Proof of performance

A synthetic test circuit for verifying HVDC thyristor valve design

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New HVDC thyristor valves from ABB can handle powers so high that a conventional back-to-back circuit is not always practicable for operational testing. A new test method is required – one that allows precise reproduction of voltage and current stresses beyond the highest levels conceivable in service. A synthetic test circuit developed by ABB to meet this need has resulted in higher valve reliability while also allowing a major saving in investment costs.

The increasing power-handling capability of ABB's HVDC thyristors has been making it very difficult, and sometimes even impossible, to test the operation of HVDC thyristor valves with a conventional back-to-back test circuit [1,2]. A synthetic test circuit was seen as a potential solution, and ABB put together a team of high-power test engineers and valve design specialists to explore this possibility. The result of their work was the development of a new synthetic test circuit [3], used commercially for the first time in May 2000 to test HVDC thyristor valves for the Three Gorges – Changzhou HVDC transmission project in China. The new test circuit, which can produce voltage and current stresses equal to or greater than those the valves would ever face in service [4], has resulted in higher reliability for these vital components.

The need for a new solution

The enormous advances in semiconductor device technology in recent years have led to power electronics equipment becoming increasingly powerful. The rapid increase in the specific power densities of thyristors used in HVDC transmission is a case in point. However, while this has been happening demand has also been growing for better system reliability and availability. As a result, very strict specifications apply today to component and module testing.

Until now, it has been the custom for test laboratories to use a six-pulse or three-pulse back-to-back circuit (also referred to as a direct test circuit) to perform operational tests on HVDC thyristor valves. The higher power ratings of modern thyristors have been making it harder, however, to perform conventional back-to-back testing under realistic conditions. The difficulties being encountered mainly concern the reproduction of voltage stress on the thyristors when only a limited number of these devices can be connected in series per set-up due to the limited capacity of the lab's power plant. To reproduce the stress accurately, at least five series-connected thyristors need to be tested in each set-up. Upgrading the installed power plant to accommodate this requirement, however, cannot be justified economically.

> ABB has used the new synthetic circuit for a complete type test and sample test program, involving 36 thyristor modules in 18 test set-ups, for the Three Gorges – Changzhou HVDC transmission project.

An alternative test circuit is developed

The option of increasing the test power of a conventional back-to-back test circuit was soon discarded as it would have incurred a major investment and did not result in a better test regime than the one offered by the solution finally chosen by ABB.

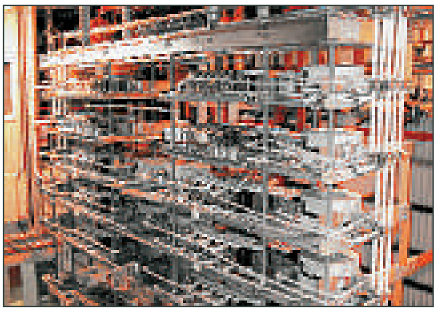
ABB high-power test engineers and HVDC thyristor valve design specialists teamed up in Sweden to explore the feasibility of developing a synthetic test circuit as an alternative to a 'beefed-up' lab power plant. The result of this teamwork was a new synthetic circuit 1, 2, 3, built and installed in ABB Power Systems' high-power test plant in Ludvika.

Circuit design and operating principle

In a synthetic test circuit the test current and voltage are supplied by two

1 Capacitor banks in the voltage section of the synthetic circuit

2 Six-pulse back-to-back bridges and test object used in the new synthetic test circuit



Main circuit equipment

The synthetic test circuit consists of three test generators, two groups of test transformers, two six-pulse thyristor converters, one smoothing reactor, two reactor banks, two capacitor banks, five auxiliary HVDC thyristor valves and one MACH 2 control system. With this equipment more than 12 series-connected thyristors can be tested in one set-up with currents of up to 4900 A and voltage up to 70 kV. The firing sequence and timing are continuously adjustable; the timing accuracy is 10 µs.

Current circuit

Generator(s): 9 MW continuous active output, 25 MVA continuous reactive output and 1300 MVA short-circuit power output. A second generator with a short-circuit rating of 2500 MVA can be connected in parallel, if required.

