Verification of Voltage Sourced Converter Based HVDC System

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1. Introduction

Compared to line commutated converters, characteristics of voltage sourced converters include fewer restrictions on AC systems and reactive power control capability. Of the types of voltage sourced converters available, MMCs are suitable for HVDC applications because they are easy to operate at higher voltages, with characteristics like a smaller level of harmonics generated and being able to ensure redundancy(1). The application of HVDC using MMC (MMC-HVDC) has increased in recent years, and Mitsubishi Electric has also focused efforts on development in this field(2). To further these efforts, Mitsubishi Electric constructed a HVDC verification facility (Fig. 1) for verifying its HVDC-Diamond system, and ran a series of verification tests. This paper outlines the results of those verification tests.

2. HVDC Verification Facility

This verification facility was constructed on the grounds of the Transmission & Distribution Systems Center in Amagasaki City, Hyogo Prefecture, and began operation in November 2018. The purpose of construction of this verification facility is to run operational tests and store data of the entire MMC system using the same converters, control protection equipment and other equipment as production models. In-house verification tests have already been completed, and this facility is currently used for verifying equipment designed for use at external converter stations.

Details of the main circuit are shown in Fig. 2, and system parameters are shown in Table 1. The system includes two sets of converters, which are then connected to the AC grid via an interface transformer. The system uses a three-winding transformer to circulate transformer power between the primary and secondary windings, allowing 50 MW transmission tests to be run with only the HVDC verification facility system. These losses are covered by the factory's AC system supply.

Table 1 System parameters

Rated power	50 MW
Rated AC voltage (factory network side)	6.6 kV
Rated AC voltage (verification facility side)	21 kV (60 Hz)
Rated DC voltage	±21 kV
Rated DC current	±1,190 A

(a) Verification facility (b) HVDC valve

Fig. 1 HVDC verification facility

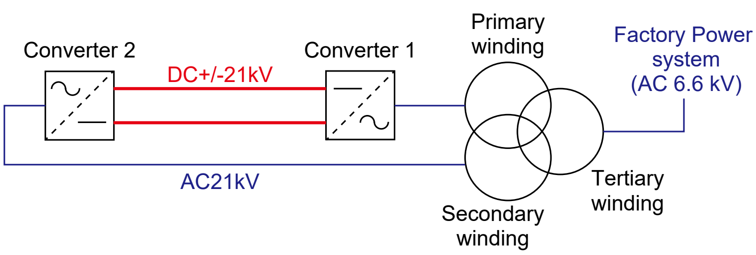

Fig. 2 Main circuit configuration

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Fig. 3 shows the converter, which is comprised of multiple unit converter sub-modules connected in series. Mitsubishi Electric's high-withstand voltage, Insulated Gate Bipolar Transistors (IGBTs) are used as the switching elements, and reducing the number of sub-modules realizes a more compact converter station footprint with lower power loss.

The control protection equipment features a common HMI (console) for operating the devices and monitoring conditions, control device for controlling the converters, protective device, and optical repeaters for relaying signals between the converters and each device.

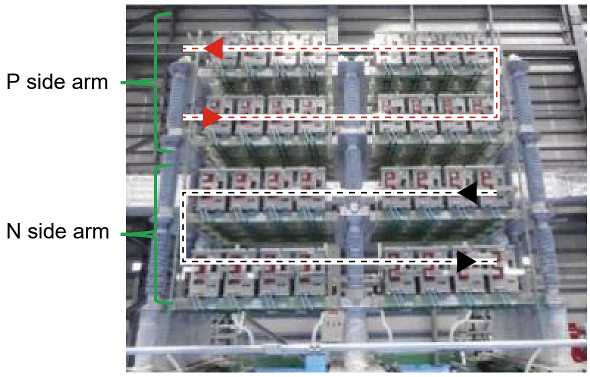

Fig. 3 Converter

3. HVDC System Verification

3.1 Start-up and stop tests[1]

Four types of tests confirmed the operation without any issues: normal start-up, normal stop, emergency stop, and black start.

The results of a typical black start test are shown in Fig. 4. In this test, the converter on the black start side is isolated from the transformer, and then the converter on the supplying system side is charged from the AC side, followed by (1) Control the supplying side converter to charge the DC circuit and blackout side converter, (2) Begin control of blackout side converter and after charging is complete, (3) Generate AC voltage with the blackout side converter, to simulate a black start.

3.2 Power interchange test[1]

Fig. 5 shows the results of a power interchange test which transmits active power and reverses power flow. The results indicated that up to 50 MW of active power can be transmitted reliably in accordance with a reference value.

