ENHANCED SURGE PROTECTIONS FOR DC ULTRA-HIGH VOLTAGE POWER SUPPLY FOR ITER NBI

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1. INTORODUCTION

Through the development of the ITER neutral beam injector (NBI), Japan has been developing a DC high voltage power supply that generates DC -1 MV and is also surge tolerant. The DC -1 MV power supply has been already installed in the NB test facility (NBTF), Italy, and DC- 1.2 MV withstand voltage was confirmed [1]. However, a ground fault occurred on a gas-insulated (SF_6) transmission line during the integration test of EU and JA power supplies, and the resulting surge voltages damaged the rectifier and the insulating transformer. To recovery the system, we examined the occurrence of the surge in detail through simulated ground fault tests using actual NBTF system and circuit analysis [2]. The protection enhancement is summarized into the following three countermeasures, (i) an improved RC snubber circuit for the diodes, (ii) current-limiting inductors and resistors for the diodes and (iii) a common mode filter for the insulating transformer. Finally, design for the production has been finalized and the component for (iii) was successfully completed.

2. ORIGINAL DESIGN OF DIODE RECTIFIER

Fig. 1 (a) shows the configuration of the diode rectifier generating 200 kV in a single unit. Its arms are designed with a safety factor of 2.7, and each arm is composed of 300 series diode to achieve high surge resistance. They are installed in the tank filled with SF6 gas for insulation, and each diode in the arms has a stray capacitance to the tank. As an additional protection, conventional RC snubbers are applied to each diode to suppress overvoltage at turn-off during rectification in normal operation as shown in Fig. 1 (b).

After the incident, a simulated ground fault at a low voltage of DC -10 kV was conducted in NBTF to investigate the cause of the damages on diodes. The cause was most likely due to overvoltage. It occurs due to two independent phenomena that cause un-uniform voltage sharing of the series diode. The first phenomenon is that voltage drops occur in the snubber circuits due to the surge current of approximately 1MHz in reverse direction of the diode just after breakdowns as shown in Fig. 1 (c). Due to the stray capacitance, leakage currents flow into the tank, and higher voltage is applied to the diode on the anode side. It may cause the diode

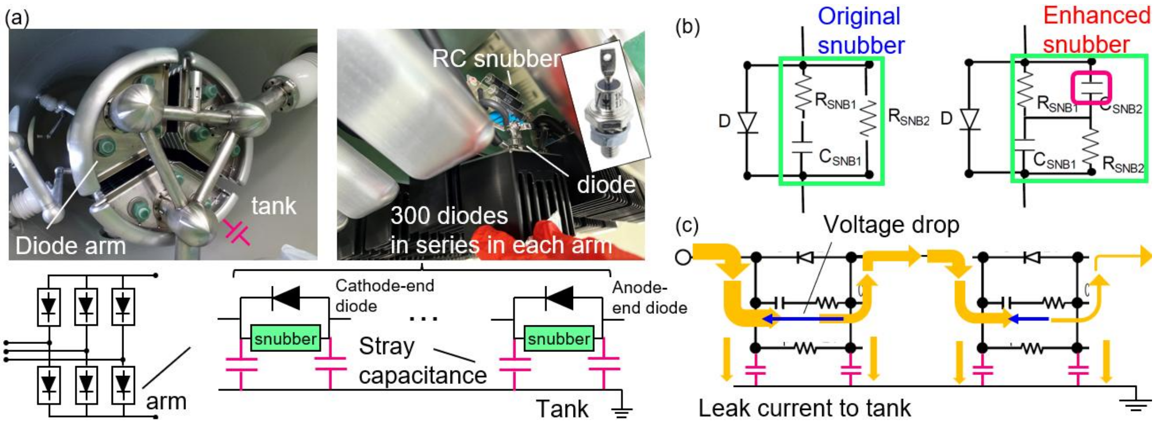

Fig. 1. (a) Configuration of the diode rectifier generating 200 kV in a single unit (b) Original and enhanced snubber (c) Un-uniform voltage distribution in series diodes due to leak current to tank through stray capacitance.

on the anode side to be destroyed in sequence. The second phenomenon is that the diodes turn off due to the flow-on surge current around 35 kHz, and at this low frequency, no leak currents flow into the tank. As shown in Fig. 2(a), the voltage of the series diode becomes imbalanced due to the difference in the timing of the reverse recovery and their transient impedance. It occurs regardless of the mounting position in the arm.

