full power to Brazil as the hydrological situation has required maximum import whenever possible. This has been limited at times due to transmission constraints between the south and southeastern systems in Brazil. For one short period power transmission of 200 MW was made to Argentina when that system suffered a severe transmission outage in the south of the country.

V. CONCLUSIONS

The Garabi Back-to-back converter station was commissioned successfully within a short time. No No problems were encountered with the main circuit equipment. The capacitor-commutated converter (CCC) functioned as predicted in the design studies.

The station has been in commercial operation since June 21, 2000. Over this ten-month period the converter station has shown a forced energy unavailability of 0.76% and a scheduled energy unavailability of 0.63%.

VI. REFERENCES

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VII. BIOGRAPHIES

Don F. Menzies was born in Shoal Lake, MB, Canada on March 28, 1947 and received his B.Sc. (E.E.) from the University of Manitoba in 1969 and his M.Sc. from Imperial College (London, England) in 1971. From 1971 to the present, he has been involved in HVDC activities including simulation studies, planning and commissioning. This included service with Manitoba Hydro, EGAT (Thailand), ASEA-Promon (Itaipu HVDC project), ABB Canada (at the Manitoba HVDC Research Center and at CITEQ, the joint research venture between Hydro Quebec and ABB), FURNAS Centrais Elétricas (Itaipu HVDC project) and finally ABB Power Systems (the Garabi Project). He is a member of Cigré and a registered professional engineer in the Province of Manitoba.

John Graham was born in Northampton, England, on December 19, 1942. He received his degree in Electrical Engineering from the University of Warwick, England, in 1965. His employment experience includes service with Teshmont Consultants in Canada and Brown Boveri in Switzerland. He has worked in Brazil since 1972, initially on the studies for the integration of the Itaipu Hydro Plant into the Brasilian system. He joined ASEA, now ABB, in 1982 and was involved in the commissioning of the Itaipu HVDC system.

Fabiano Uchoas Ribeiro was born in Pereira Barreto, Brazil, on January 14, 1974. He received his degree in Electrical Engineering from the Federal School of Itajubá (EFEI), Brazil, in 1997. From 1997 to 1999, he worked as application engineer in a General Electric representative company, mainly focussing in Protection System for Industries. Since January 2000, he is working in CIEN. He has participated of the system tests of Garabi I, and now provides the support for its operation, besides of participating of the project Garabi II.