

Operational Tests of the Three-Gorges — Changzhou HVDC Thyristor Valves by Using a Synthetic Test Circuit

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Abstract — Three-Gorges — Changzhou (3G) HVDC thyristor valves have a high power rating per thyristor level. Testing of these thyristor valves by using a conventional Back-to-Back test circuit would necessitate huge investments and would not give an improved testing regime than produced by the solution chosen. A synthetic test circuit using the conventional Back-to-Back test circuit to supply the current and an oscillating circuit to supply the voltage has been developed for the testing of the 3G thyristor valves. The conditions of the four operational states of HVDC thyristor valves can be adequately represented in this synthetic test circuit. The test parameters used gave test stresses on the test object equal to or higher than those that are foreseen to appear in service. The successful type test results showed that the design of 3G HVDC thyristor valves is fully adequate. The tested modules have also shown a substantial margin in the thyristor valve design since, for most of the tests, the test parameters were globally more severe than specified.

Index Terms — Synthetic test circuit, operational tests, Three-Gorges thyristor valves, testing

I. INTRODUCTION

THE 3G HVDC thyristor valves are designed to transmit 3000MVA at ± 500 kV [1]. Using a conventional six-pulse Back-to-Back test circuit (direct test circuit) to test the 3G HVDC thyristor valves would had need a huge power installation in the test plant. To expand the testing power of the direct test circuit is neither an economical nor a very practical solution. Synthetic test circuit, as an alternative, is widely used by the different test laboratories for the operational testing of thyristor valves. This method is also recommended by CIGRE [2] and allowed by IEC [3]. One of the main advantages of using a synthetic test circuit is that the number of series connected thyristors per test set-up could easily meet the minimum number stated in the IEC standard.

The synthetic test circuit developed in ABB Power Systems is based on the current injection method [4]. This circuit meets

the requirements of IEC standard as well as the test requirements specified in the user specification.

In a synthetic test circuit, the current and voltage are fed by two power sources. The auxiliary valves are connecting alternatively the test valve to the two sources during different time intervals in order to produce the required stresses (voltage and current). The two sources are feeding simultaneously the test valve during the commutation and prior to the extinction process in order to minimize the influence caused during the transfer from one source to another, especially from the current source to the voltage source. To obtain this test condition, the voltage source has to be connected prior to the current zero of the current source in the same way as used for synthetic tests on circuit-breakers (current injection method). The current injection has two roles: to get a single source feeding the test object at current zero and to represent the current derivative (di/dt) prior to the current zero crossing as it will appear in service.

The current injection synthetic testing method is widely used for the testing of high voltage AC circuit breakers. This method is generally considered superior to other synthetic test methods in terms of stress representation, especially close to current zero during the current extinction process.

II. THREE-GORGES — CHANGZHOU HVDC THYRISTOR VALVES

3G HVDC thyristor valves are built with several thyristor modules. Each module has six thyristor levels including their snubber circuits, thyristor control units and voltage dividers. A saturable reactor is connected in series with each thyristor module. One of 3G HVDC thyristor valve under the dielectric test program is shown in Fig.1.

3G thyristors are using a well-proven semiconductor product developed by ABB Semiconductors in Switzerland. The main technical data of the thyristors used are shown in Table 1.

Table 1 Main technical data of the 3G thyristors

V_{DSM}	Q_{rr}	I_{TSM}^*	V_T	r_T
7200V	3600 μ As	36kA	1,26V	0.197m Ω

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

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Fig.1 View of 3G HVDC thyristor valve

III. SYNTHETIC TEST CIRCUIT FOR THE OPERATIONAL TESTS

The synthetic test circuit for the operational tests of the 3G HVDC thyristor valves is shown in Fig.2. The operating principle of this circuit is reported in [4] and will be briefly described in the following paragraph.

