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The Kii Channel HVDC Link in Japan

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Summary

The Kii-channel HVDC Link is one of the world's biggest HVDC links that utilizes submarine cables and it has been in commercial operation since June 22, 2000. The purpose of the link is a bulk power transmission from a coal-fired thermal power plant to a load center. It also contributes to stabilize and reinforce the power systems in the western part of Japan. Installed capacity of the HVDC is 1400MW (+/-250kV, 2800A) and the system configuration is bipolar, metallic return scheme, composed of cables (48.9km) and overhead lines (50.9km). In the future, it will be up-rated to 2800MW (+/-500kV, 2800A). Many new technologies, such as DCGIS and large diameter LTTs, were applied in the project. Several coordination controls were also applied to the HVDC. Operation data for a year since the commissioning of the HVDC proved its high reliability and showed very high energy utilization of more than 90%.

Keywords: HVDC, DCGIS, LTT, metallic return, power modulation

1.INTRODUCTION

The Kii-Channel HVDC link is one of the world's biggest HVDC link which utilizes submarine cables, connecting Shikoku power system and Kansai power system in Japan. Main purpose of the link is to transmit electricity, which is generated at Tachibana-bay coal-fired thermal power plant (1050MW-2units and 700MW-1unit) in Shikoku island, to Kansai area where heavy energy demand exists. The HVDC link also contributes to stabilize and reinforce the power systems in the western part of Japan [1].

Figure 1 shows the geographical location of the HVDC and related a.c. power systems. On the east coast of Shikoku island, there is Anan converter station that is connected to Tachibana-bay power plant via a.c. 500kV transmission line (5km). The power converted from a.c. to d.c. is delivered to main island of Japan (Honsyu side) through the underground and the submarine cables (49km) across the Kii-Channel to Yura switchng station. On the shore in Honsyu side, Yura switching station (cable terminal) locates where d.c. cables are connected to 51km of overhead lines. At the end of the d.c. overhead lines, there is Kihoku converter station in main island where a.c. 500kV overhead lines are connected to the Kansai a.c. power system network. Then a hybrid loop system is formed by the HVDC and existing interconnecting a.c. lines (Honshu-Shikoku interconnecting line), enabling more reliable and flexible power system operation.

The project had been jointly promoted by three electric power companies: the Kansai Electric Power Company, Shikoku Electric Power Company and Electric Power Development Company. Under the cooperation of these three companies, R&D and field tests of new converter equipment, new concept control and protective relay systems had been carried out to achieve lower loss, more compact equipments, lower cost and more reliable HVDC system. Results of the R&D were fruitful and many new technologies were applied to the HVDC link.

This paper presents the outstanding features of the HVDC, applied new technologies and the operating experience for a year since the commissioning of the HVDC.

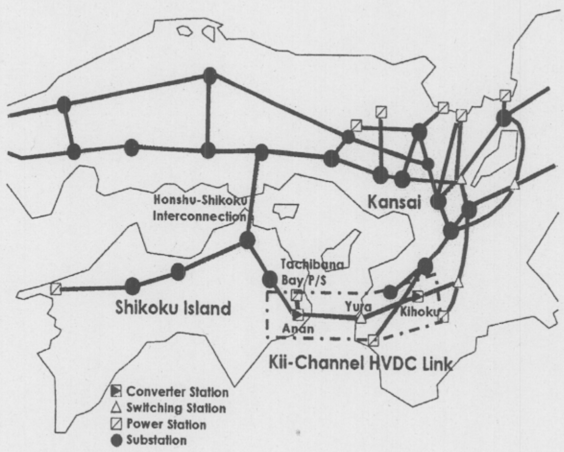

Fig. 1 Location of the Kii-Channel HVDC link

2.SYSTEM CONFIGURATION

Figure 2 shows the schematic diagram of the Kii-Channel HVDC Link. Installed capacity of the link is 1,400MW (+/-250kV, 2,800A) and it will be up-rated to 2,800MW (+/-500kV, 2,800A) in the future. The system configuration and the layout of the converter stations were taken into account of the up rating, including purchase of the installation area. Also, some of the installed equipment, such as smoothing reactors, DCGIS and submarine cables were already designed for d.c.500kV operation.