Transformer group 1 (rectifier bridge):
3 x 66.7 MVA

Transformer group 2 (inverter bridge):
3 x 33.3 MVA

Rectifier and inverter bridges:
Six-pulse back-to-back connection with 11.2 kV and 4900 A on the DC side

Smoothing reactor:
1200 A, 10 mH and 10 mΩ per winding; 12 windings are available for various parallel or series connections.

Voltage circuit

DC generator: 70 kV/15 A, voltage output continuously adjustable
Source-side capacitor bank, C2: 81 µF, adjustable in 4.5 µF steps
Source-side reactor bank, L2: 211 mH, adjustable in 0.2 mH steps
Source-side capacitor bank. C1: 72 µF, adjustable in 0.9 µF steps
Commutation reactor bank, L1: 4 units at 3.2 mH, 6.4 mH, 12.8 mH and 25.6 mH.

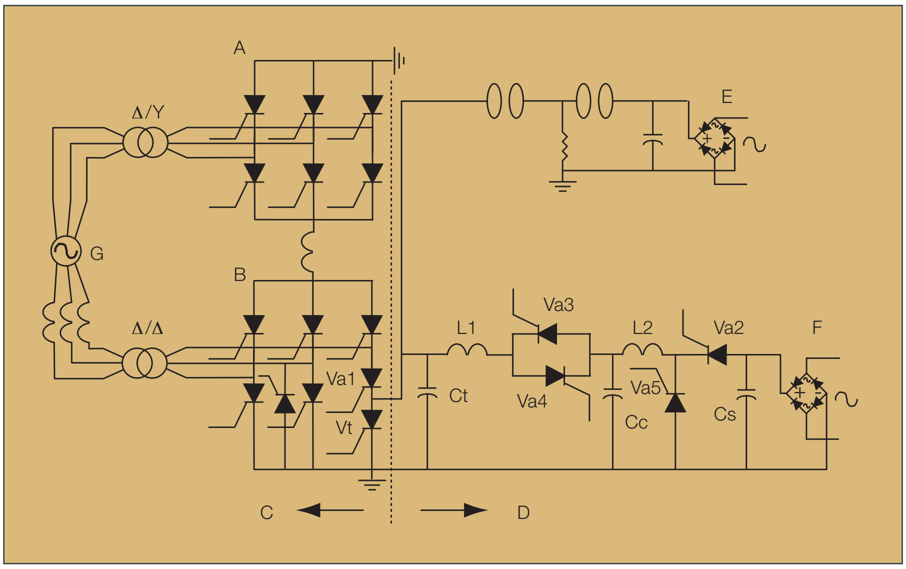
Impulse voltage generator

200 kV/10 kJ

separate power sources. The new ABB synthetic circuit combines a conventional six-pulse back-to-back circuit, which supplies the current, and a newly developed voltage oscillating circuit 4, which applies the voltage. The way in which the circuit works is described briefly below (for a detailed description, see [3]):

One of the valve functions of the six-pulse rectifier in a back-to-back circuit involves the test object, Vt, conducting a current (representing the service current) after firing. Just before commutation ends, the voltage source is connected by firing the auxiliary valve, Va3. At this moment, and until the source current passes through zero, the test object conducts a current which is equal to the sum of the current fed by the current source and the injection current supplied from the voltage source. The test object continues to conduct the injection current for about 600 µs after the source current passes through zero. Inductance L1 and the voltage across Cs are chosen such that they have the same current derivative (di/dt) as in service for approximately 200 µs before current zero [5]. The reverse recovery voltage and forward voltage are produced by firing auxiliary valves Va4 and Va5 at specific instants. Auxiliary valve Va1 is used to isolate the high-current circuit from the high-voltage circuit.

4 Basic diagram of the synthetic test circuit



A = Inverter
B = Rectifier
C = High-current section
D = High-voltage section
E = Impulse generator
F = DC source

An accurate reproduction of service conditions

Turn-on and turn-off are the two most critical states in thyristor operation [6]. During turn-on a high initial current derivative, generated by the charged stray capacitance and snubber capacitor of the thyristor valve, passes through the thyristors. This can give rise to excessive power density in the silicon and cause failure due to local melting. During turn-off, which is the primary function of solid-state switches like thyristors, interaction between the thyristor and the network causes a voltage overshoot across the former.

