# The 1,400-MW Kii-Channel HVDC System

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*OVERVIEW: High-voltage direct current (HVDC) transmission systems are widely used in many projects all over the world. In Japan, several HVDC systems are in operation, and a new system, the Kii-Channel HVDC, was put into operation in June, 2000. The HVDC is a bulk transmission system and its transmission capacity is to be built up to 2,800 MW. Hitachi supplied the main equipment for this system, such as thyristor valves, converter transformers, and control & protection panels. These products are based on state-of-the-art technologies described below.*

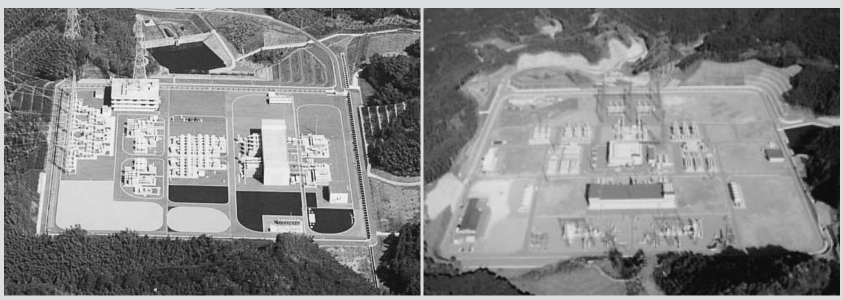
## INTRODUCTION

HIGH-voltage direct current (HVDC) transmission systems (including frequency-conversion systems and submarine DC-link and non-synchronous interconnection systems) are used in many projects all over the world. HVDC systems feature easy power-flow control, stable cable transmission, and economical operation for long-distance transmission. The capacities of some of these systems exceed 3,000 MW. In Japan, 50/60-Hz frequency-converter systems are more common than other systems. A DC submarine cable transmission system is also used between Honshu and Hokkaido as well as for non-synchronous interconnection between the Hokuriku Electric Power System and the Chubu Electric Power System. Before the beginning of 2000, the capacity of these systems ranged from 300 to 600 MW and was 1,800 MW in total.

The Kii-Channel HVDC system constructed by the Kansai Electric Power Co., Inc., the Shikoku Electric Power Co., Inc., and the Electric Power Development Co., Ltd., has been in commercial operation since July, 2000. Hitachi supplied the main equipment for the pole-II terminals of the project. In this article, we describe the project features and new technologies.

## HVDC SYSTEM

The Kii-Channel HVDC system is the first bulk HVDC transmission system and the largest HVDC system in Japan, which is to transmit power from the Anan converter station in Shikoku to the Kihoku converter station in Honshu via the Yura switching station through an approximately 50-km-long submarine cable and an approximately 50-km-long overhead transmission line to send part of the power from the Tachibana-bay thermal power plant (the total



**Anan converter station** **Kihoku converter station**

*Fig. 1— Terminals of the Kii-Channel HVDC System: Anan Converter Station and Kihoku Converter Station. The Anan converter station is located in a seaside area near the Tachibana-bay thermal power plant in Shikoku. The Kihoku converter station is located in an inland area in Honshu. Both terminals are connected by an approximately 50-km-long submarine cable and an approximately 50-km-long transmission line.*

generation capacity is 2,800 MW) (see Fig. 1). This system is of the largest class in the world. It was put into commercial operation as the Kii-Channel HVDC project, Phase I (1,400 MW, DC±250 kV, 2,800 A), in June, 2000. A one-line diagram of the HVDC system is shown in Fig. 2.

The specifications of the main equipment of this HVDC project are listed in Table 1. Hitachi supplied the main equipment including thyristor valves, converter transformers, and system control and protection panels for the pole-II terminals. In addition, for the Kihoku converter station, Hitachi also supplied a substation control system (SCS). The main features of the Kii-Channel HVDC system are listed in Table 2, which shows such advantages of the HVDC system as its high-speed power-flow control.