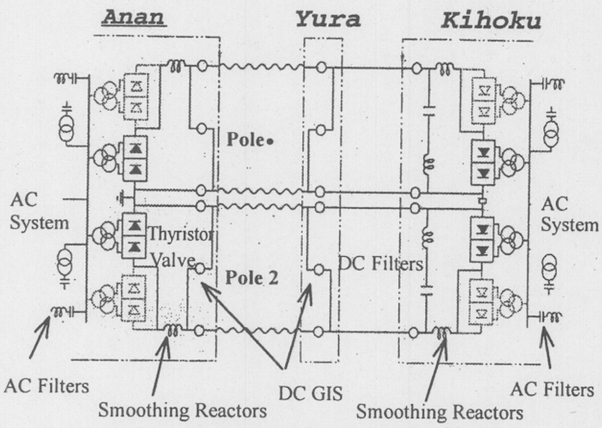

Fig. 2 Schematic diagram of the HVDC

The system configuration is bipolar, metallic return scheme, because of avoiding electrolytic corrosion in the adjacent area.
Since the specification of the return cables are the same as the main cables, even if one of the main cables were damaged, it would be immediately substituted by one of the return cables. This could be achieved by switching the disconnecting switches of Anan and Yura. Then, the system could be back in normal operation again. The specification of the main equipment is shown in Table 1.

Table 1 Outline of Kii-Channel HVDC Link

Ratings	At the Beginning	Bipole, Metallic return 1400MW,+/•250kV
	In the future	Bipole, Metallic return 2800MW,+/•500kV
Thyristor Valve		250kV,2800A 700MW×2groups, Light-triggered, Quadruple-6tiered, Air-insulated, Water-cooled
Overload capacity		125%,30 minutes
Submarine cable		4 cables,48.9km,3000mm^2
Overhead line	Main	2 lines,50.9km,(810mm^2×4)
	Neutral	2 lines,50.9km(610mm^2×2)
Grounding of neutral line		Direct grounding at one end (Anan converter station)

3.FEATURES OF THE HVDC AND APPLIED NEW TECHNOLOGIES

(1)Thyristor Valve
For the thyristor valves, high voltage, large capacity light-triggered thyristors (LTTs; 150mm in diameter, 8kV-3500A) were used and assembled in 6 modules/arm configuration (6 stages for quadrivalve). This enabled much more compact valves than before and excellent aseismatic structure.

LTTs has been used for many years at existing HVDC projects in Japan, such as Hokkaido-Honshu link, Shin-Shinano Frequency Converter, Sakuma Frequency Converter and Minami Fukumitsu BTB. Thyristors of 100mm diameter, 6kV-2500A are used for these projects and they exhibit excellent reliability. However, for achieving more compact and lower loss converter required further advance in thyristor device technology. But it is very difficult to fulfill both large capacity and excellent switching property. They are in a trade-off relationship. To overcome this dilemma, proton radiation process were applied to control carrier lifetime in a limited area of the silicon wafer. Application of the new device and unique valve structure enabled compact valves of excellent aseismatic characteristics. Figure 3 shows the thyristor valve installed in Anan converter station. At Hokkaido-Honshu HVDC link in Japan(600MW,+/-250kV), valve structure is 8 stages for quadrivalve (8 modules/arm) and the height is about 12 meters. In Kii-channel HVDC, it is 6 stages for quadrivalve (6 modules/arm) and about 9 meters high at Anan converter station (3/4 of the Hokkaido-Honshu valves).

