

Operational Tests of Garabi II HVDC Thyristor Valves

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Abstract — A synthetic test circuit is used to test the Garabi II HVDC thyristor valves. This synthetic test circuit comprises a conventional Back-to-Back direct test circuit and a voltage oscillating circuit to reproduce the current and voltage stresses that could meet in service for the thyristor valves. The test circuit parameters are carefully chosen to give a close representation of the system parameters. The sample test results from this synthetic test circuit are comparable with that acquired previously from a conventional Back-to-Back direct test circuit. However, this synthetic test circuit offers several technical merits and is superior to the Back-to-Back direct test circuit in terms of economy as well.

Index Terms — Garabi II thyristor valves, synthetic test circuit, operational tests, testing

I. INTRODUCTION

AN identical design is used in the design of Garabi I and Garabi II HVDC thyristor valves. These HVDC thyristor valves are destined to interconnect the 500kV 50Hz AC systems in the Argentinean and 500kV 60Hz AC systems in Brazilian [1] by a Back-to-Back connection. The Garabi HVDC thyristor valves transmit a power of 550MVA at ± 70 kV voltage rating. Although the voltage rating per valve is not very high, to verify the design by testing one complete valve by using a conventional six-pulse Back-to-Back direct test circuit is impossible due to the limited test power installation in the test laboratories. To increase the testing power to test the complete valve is neither an economical nor a very practical solution. Unit test or section test is adopted in practice. A Back-to-Back direct test circuit was used to test the Garabi I HVDC thyristor valves with two thyristor levels in series per arm (per valve function.)

To better represent the service stresses appeared on the test thyristors, minimum five thyristors in series per test set-up is deemed as an adequate number [2]. To expand the direct testing power to test minimum five thyristors in series connection per set-up is not an economical solution.

Synthetic test circuit, as an alternative, is widely used by the test laboratories for the tests and is recommended by CIGRE [2]. In a synthetic test circuit the test current and voltage come from two power sources. By the helping of auxiliary valves the

test objective is alternatively connected to two sources under two different intervals. These two power sources apply different stresses on the test object corresponding to different time periods. To minimize the influence caused by transit from one source to another, especially from the current source to the voltage source, an overlap of these two sources is necessary. To realize this the voltage source is connected prior to the current zero of the current source in a way of current injection. This injection current functions in two ways: to create time for auxiliary valve blocking. The auxiliary valve is needed to separate the two sources and to represent the current derivative prior to the current zero crossing in service. By the use of synthetic test circuit the number of thyristors in series connection per test set-up could easily meet the requirements of IEC standard [3].

The synthetic test circuit used to sample test the Garabi II HVDC thyristor valves is based on the current injection method. This circuit meets both the IEC standard and the strict test requirements for the operational test of Garabi II HVDC thyristor valves.

II. GARABI II HVDC THYRISTOR VALVES

One Garabi II HVDC thyristor valve consists of six thyristor modules which give a DC current output 4000A at 70kV. Each thyristor module comprises six thyristor levels as well as their snubber circuits, thyristor control units and voltage dividers. One complete module includes a saturated reactor too, which is connected in series with the six thyristors as shown in Fig.1.