As one arm of a six-pulse rectifier in a Back-to-Back circuit, the test modules (Vt) conduct a current representing the service current shape after firing. Prior to the end of the commutation (current zero), the voltage source is connected to the test valve (Vt) by the firing of the auxiliary valve Va3. At this moment and up to the current zero of the current source, the test modules conduct a current, which is the sum of the current fed by the current source and the current supplied from the voltage source. After the blocking of the current fed by the current source by the auxiliary valve (Va1), the test modules are fed uniquely by the synthetic circuit and continue to conduct the injection current for about 600μs. The inductance L1 and the voltage on Cs are chosen to have the same current derivative (di/dt) as in service for approximately 200μs 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.

The circuit parameters have to be carefully chosen in order to be representative of system conditions, and to adequately reproduce the stresses on the thyristor modules in the two most critical operation states, i.e. at turn-on and at turn-off [5]. The integration of a conventional six-pulse Back-to-Back direct test circuit in the synthetic test circuit offers several technical merits beside the close representation of in service valve current shape. They are: no transition time from normal operation to fault operation for valve fault current tests, possibility of performing the minimum firing voltage tests

without changing the test set-up 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.

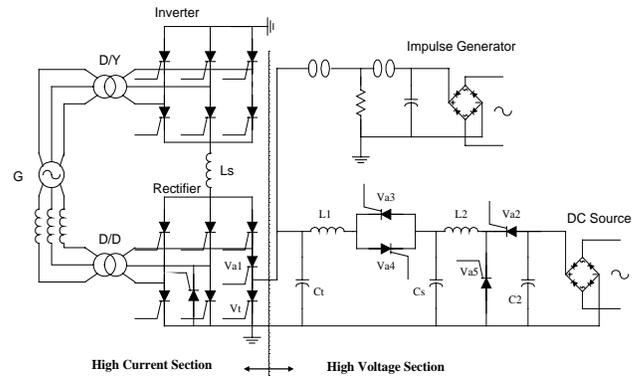


Fig. 2 The synthetic test circuit for the operational tests of 3G HVDC thyristor valves

IV. TEST DESCRIPTIONS

The complete operational type test program, as required in IEC60700-1 and the Technical Specifications of 3G HVDC Thyristor Valves, has been strictly followed during the tests for 3G thyristor valves. The whole operational test program for the 3G HVDC thyristor valves was performed with the above-described synthetic test circuit. The required operational test program includes:

- Heat-run test and protective firing test;
- Maximum temporary operating duty test ($\alpha=90^\circ$);
- Minimum AC voltage tests (minimum firing voltage test and minimum extinction voltage test);
- Intermittent direct current test;
- Tests with transient forward voltage during the recovery period;
- One-loop fault current test with re-applied forward voltage;
- Three-loop fault current test without re-applied forward voltage.

A. Design of Test Parameters

A careful follow up of the stresses applied to the thyristor modules (applied voltages, di/dt, thyristor junction temperature, thyristor losses and snubber losses) during each series of tests have been done in order to produce stresses equal to or greater than those that would be applied in service (taking into account the safety test factors given in IEC60700-1).

The characteristics of synthetic tests are such that both the test current and voltage waveforms are different than those occurring during service or in a Back-to-Back direct test circuit. During the on-state condition, an extra injection current loop (sinusoidal shape) is added to the normal valve

current shape prior to the commutation. This results in extra conduction losses of the thyristor and prolongs the conduction period. During the 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 and the reverse and forward voltage waveforms have not the same voltage jumps as seen in service.

To compensate the low dv/dt and absence of some voltage jumps in the applied thyristor voltage, higher test voltages were chosen during tests. The test voltage levels were determined by using several formulas. The first calculation step is to calculate the voltage levels seen by the thyristor valve at turn-on and turn-off for the required testing operation modes in service. Then, the losses in the different components were derived (conduction losses in the thyristors, turn-on losses, snubber losses, recovery charge losses in the snubbers and in the thyristors). Losses were calculated according to the equations given in [6]. These test parameters were used as reference values for the calculation of the synthetic test circuit parameters. Since the synthetic circuit voltage waveshape is quite different from the normal waveshape across the thyristor valve, the same calculations as performed for an equivalent Back-to-Back direct circuit were made in order to select a proper synthetic test voltage producing losses equal to or higher than the required operation modes.

The test parameters for the operational tests of the 3G HVDC valves are given in Tab. 2.