3. ENHANCED SURGE PROTECTION FOR DIODE RECTIFIER

The authors proposed a new snubber that matches the voltage non-uniformity caused by both surge and reverse recovery characteristics. In this snubber, a capacitor is added in parallel to the resistor of the original RC snubber as shown in Fig. 1 (b). Current-limiting inductors and resistors on the output of the rectifier are also effective in reducing surge voltage, because they can reduce the voltage drop in the diodes and snubber circuits. With regard to surge voltage of the diode, we confirmed that it could be suppressed to approximately 60% of the rated value by the low-voltage ground fault test using a small prototype of the snubber and current-limiting inductor as shown in Fig. 2 (a). For the voltage imbalance due to the reverse recovery characteristics, we conducted tests with 40 spare diodes connected in series. The optimum capacitance was investigated applying 50 Vp-p to the diodes. Then, it was statistically confirmed that none of the 9000 diodes used in NBTF are damaged with the optimized snubber as shown in Fig. 2 (b).

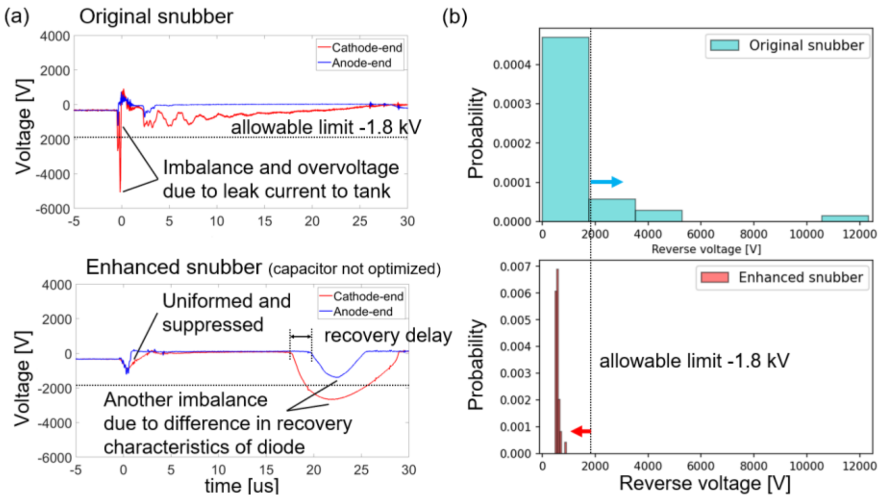

Fig. 2. (a) Diode voltage in low-voltage ground fault test in NBTF (converted to values at acceleration voltage of -1000 kV) (b) Histogram of diode voltage during reverse recovery obtained with 40 spare diodes.

4. MANUFACTURING OF SURGE PROTECTION FOR 1 MV INSULATING TRANSFORMER

In the case of the transformer, overvoltage occurred between the three-phase output line and the neutral line. The low-voltage ground fault test in NBTF confirmed that a common mode filter that makes the ground voltage of the four wires the same is effective [2]. This is also confirmed by numerical analysis [3]. The implementation design was completed, the device was manufactured (Fig.3), and it passed the LI 1.5 MV impulse withstand voltage test across the filter and the DC -1.2 MV withstand voltage test to ground.

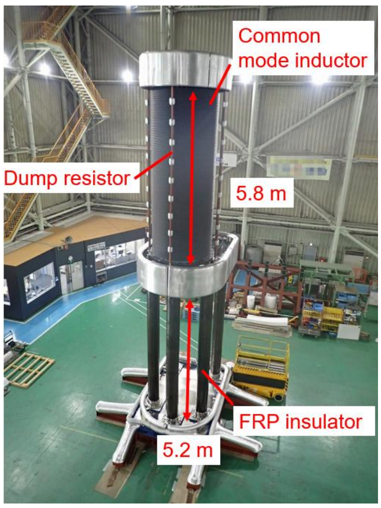

Fig. 3. Common mode filter for -1 MV insulating transformer.

References

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