The system has a DC continuous operation function during AC-system faults to ensure the power system

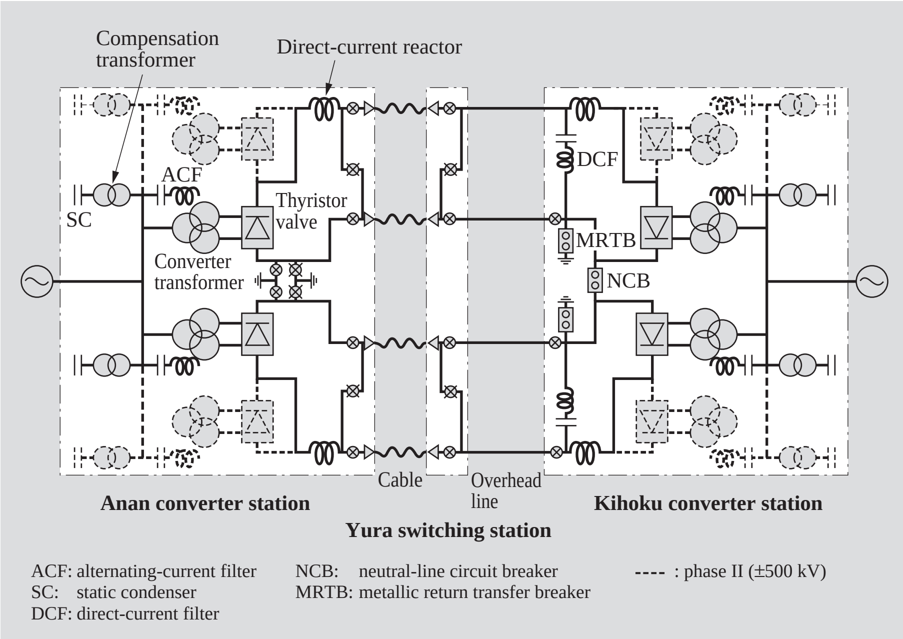



*Fig. 2— Main Circuit Diagram of the Kii-Channel HVDC, Phase I.*
*1,400-MW transmission with bipolar metallic return 700-MW × 2 HVDC systems.*

TABLE 1. Specifications of the Main Equipment of the Terminals (Kii-Channel HVDC, Phase I)

| | Anan converter station | Kihoku converter station |
|---|---|---|
| Thyristor valve | DC 250 kV, 700 MW (125% over-load) × 2 pole | DC 250 kV, 700 MW (125% over-load) × 2 pole |
| Converter transformer | 500/110/110 kV, 872 MVA × 2 pole | 500/110/110 kV, 872 MVA × 2 pole |
| Compensation transformer | 500/60/66 kV, 270 MVA × 2 pole | 500/71 kV, 450 MVA × 2 pole |
| Shunt capacitor | 66 kV, 120 MVA × 4 group | 77 kV, 120 MVA × 6 group |
| Harmonic filter | 500 kV, 270 MVA (5th, 11th, 13th, HP) | 500 kV, 270 MVA (5th, 11th, 13th, HP) |
| DC switch | DC 500-kV reactor DC-GIS | DC 500-kV reactor MRTB, NCB |
| AC switch | 500-kV GIS | 500-kV air-insulated + GIS |

HP: high pass
DC-GIS: direct current gas-insulated switchgear

TABLE 2. Characteristics and Main Functions of Kii-Channel HVDC System

| Characteristics | Purpose/duty | Function |
|---|---|---|
| Bulk power transmission | • High reliability | • Continuous operation during AC-system faults<br>• High-speed power recovery<br>• Over-load operation for power-system emergencies |
| AC-DC hybrid power transmission | • Transient power-system stability | • Power modulation (PM)<br>• Emergency frequency control (EPPS, EFC) |
| Isolated power generation | • Cooperative control with generator | • Generator-frequency control (EPPS, EFC)<br>• Supplemental subsynchronous damping control (SSDC)<br>• Higher harmonic/overvoltage control |
| Flexible operation | • High reliability<br>• Easy operation<br>• Easy maintenance | • Redundant system |

EPPS: emergency power presetter EFC: emergency frequency control
SSDC: supplemental subsynchronous damping controller PM: power modulation