B. Test Description

Before the start of each required test duty, the inlet coolant temperature and its flow rate were carefully controlled. A ten minutes preheating period having the heat-run test parameters

was also performed in order to closely represent the pre-load condition of test object before any of the required test duty.

A total of 15 (fifteen) modules or 90 thyristors levels of 3G HVDC thyristor valves were type tested. All 15 modules were tested according to the test program and parameters listed in table 2 except for the protective firing test. An eight hours protective firing test was performed on one test set-up only (2 thyristor modules).

A RCR voltage divider has been used to measure the applied voltage while a Rogowski coil has been used to measure the current through the test object. Current transformers were used to measure the line currents fed by the transformers. Several voltage probes were employed to monitor the phase-to-phase voltages and DC side voltage. All these signals were recorded and processed by a digital data acquisition system.

The MACH 2 system, a control system developed by ABB for power system control and protection, was used to control the synthetic circuit operation. Pre-programmed test sequences for each test duty were recalled. The pre-programmed test sequences comprise the current and voltage order, firing sequences for the test object and the auxiliary valves and the test duration. The coolant temperature and the flow rate in each individual valve were also monitored by the MACH 2 system during tests. A graphical operator window was displayed from the MACH 2 control system in order to obtain an easy access for execution or modification of the above functions. The MACH 2 control system is also used to set-up the test circuit (back-to-back and synthetic source) by using remote control functions.

The following figures show typical examples of the recorded oscillograms:

Tab. 2 Test parameters for the operational tests of 3G 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)	U _{R_block} (kV)
Protective firing test	8 h.	≥3217		≥43.7	≥33.5			
Heat-run test	30 min.	≥3217		≥43.7	≥33.5			
Maximum temporary operating duty test (α=90°), repetitive voltage test	10 sec.	≥1050		≥62.7		≥57.0		
Maximum temporary operating duty test (α=90°), heat run test	10 sec.	≥1050			≥43.0			
Maximum temporary operating duty test (α=90°),heat run test	2 sec.	≥1050			≥50.3			
Minimum AC voltage tests	15 min.	≥3217		≤10.8		≤5.4		
Minimum AC voltage tests	1 min.	≥1000		≤3.2		≤0.7		
Intermittent direct current tests	2 min.	<200			≥33.5			
Tests with transient forward voltage during the recovery period		≥3217		≥43.7	≥33.5			
One-loop fault current with re-applied forward voltage		≥3217	≥34.7	≥43.7	≥33.7		≥44.3	
Three-loop fault current without re-applied forward voltage		≥3217	≥35.9	≥43.7	≥33.7			≥26.9

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

U_H — reverse power frequency recovery voltage peak
U_{R_block} — reverse block voltage peak

U_F — forward voltage prior to firing

- Fig.3: Test current and voltage during one cycle in the heat-run test duty.

- Fig. 4: Maximum temporary operating duty with α equal to 90 electrical degree. The test object was fired twice per cycle in order to obtain the required snubber losses.

- Fig. 5: Intermittent direct current and voltage during the intermittent direct current test. After the ten minutes preheating period, the current from the current source is gradually reduced to the level that the DC current becomes intermittent. As shown on this oscillogram, the voltage circuit is triggered after the last power frequency current pulse for reproducing the turn-off voltage and the following turn-on voltage during such mode of operation with high firing angles.

- Fig. 6 and Fig. 7: Oscillograms of one-loop fault current test with re-applied forward voltage and three-loop fault current test without re-applied forward voltage. The upper trace is the test current through the test object while the middle trace is the line current measured by the current transformers. The lower trace is the voltage applied on the test object during the test.

- Fig. 8: Test with transient forward voltage during the recovery period. As required, three different impulses with front times of $1\mu s$, $10\mu s$ and $100\mu s$ respectively were applied at different times in the interval from 0 to $1500\mu s$ after current extinction. Fig. 8 illustrates specifically an oscillogram of the $1\mu s$ transient forward voltage impulse applied on the test object $400\mu s$ after current zero.