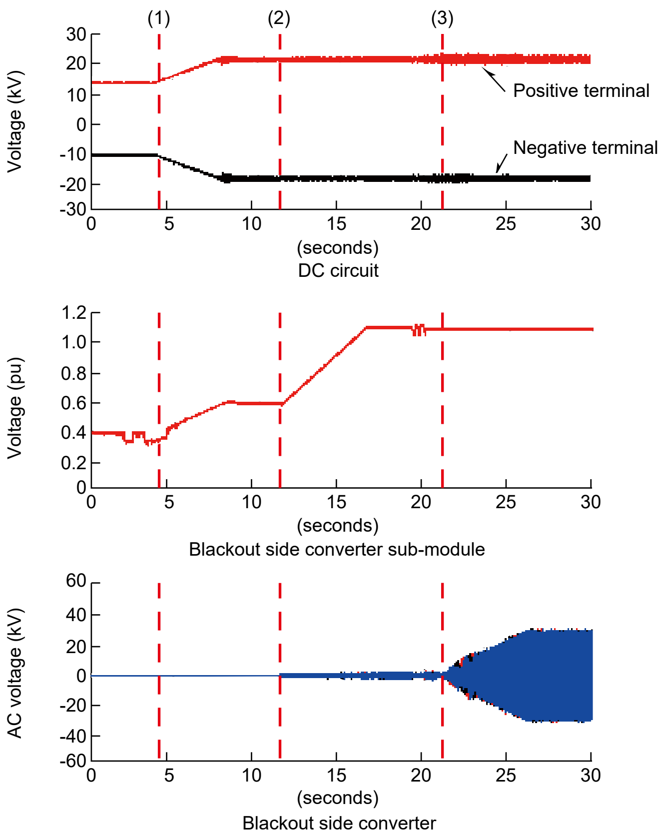

Fig. 4 Black start test

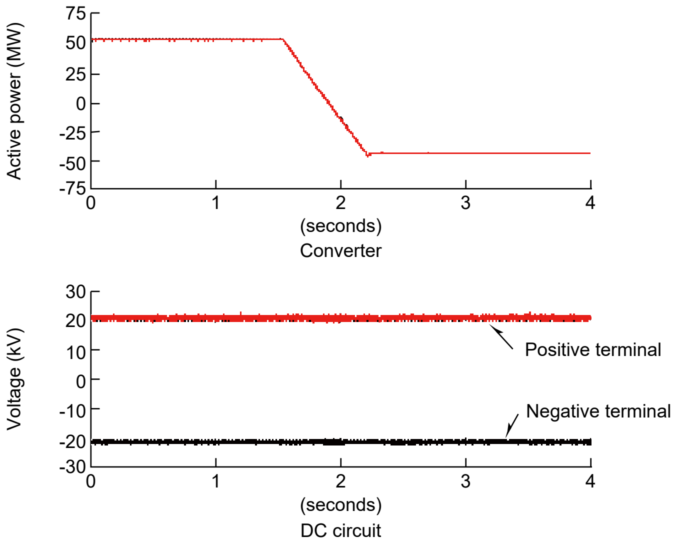

Fig. 5 Reverse power flow test

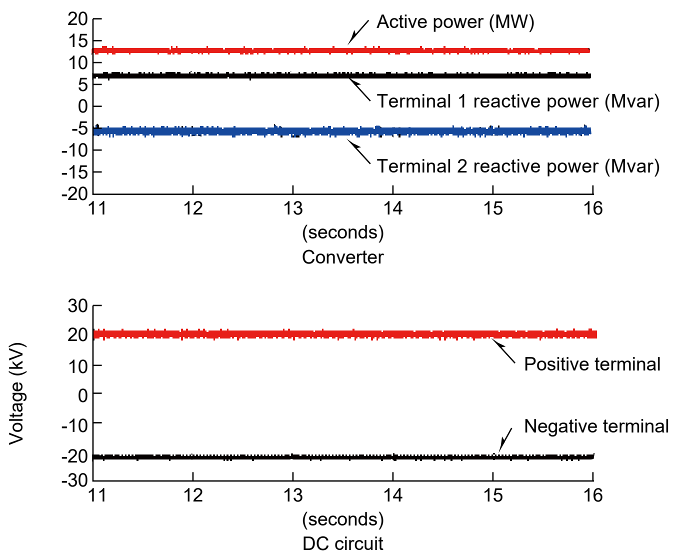

Fig. 6 Active/Reactive power simultaneous output test

3.3 Reactive power output test[1]

A STATCOM operating test and active/reactive power simultaneous output test were performed, indicating that reliable operation was possible in accordance with a reference value. Fig. 6 shows the results of the simultaneous output test with 13 MW active power and 7 Mvar reactive power.