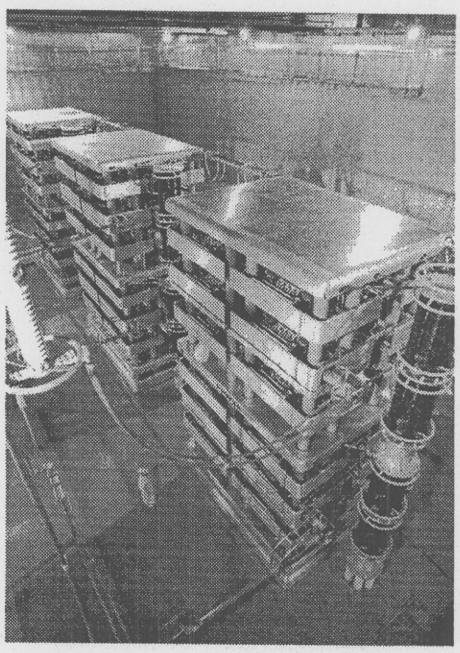

Fig. 3 Thyristor valve of Anan converter station

(2)D.C. Gas-Insulated Switchgears (DCGIS)
In Anan converter station and Yura switching station, d.c. gas insulated switchgears (DCGIS) which consist of disconnectors and bus were installed because of the heavy salt contamination in coastal area. DCGIS were used at the first time in the commercial operation. All of the energized conductors are enclosed in a tank, therefore installation space was greatly saved.
In the course of developing the DCGIS, complete elimination of metallic particles in the tank had been critical problem. If such particle existed in the GIS, they were to be lifted up towards the main conductor along with the electric field. Particles would move to-and-fro between conductor and the tank, or move around the conductor discharging on the tip of their own. On such condition, insulation level of the GIS is drastically decreased, then, if some switching surge come in, there would be a flash over. To avoid such tragedy, several types of particle traps were set in the tank. As quality control after installation, conditioning tests, in which DCGIS was hammerd and vibrated with charging d.c. voltage,were carried out to eliminate metallic particles. Because the charging on the insulating spacers would also bring about reduction of the insulation level, semi-corn type insulating spacers were developed to mitigate charging.

In Kihoku, metallic return transfer breakers (MRTBs) and pole separating breaker were installed. Both types of breakers use self-excitation oscillation to achieve zero crossing current. MRTB eliminates the arc of the return line at a grounding fault which is transferred to MRTB by grounding the return line compulsorily.

Figure 4 shows the DCGIS installed in Anan converter station.

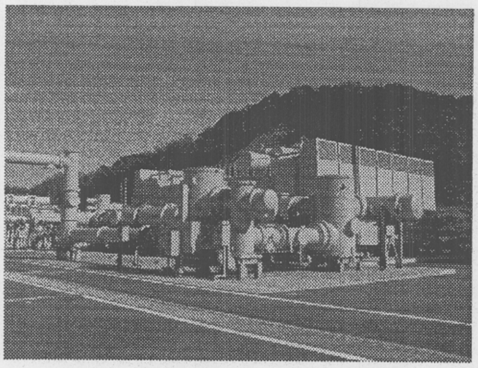

Fig.4 DCGIS installed at Anan converter station
(Behind the DCGIS is the smoothing reactor)

(3)Filters and Reactive Power Compensation
For the same reason of the DCGIS, dead tank type a.c. filters are used in Anan converter station.

500kV dead tank type a.c. filters were developed since the highest voltage rating of the dead tank type filter was a.c. 275kV. Precise analyses of electric field in the capacitors of the filters had been carried out to optimize internal insulation structure. As a result of the study, compact and reliable filters were completed. Each pole has 11th, 13th order and high pass filters. One 5th order filter, which is needed to dump non-theoretical harmonics emerging on some special system conditions, is installed at both terminals.

D.c. filters consists of 12th order and high pass type, and are installed only at Kihoku where there is no concern about salt contamination because it is located far from the sea, however, the dead tank type d.c. filters are adopted to achieve compact size and higher reliability for 500kV designed. On Anan side, since cables are directly connected to the d.c. circuit, their capacitance can play roles of a d.c. filter.

Reactive power compensation can be done by switching the shunt capacitor banks. For Anan converter station, there are less shunt capacitor capacity than Kihoku side because it can expect reactive power supply from nearby thermal power plant. Shunt reactors at Anan also play an role to balance reactive power at low load operation or the operation when d.c. power flow is stopped.

(4)Converter Transformer and Smoothing Reactor
Converter transformers are Three-phase three-winding type in both converter stations. Smoothing reactors are designed for d.c. 500kV from the beginning. And it is directly connected with DCGIS in the case of Anan converter station.

During the design process, analyses of electric field including the polarity reverse event, had been carried out to optimize internal insulation structure. Consequently, 20% reduction of insulation length could be achieved.

The inductance of the reactor was decided so that the resonant frequency between submarine cables and the reactor never coincide with fundamental frequency (60Hz).

(5)Submarine Cables
For submarine cables, records making large capacity, high voltage (d.c. 500kV design) OF (Oil-Filled) type were used. The conductor size is 3,000mm^2. Two main cables and two return cables were laid on the seabed. These specifications are the same, so the return cable can be used as a spare of main cable.
There were two types of cables as candidates: mass impregnated type and oil-filled type. However, oil-filled type was preferable than mass impregnated type, because it could be used higher conductor temperature. For large-scale transmission, conventional paper insulation is no longer the best solution, because it tends to be thick and prevents heat radiation affecting on the

mechanical strength. Applying the PPLP (PolyproPylene Laminated Paper) was the solution for that, and it was the very first time to use for d.c. cables in the world. PPLP has been used in a.c. cables and the electrical property is excellent.
Optical fibers were installed in the cables as thermal sensors, in addition to the telecommunication purpose. These sensors can monitor the cable temperature, all along with the cable for about 49km.