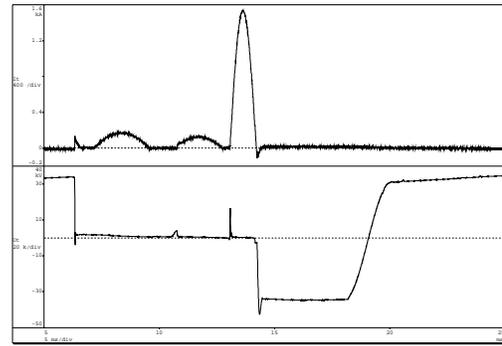


Fig. 5 Intermittent direct current test

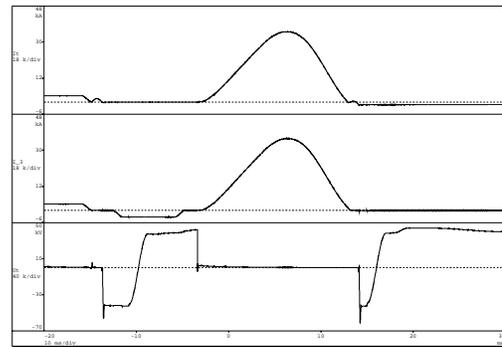


Fig. 6 One-loop fault current with re-applied forward voltage

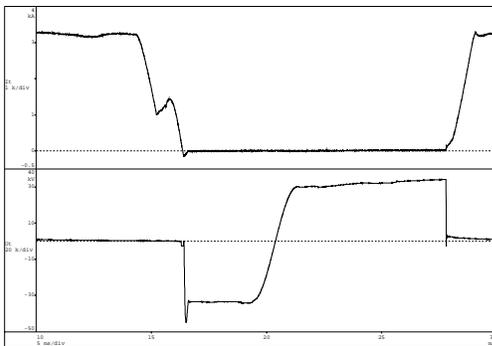


Fig. 3 Periodic firing and extinction tests

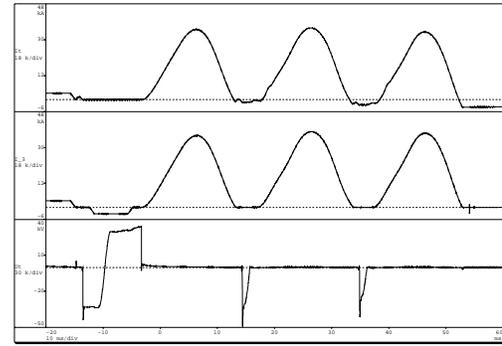


Fig. 7 Three-loop fault current without re-applied forward voltage

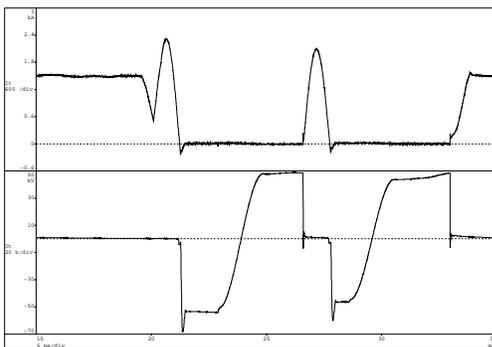


Fig. 4 Periodic firing and extinction test ($\alpha = 90^\circ$)

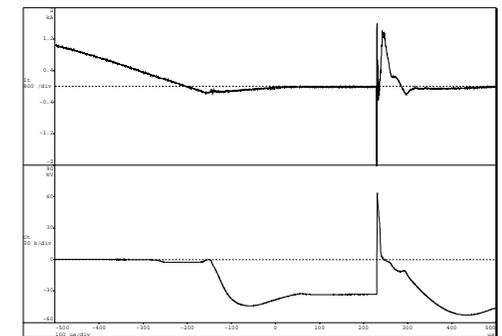


Fig. 8 Test with transient voltage during the recovery period

C. Test Result

No component or parts of the thyristor modules were damaged or failed during the operational tests.

The routine tests have been repeated after the operational tests and no defective components were found. There was no evidence of any component degradation after the operational type tests.

The fifteen 3G HVDC thyristor modules successfully passed the operational type tests.