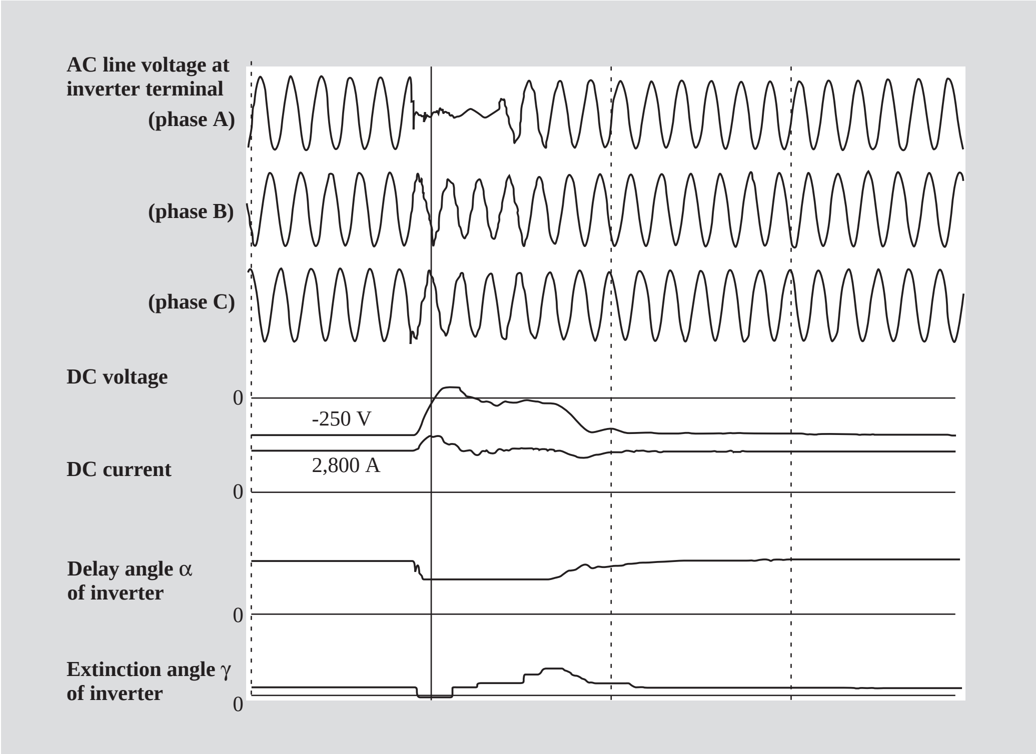



*Fig. 3— Results of Continuous Operation.*
*Although the system voltage drops due to a fault in the AC system, the power is recovered quickly after the fault without commutation failure.*

stability. This function is based on a new method to minimize the chance of commutation failure. In systems with conventional control, operation stops when the AC voltage drops to avoid commutation failure, but in this system, transmission control continues during an AC-system fault as a result of new control methods developed for quick detection of extinction angles, harmonic voltages, and AC transient voltages. These methods enable the power system to be stabler than that in systems with conventional control (see Fig. 3).

This function was found effective during AC-system faults due to a lightening impulse.

Power modulation is a technology used to stabilize AC power with DC power modulation against power fluctuation due to an AC-system fault (see Fig. 4). The power flow of the HVDC system is additionally controlled against power fluctuation, which is detected by measuring the frequency deviation of the terminals. This function was tested before the system was put into commercial operation and its effectiveness against power fluctuation was verified.

The new technologies described above were developed as a result of a system study and simulation and they are based on Hitachi's experience as a leader in power transmission and distribution field.