(6)Environmental Consideration
A.c. 500kV XLPE (Cross-Linked Polyethylene) cables are used to connect equipments in converter stations. They connect between a.c. buses and transformers, a.c. buses and a.c. filters. These minimize the exposure of energized parts, prevent salt contamination and save installation space of the equipment. Especially in Anan converter station, most of the energized conductors are enclosed except for the a.c. line parts before the GIS bus.
Thyristor valves are installed in the valve hall, where dust count is kept under 100,000, and the humidity is controlled less than 70%. The hall itself is electro-magnetically shielded to prevent radio noise emission.
Converter transformers and smoothing reactors are enclosed in sound barrier to mitigate audible noise to the surrounding residents.
Each of the neutral point of the transformers is grounded through resistors of 5 ohms. These resistors prevent d.c. stray current to stray into the a.c. network when d.c. line fault occurs. Effectiveness of the neutral grounding resistor was confirmed at the artificial d.c. line fault test.

(7)Control and Protection
In terms of control and protective relay systems, higher operability is required because the capacity of the HVDC is large and its influence to the existing a.c. network is serious. Then, a continuous operation control during and after the interconnected a.c. line faults was newly developed. Also, several damping controls had been developed to stabilize connected a.c. power system since they can be easily accomplished by modulating the HVDC power in the a.c.- d.c. hybrid loop system. Power Modulation (PM) control is used to stabilize power swing, which is initiated by line faults within the power system.

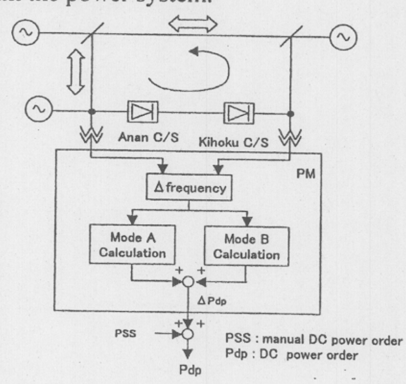

Fig. 5 Block diagram of PM

In addition, coordination controls with nearby thermal power plant were applied. One of the controls is Supplemental Subsynchronous Damping Control (SSDC), and is used to avoid interaction between d.c. current control and turbine shaft (SubSynchronous Torsional Interaction : SSTI). Also, in the case of the transition to the islanded operation, in which the turbine generator and d.c. system is separated from Shikoku a.c. network, there are other coordination controls: one is EFC(Emergency Frequency Control), which maintains frequency of the islanded system and the other is EPPS(Emergency Power Preset Switch), which balances the d.c. power to the turbine generators output power during the transition.

4.COMMISSIONING TEST

HVDC system performance test had been carried out in the condition of connecting with commercial power system from January to June 2000. In addition to the verification of fundamental control, operation and protection functions, several power system control functions were also tested. These include PM, EFC and EPPS functions.

Shikoku Islanded system mode test was also carried out, in which interconnection between Shikoku system and main island (Honshu) system was only connected by the Kii-channel HVDC link (a.c. ties were disconnected). In this test, the EFC for the Shikoku Islanded mode operated properly and maintained the systems frequency stable.

Another islanded mode, HVDC system connect only Turbine generator was also tested. This mode was create by manual tripping of the tie lines circuit breaker which connects Anan converter station and AC 500kV network. In this test, SSDC and other coordination control functions were confirmed.

Artificial d.c. line fault tests, in which grounding faults on d.c. overhead lines were artificially triggered at both ends of the lines, were also carried out and proper performance of protection and control systems were confirmed. Observed over voltages, over current and stray current were within the design criteria.

Due to these intensive tests, the HVDC link has shown outstanding performance and contribution to the systems stability.

5.OPERATING EXPERIENCE

(1)Energy Utilization, Availability
The Kii-Channel HVDC Link is now smoothly operate since the commissioning on June 22, 2000.