V. SUMMARY

A synthetic test circuit was used to verify the design of Three-Gorges — Changzhou HVDC thyristor valves. This synthetic test circuit is based on the current injection method. This circuit comprises a conventional six-pulse Back-to-Back test circuit and a voltage oscillating circuit.

To correctly stress the test object, the test parameters have to be carefully chosen in each operational test duty. These test parameters should produce stresses equal to or greater than those that would meet in service (taking into account the safety test factors given in IEC60700-1).

A total of fifteen Three-Gorges — Changzhou HVDC thyristor modules have been type tested with this synthetic test circuit for the entire operational test program specified by IEC60700-1 and in the Technical Specifications of Three-Gorges — Changzhou HVDC Thyristor Valves.

The successful type test results showed that the design of Three-Gorges — Changzhou HVDC thyristor valves is fully adequate. The tested modules have also shown a substantial margin in the thyristor valve design since, for most of the tests, the test parameters were globally more severe than specified.

VI. REFERENCES

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VII. BIOGRAPHIES



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 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 ABB Switchgear AB, Sweden, in May 1996 as a research and development engineer. He was appointed as Company Specialist in the field of High Power Testing of Electrical Power Equipment in January 1999. He joined ABB Power Systems AB in September 2000 as a research and development engineer for the electrical design of HVDC and SVC thyristor valves. His special fields of interest include study of transient phenomena in power systems, laboratory reproduction of network switching conditions, synthetic testing of HVAC circuit breakers and HVDC circuit breakers, direct and synthetic operational tests of HVDC thyristor valves and SVC valves, application of thyristor valves in power systems.



Hans-Ola Bjarne was born in Stockholm, Sweden in 1949. He obtained his Master degree from Royal Technical University, Sweden in 1976. He was a college lecturer in Stockholm from 1977 to 1982. He joined ASEA in 1982 as a research and development engineer. From 1990 to 1995 he had been with STRI (Swedish Transmission Research Institute) as a research scientist and project manager. From 1995 to 1997 he was a development engineer in ABB Power Transmission, Australia. Since 1997 he has been working in ABB Power Systems AB as the manager of Thyristor Valve Electrical Design Department. He is member of IEC working group IEC 22F MT9.



Pierre Riffon was born in Montreal, Quebec, Canada on October 18, 1958. He received his B.Sc.A. in electrical engineering from École Polytechnique de Montréal in 1980 after which he joined Hydro-Québec's Research Institute (IREQ) as a Test Engineer for the High Power Laboratory. Since 1988, he has been working as a Test Specialist for the Hydro-Québec's Quality Control department and is responsible for type tests on high voltage substation equipment and special project apparatus (static and series compensation, HVDC Converter, etc...). Mr. Riffon has been involved on several HVDC Projects either for Hydro-Quebec and for Hydro-Quebec International as a test specialist (consultant) for several international HVDC projects. Mr. Riffon is a member of the IEEE Transformers Committee on which he is participating to several Subcommittees and Working Groups. He is member of: - HVDC Converter Transformers and Smoothing Reactors Subcommittee; - Dry Type Reactors Working Group; - Switching Transients Induced by Transformer/Breaker Interaction Working Group; - Co-chairman of IEEE Working Group on Test Requirements for Instrument Transformers for Nominal Voltage 115 kV and above. Mr. Riffon is also the chairman of the Canadian IEC Technical Committee TC17 and Subcommittees SC17A and SC17C, Switchgear and Controlgear. He is also the convener of an IEC WG on High-Voltage alternating current by-pass circuit-breakers and the Task Force leader of an IEC group working on the Guide for Asymmetrical Short-Circuit Breaking Test Duty T100a. He is also a member of IEEE Power Engineering Society and of Ordre des Ingénieurs du Québec.



Ma Weimin was born in Wuhan, China in 1966. He obtained his Ph.D. for the study of large power transmission line from Wuhan Institute of Hydraulic and Electric Engineering in 1994. From 1994 to 1996 he worked in Tsinghua University as a post-doctor. After finishing the study work on digital measurement in high voltage engineering field he joined State Power of China as a senior engineer mainly for the Three Gorges to Changzhou HVDC project and Three Gorges to Guangdong HVDC project technical specification, test supervision and construction.