Fig. 1. One complete Garabi HVDC thyristor module

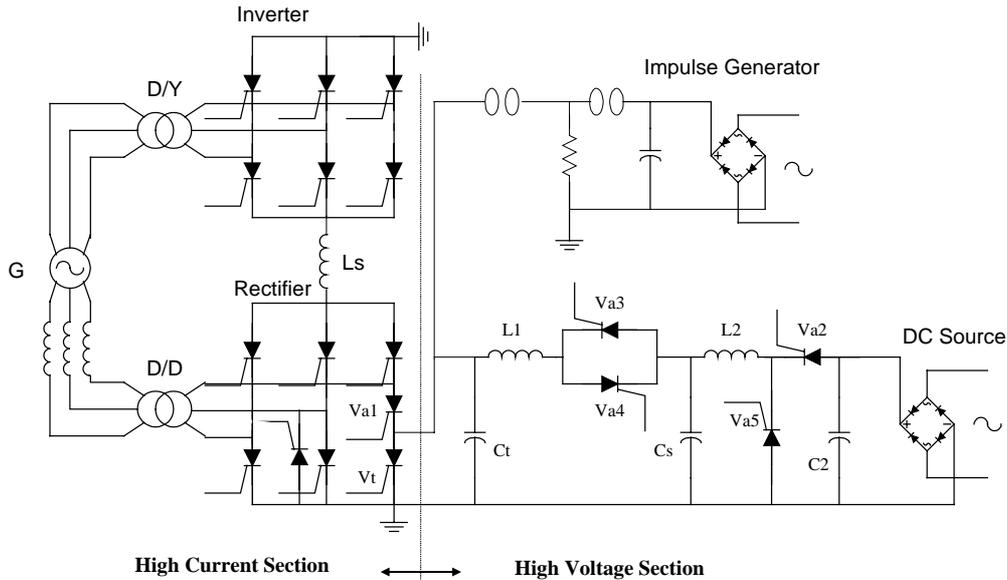


Fig. 2. The synthetic test circuit for the operational tests of Garabi II HVDC thyristor valves

Garabi II thyristors are well-developed semiconductor products by ABB Semiconductors in Switzerland. The main technical specifications are given in Tab. 1.

Tab.1 Main specifications of Garabi II thyristors

V_{DSM}	Q_{rr}	I_{TSM}^*	V_T	r_T
6700V	2600 μ As	36kA	1.69V	0.56m Ω

* surge on-state current with reapplied off-state voltage

III. SYNTHETIC TEST CIRCUIT FOR THE OPERATIONAL TESTS OF GARABI II HVDC THYRISTOR MODULES

The synthetic test circuit for the operational tests of Garabi II HVDC thyristor modules is depicted in Fig.2. The six-pulses Back-to-Back bridges, two anti-parallel connected valves for fault current test, two auxiliary modules and two test modules are configured in one bank as shown in Fig.3. The test generator to feed the six-pulses Back-to-Back bridges is shown in Fig.4. This circuit has been reported in detail in ref. [4] [5].

As one arm of the six-pulse rectifier in a Back-to-Back circuit the two test modules conduct a current representing the service current after firing. Prior to the commutation end (current zero), the voltage source is connected by firing the auxiliary valve Va3. At this moment and up to the current zero of the current source, the two test modules conduct a current, which is the sum of the current fed by the current source and the injection current supplied from the voltage source. The two test modules continue to conduct the injection current for about 600 μ s after the current zero of the current source. The inductance L1 and the voltage on Cs are chosen to have the same current derivative (di/dt) as in service for approximately 200 μ s prior to current zero. The reverse recovery voltage and forward voltage are produced by the firing of auxiliary valves Va4 and Va5 at specific instants.



Fig.3 View of six-pulse Back-to-Back bridges, two auxiliary modules and two test modules

As the circuit parameters are chosen representative of system conditions, this synthetic test circuit can correctly reproduce the stresses on the test thyristors in the most two critical operation states, i.e. turn-on and turn-off of valve operation. The way to integrate a conventional six-pulse Back-to-Back direct test circuit in the synthetic test circuit offers several technical merits besides of direct representative of current in service. They are: no transit time from normal operation to fault operation for valve fault current tests, minimum firing voltage test without change of the test set-up possible and real time interaction with valve control and converter firing systems for the intermittent direct current test. By using of two sources to supply the current and voltage independently the test parameters are fully controllable.