Monthly data of transmitted energy and energy utilization of the link are shown in figure 6. The energy utilization exceeds 90 % from August 2000 to February 2001. The monthly average is still high as 83%. This clearly states that the link is really used for bulk power transmission. In terms of the availability, there are some influences of initial troubles, but if they are eliminated, the availability of the link ranges around 97%. The number is fairly good, but as many of the initial troubles were already repaired, a higher availability will be expected from now.

It should be emphasized that the transmitted energy through the link has already reached to 10 TWh within a year. However, the achievement done by the new HVDC link, and that is with submarine cables, is outstanding in the world.

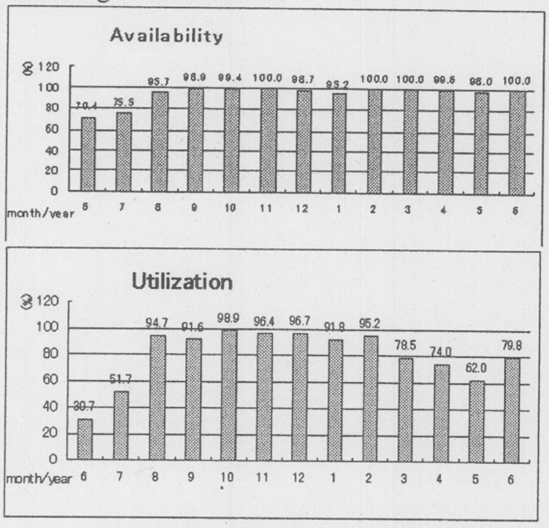

Fig. 6 Transmitted energy and energy utilization

(2)Transient Reliability

When lightning strikes on the a.c. lines, which are close to the converter station, existing HVDC, such as Hokkaido-Honshu link, has to stop its operation during the fault. Then, after the a.c. side fault is cleared, it restarts the operation. For this scheme, improvement of the system reliability is limited. Then, a continuous operation control during and after the interconnected a.c. line faults, had been newly developed and applied to the Kii-Channel HVDC Link.

To develope this operation, some new technologies were incorporated: new type of Phase Locked Loop (PLL) with phase memory function, high speed open loop gamma control with correction function for harmonic distortion, or gamma detecting type closed loop gamma control. Such new controls permits the optimal control, so that both of the prevention of commutation failure and rapid power recovery after the a.c. side fault clearing can be accomplished simultaneously.

There were 12 times a.c. side lightning strike faults in inverter side, and the converter could be continuously operated in all cases. Figure 7 shows one of the example of the continuous operation during one phase a.c. line grounding fault. The fault occurred near Kihoku converter station when only 700MW monopole was operated and the power flowed from Anan converter station to Kihoku conveter station. Although the a.c. voltage degresed to zero during the fault, d.c. current contiuously flowed 1 pu.

This meaned that the contiunous operation was sucsessed.

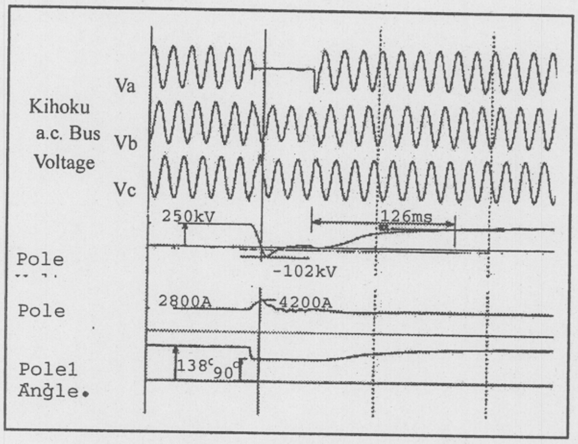

Fig. 7 Continuous operation during the a.c. fault

One lightning strike occurred on overhead return circuit for pole 1, near Kihoku converter station. At that time, MRTB operated successfully to extinguish the arc then cleared the fault.

Another example of the real operation of new control was PM. When the thermal power plant of the Shikoku side tripped, the PM could detect the disturbance and operated to damp the local oscillation. It was confirmed that the damping control was properly operated.

6.CONCLUSION

The Kii-Channel HVDC Link has incorporated many new technologies, such as large capacity LTTs, DCGIS and advanced system controls. These new features contribute to achieve lower loss, compact, lower cost and reliable facilities. High energy utilization and availability of the link proves itself of the excellent reliability. Therefore the new HVDC link greatly contributes to the improvement of the system stability in western part of Japan.

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