During testing, the new synthetic circuit provides the same network parameters in the turn-on and turn-off states. This ensures a direct representation of the complex thyristors/network interaction. Since two sources are used, the test current and voltage can be adjusted independently to give the required stresses.

> By providing the same network parameters in the turn-on and turn-off states, the new synthetic test circuit ensures a direct representation of the complex thyristors/network interaction.

A complete operational type test program, as specified in the IEC and IEEE standards, can be conducted with the new test circuit 5. The program for operational testing of HVDC thyristor valves includes:

3 The test circuit generator, supplying continuous test currents of up to 4000 A_{rms} at 50 Hz

- Maximum continuous operating duty tests
- Maximum temporary operating duty test (α=90°)
- 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
- Multi-loop fault-current test without re-applied forward voltage

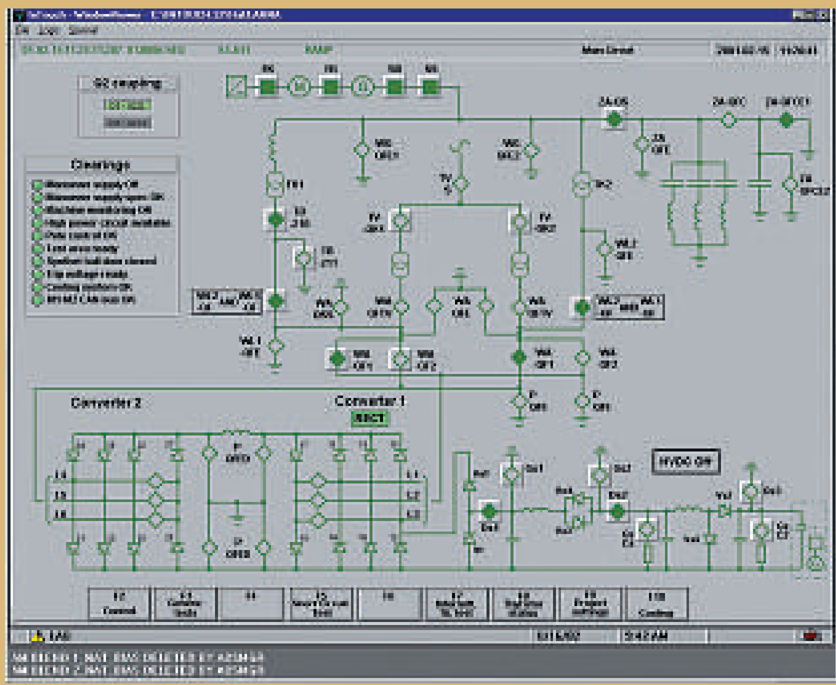
Three Gorges – Changzhou HVDC thyristor valves

ABB has used the new synthetic circuit for a complete type test and sample test program, carried out on thirty-six thyristor modules in eighteen test set-ups, for the Three Gorges – Changzhou HVDC transmission project 6. Recordings made during the test cycles are shown in 7.

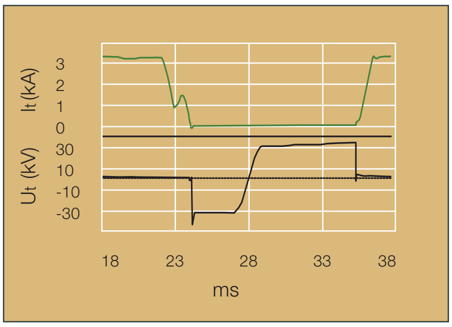
The type test results that were obtained verified the adequacy of the HVDC thyristor valves' design. The fact that the test stresses were equal to or greater than those that would be met in service further testifies to the very high reliability that can be expected of the tested thyristor modules.