3.4 Long-term stability test

A heat run test was performed that involves continually operating the equipment at the rated output until its temperature stabilizes. The equipment was energized constantly for 8 hours at 50 MW active power and 0 Mvar reactive power for the heat run test, and the temperature rise of the equipment was observed to be appropriate, without any faults caused by localized overheating (Fig. 7).

3.5 DC bus short circuit test

When short circuit faults occur in a DC bus, fault current continues to flow through antiparallel diodes in IGBT modules until AC-side circuit breakers are tripped, even if all IGBTs are gate locked. As the current flowing through the internal diode is much higher than the rated current, the junction temperature of the diode exceeds the given value over a short period (around one cycle), causing the diode to fail. To prevent this, an over-current bypass diode (Bypass Diode: BPD) is installed parallel to the IGBT internal diode as shown in Fig. 8 to divert current flow, which ensures that the BPD carries the fault

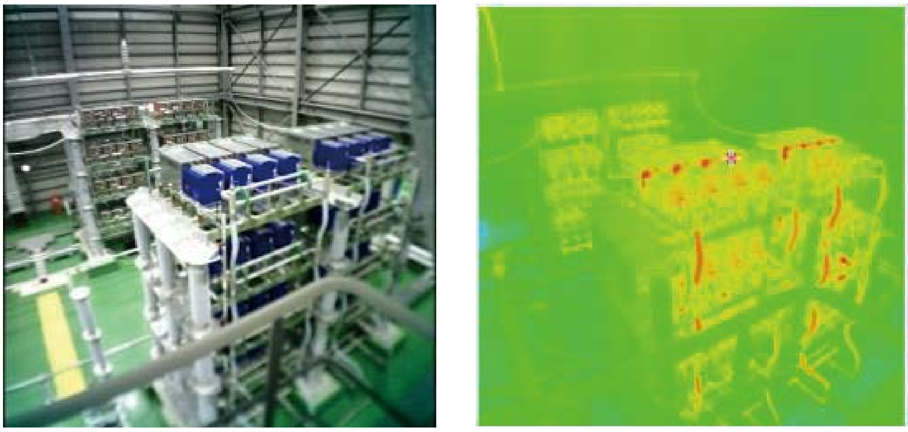

Fig. 7 Thermal imaging of converter during heat run test

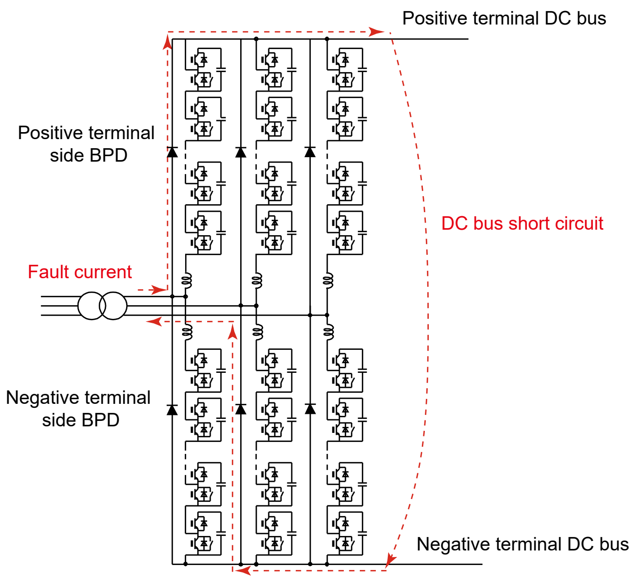

Fig. 8 Short circuit protection operating principle

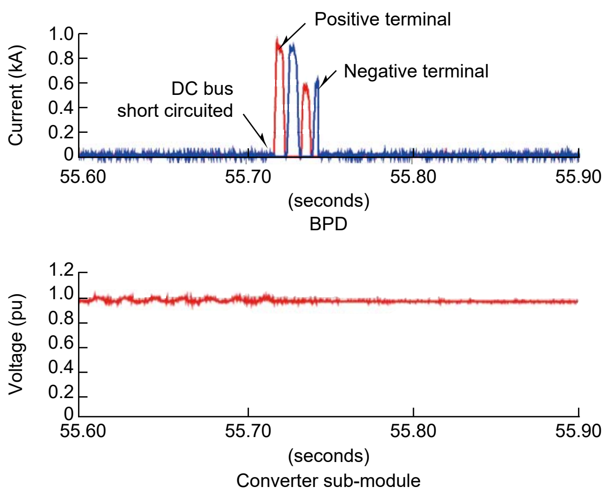

Fig. 9 DC bus short circuit test

current in the event of a short-circuit fault to protect the converter.