Fig.4 Test generator to feed the six-pulse Back-to-Back circuit

IV. TEST DESCRIPTIONS

The complete sample operational test program, as required in the Technical Specifications of Garabi II HVDC Thyristor Valves, has been strictly followed during the operational tests of Garabi II thyristor modules. These sample operational test duties include:

- Heat-run test
- Maximum temporary operating duty tests
- One-loop fault current test with re-applied forward voltage

A. Design of Test Parameters

The test generator in the test plant can supply a continuous test current up to $4000A_{rms}$ at 50Hz. The DC generator provides a continuous current output 15A at 70kV. These power installations are sufficient to test two Garabi II HVDC

thyristor modules in series connection per test set-up.

With a synthetic test circuit the test current and voltage waveform differ to the ones under service or a direct test circuit. At the thyristor on-state, an extra injection current with a sinusoidal shape is added prior to the commutation current zero. This results in an extra conducting loss of the thyristor and prolongs the conducting period. At the thyristor turn-off interval, the damping effect of the snubber circuit in auxiliary valve Va1 decreases the rate of rise of recovery voltage (dv/dt) on the test valve. At the thyristor off-state, the waveforms of reverse voltage and forward voltage have no voltage jumps as in service.

In the operational tests of HVDC thyristor valves, three parameters are most critical. They are: losses of thyristors and their snubber circuits, current derivative before the zero crossing and recovery voltage after blocking [6] [7].

In order to produce test stresses equal to or greater than those that would had been applied in a direct test circuit during each series of tests a careful follow up of the stresses applied to the thyristor modules have been done. Stresses for the thyristor valves used in the 60Hz AC system Brazilian side were calculated. The test stresses applied by the 50Hz test facility were equal to the calculated values.

The test parameters for the operational tests of Garabi II HVDC modules are given in Tab. 2.

B. Test Description

Total six modules or 36 pieces of thyristors of Garabi II HVDC thyristor valves have been sample tested. All six modules were tested according to the test program and parameters listed in table 2.

Tab. 2 Test parameters for the operational tests of Garabi II HVDC thyristor modules

Test Duty	Duration	I_{dc} (A)	I_{fault} (kA)	U_E (kV)	U_H (kV)	U_F (kV)	U_{F_block} (kV)
Preheating	10 min.	≥ 3000			25.0		
Heat-run test	30 min.	≥ 4020			34.7		
Maximum temporary operating duty test	2 sec.	≥ 1206		45.0		40.3	
Maximum temporary operating duty test ($\alpha=90^\circ$)	6 sec.	≥ 1206			37.3		
Maximum temporary operating duty test ($\alpha=90^\circ$)	2 sec.	≥ 1206			40.0		
One-loop fault current with re-applied forward voltage		≥ 4020	25.4		34.7		10.7

U_E — transient recovery voltage peak
 U_{F_block} — forward block voltage peak

U_H — reverse power frequency recovery voltage peak

U_F — forward voltage prior to firing

A RCR type voltage divider is used to measure the voltage and a Rogowski coil is used to measure the current through the test object. A current transformer is used to measure the line current of the secondary side of transformer. Several voltage probes are employed to monitor the phase-to-phase voltage and DC side voltage. All these signals are recorded and analyzed by a digital data acquisition system.

MACH 2 system, a control system developed by ABB for the power system control and protection, is used to control the synthetic testing. Pre-programmed test sequences were recalled when each test duty was performed. The pre-programmed test sequences combine the current and voltage order, firing sequences of the test object and the auxiliary valves, and the test duration. The coolant temperature and the flow rate in each individual valve are monitored by the MARCH 2 system too during the tests. A graphical operator window of MARCH 2 makes an easy access to execute above functions and to make the connection of main circuit permissible remotely.

Before the start of each test duty, the inlet coolant temperature and flow rate are controlled and ten minutes preheating test with the preheating parameters was performed in order to closely represent the pre-load condition of test object.

Fig.3 is the test current and voltage record in two cycles in the heat-run test duty.