6 A double valve structure for the Three Gorges – Changzhou HVDC project in China.

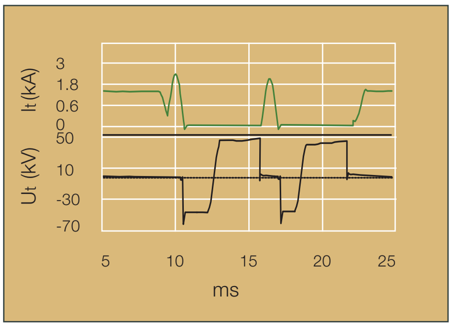
5 Operator window for test circuit operation and control of the firing sequences, timing and coolant status



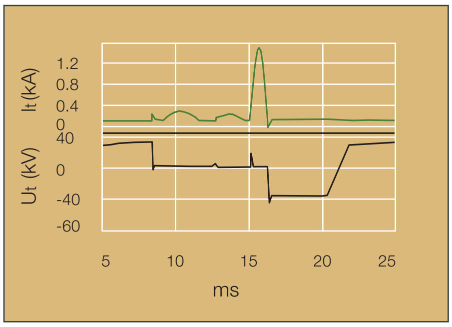
7 Test results for thyristor modules for the Three Gorges – Changzhou HVDC transmission project



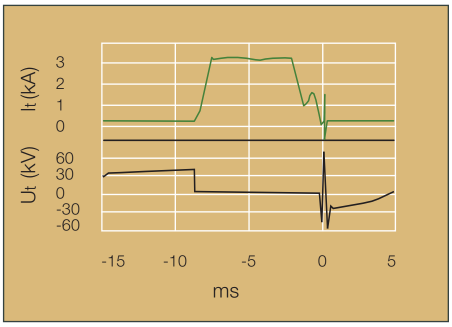
Periodic firing and extinction



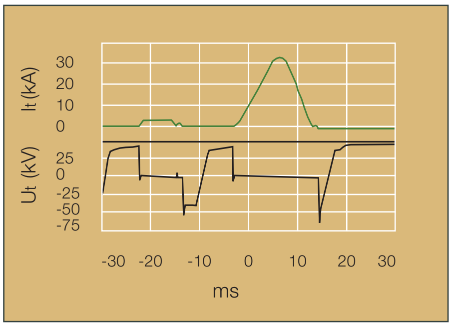
Periodic firing and extinction, α = 90°



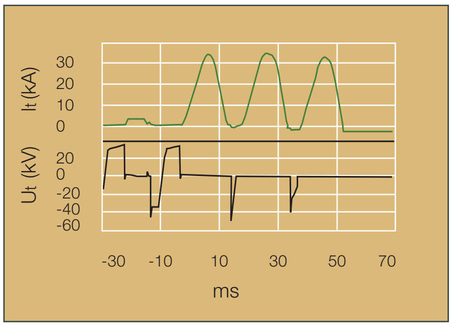
Intermittent direct current test



Test with transient voltage during recovery period



One-loop fault current with re-applied forward voltage



Three-loop fault current without re-applied forward voltage

Comprehensive testing – guaranteeing highest reliability

High reliability is guaranteed for ABB's HVDC thyristor valves by stringent operational tests, dielectric tests and tests of the valves' insensitivity to electromagnetic interference. To verify dielectric strength and EMC, ABB works together with the Swedish Transmission Research Institute, which has its own high-voltage laboratory in Ludvika. It is this dedication to comprehensive testing that has helped to give ABB HVDC thyristor valves their reputation for high quality. The new synthetic test circuit thus contributes to a further strengthening of ABB's leading position in HVDC transmission.

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[3] **B. L. Sheng, E. Jansson, A. Blomberg, H-O. Bjarme, D. Windmar:** A new synthetic test circuit for the operational tests of HVDC thyristor modules. Proceedings of IEEE APEC 2001 Conference, Anaheim, USA, pp 1242–1246.

[4] **B. Sheng, H-O. Bjarme, P. Riffon, W. Ma:** Operational tests of Three Gorges – Changzhou HVDC thyristor valves by using a synthetic test circuit. Proceedings of Cigré ICPS 2001 Conference, Wuhan, China, pp 396–400.

[5] Task Force 03 of Working Group 14.01: Test circuits for HVDC thyristor valves. Cigré Technical Brochure 113.

[6] Task Force 01 of Working Group 14.01: Voltage and current stresses on HVDC valves. ELECTRA No. 125, July 1989.