This test involves triggering a DC bus short circuit fault at the verification facility to verify that the BPD operates to protect the converter. It was confirmed that diverting the fault current to the BPD when a DC bus short-circuit fault occurs prevented the fault current flowing to the converter, as shown in Fig. 9, and also limited over-voltage generated at the converter's capacitor to provide normal protective action.

3.6 Radio noise test

Electromagnetic noise generated when a converter is operating includes various frequency components, and may adversely affect communications around the converter station. To address this, the verification facility was used to measure (with an antenna) the electromagnetic noise generated when the converter was operating. The results of electromagnetic noise measurements in the Japanese AM radio frequency bands when the converter was operating and stopped are shown in Fig. 10. No harmful level of noise was observed in these frequency bands.

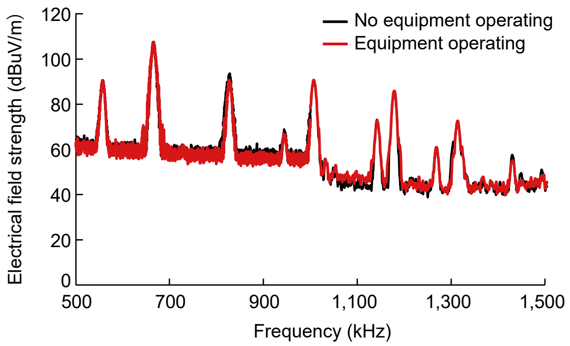

Fig. 10 Radio noise test

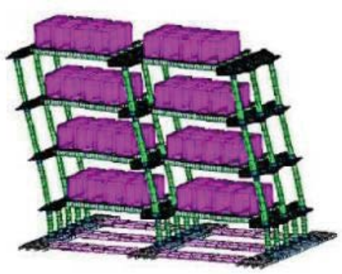

Fig. 11 Results of seismic analysis of converter (dynamic analysis)

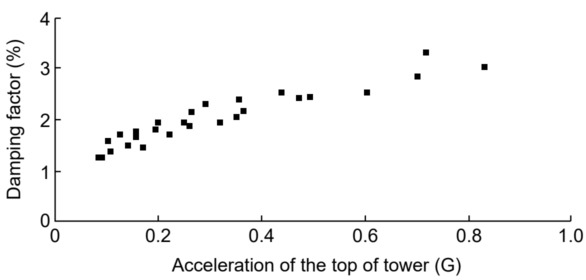

Fig. 12 Damping factor of converter valve tower

3.7 Seismic analysis

Converters suitable for HVDC systems are composed of series-connected sub-modules as shown in Fig. 3 to provide high voltage operation.

Stacking submodules can reduce the footprint of the converter, but the resulting higher center of gravity raises the issue of seismic performance.

In Japan, the required seismic specification is JEAG 5003 (Guideline for seismic design for electric equipment at substations, etc). Evaluation by dynamic analysis confirmed that this specification was met (Fig. 11). In this converter, polymer insulators were applied to the insulation supports using FRP (Fiber Reinforced Plastics) as a structural member. Data[3] on the damping factor of the polymer insulators obtained in the verification test equivalent to the actual equipment is applied (Fig. 12). The resonant frequencies of the converters were measured and the accuracy of the analysis was confirmed to be sufficiently high.

4. Conclusion

A verification facility was constructed to conduct a variety of tests for HVDC-Diamond, Mitsubishi Electric's HVDC system. This allowed data to be acquired on control (normal start-up, normal stop, emergency stop, black start, power interchange test, reactive power output test), long-term stability (heat run test), protection (DC bus short circuit test), practical performance (radio noise test and seismic evaluation), which indicated that the product can be supplied without any performance issues.

Based on these results, plans are being formulated for the development of more compact HVDC systems with even lower losses.

References

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(2) Takahashi. T., et al.: Operating Tests at VSC Based HVDC Verification Facility, The 2019 Annual Meeting of The Institute of Electrical Engineers of Japan, 6-339 (2018)

(3) Yoshid. Y., et al.: 500 kV Large Capacity Thyristor Valve to Evaluate Seismic Performance, IEEJ Transactions on Power and Energy B, 115, No.11, 1358-1364 (1995)