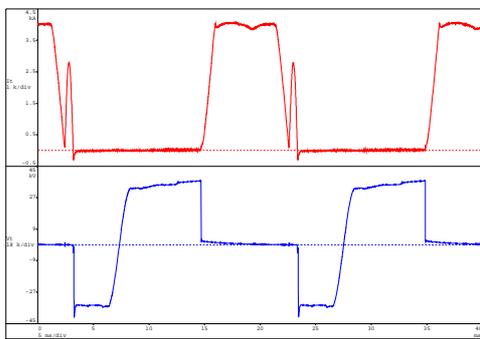


Fig. 3 Periodic firing and extinction tests

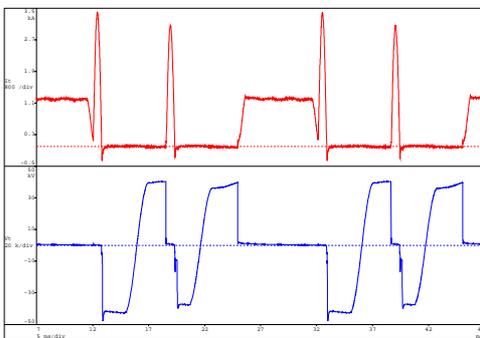


Fig. 4 Periodic firing and extinction test ($\alpha = 90^\circ$)

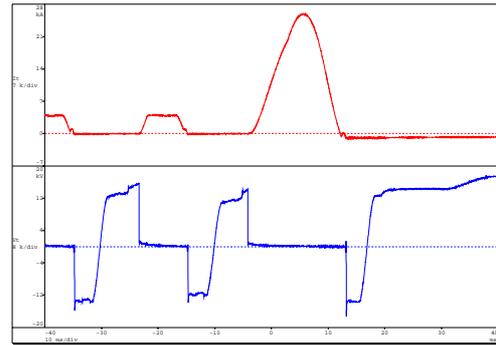


Fig. 5 One-loop fault current with re-applied forward voltage

Fig. 4 is the test oscillogram of maximum temporary operating duty with α equal to 90 electrical degree. The test object was fired twice per cycle and two cycles of current and voltage were shown in this figure.

Fig. 5 is the test oscillograms of one-loop fault current test with re-applied forward voltage.

C. Test Result

No component or part of the modules was damaged or failed during the operational tests.

Routine tests repeated after the operational tests didn't find any malfunction component. No evidence shows that component performance degradation after the sample operational tests.

The six Garabi II HVDC thyristor modules passed the sample operational tests successfully.

V. SUMMARY

A synthetic test circuit is used to sample test the Garabi II HVDC thyristor valves. This synthetic test circuit is based on the current injection method and is integrated with a conventional six-pulse Back-to-Back direct test circuit and a voltage oscillating circuit.

A 50Hz test generator was used to feed the Back-to-Back circuit and a DC generator was used to compensate the losses in the voltage oscillating circuit. The test parameters are carefully chosen in each operational test duty in order to stress the test object correctly. These test parameters produce stresses equal to or greater than those that would had been applied in a Back-to-Back direct test circuit.

A total of six Garabi II HVDC thyristor modules have been operational tested by using of this synthetic test circuit.

The sample test results acquired under this synthetic test circuit are comparable with that acquired in a Back-to-Back direct test testing previously. All the results showed that the design of Garabi HVDC thyristor valves is fully adequate. The tested modules exhibit a higher reliability as a result.

VI. REFERENCES

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VII. BIOGRAPHY



Baoliang Sheng was born in Changchun, China in 1961. He obtained his B.Sc degree in 1982 from Xi'an Jiaotong University, China, and his Ph.D. in 1995 from Delft University of Technology, the Netherlands, both in electrical engineering. From 1982 to 1992 he worked at National High Power Laboratory (XIHARI), China, as a test engineer and research engineer. He worked at KEMA, the Netherlands, as a research engineer and towards his Ph.D. at Delft University of Technology from 1992 to 1996. He joined the High Power Laboratory of

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