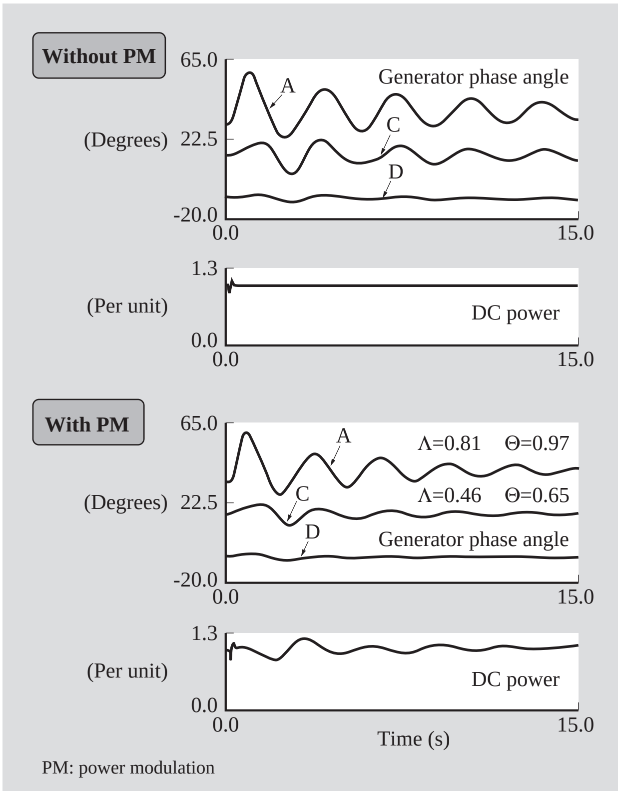



*Fig. 4— Simulation of Power-Flow Damping.*
*The graphs show power fluctuation in system generators A, C, and D at the time of a 3-line ground fault/open circuit in a 60-Hz system. Power fluctuation is damped by DC power control. Damping effect is larger for smaller values of indexes Λ and Θ.*

## THYRISTOR VALVE

Thyristor valves are the main pieces of equipment in HVDC power transmission systems. They convert AC/DC voltages. The thyristor valves in the Kii-Channel HVDC system are water-cooled and air-insulated, with direct-light-triggered thyristors that were used in several other HVDC projects in Japan (see Table 3).

To reduce the loss of the thyristor valves and minimize their size for the Kii-Channel HVDC project, Phase II, a 500-kV, 2,800-MW system (1,400 MW per pole) and newly designed thyristor valves were used in this project (see Fig. 5). The new design has the following elements;

(1) compact thyristor-valve module with 8-kV, 3,500-A direct-light-triggered thyristors;
(2) compact thyristor valves with dimensions tested through field and model experiments;
(3) valve structure designed based on a simulation technology for seismic conditions.

The number of thyristors connected in a series was reduced due to the use of high-voltage thyristors developed for this project, which resulted in compact thyristor valves. The thyristor valves have a quadruple multi-valve structure. A model test was conducted to evaluate the performance of the valves and new structures including supporting frames, under seismic-event conditions. The thyristor valves in this project are 0.87 times higher and their volume density is 0.5 times greater compared to the height and volume density of conventional valves (see Fig. 6).

The coolant used for primary heat exchange in the thyristor valves is deionized water. At the Kihoku converter station located in the highlands with a limited supply of cooling water, the cooling system is a combination of air coolers and water coolers. New

TABLE 3. Performance of Thyristor Valves for Kii-Channel HVDC, Phase I

| Capacity | 700 MW |
|---|---|
| DC voltage | 250 kV |
| DC current | 2,800 A (3,500 A-30 min. over-load) |
| Main devices | 8-kV, 3,500-A direct-light-triggered thyristor (LTT's) |
| Insulation | Air-insulated |
| Cooling | Deionized water |
| Structure | Quadruple multi-valve unit (MVU) |
| Dimension | 5.2 m × 3.8 m × 9.5 m |

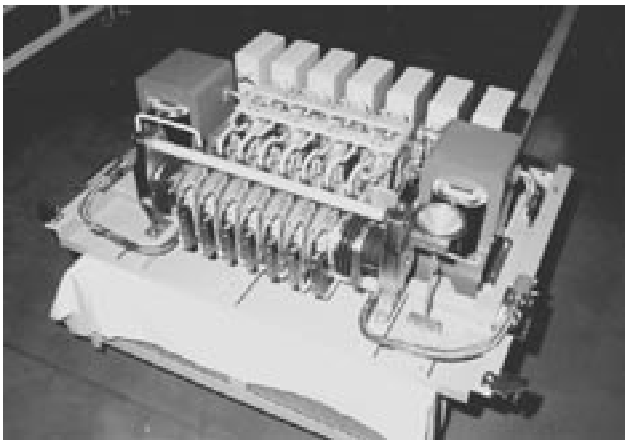


*Fig. 5— Thyristor-Valve Module.*
*Compact thyristor-valve module with 8-kV, 3,500-A direct-light-triggered thyristors.*


*Fig. 6— A 700-MW Quadruple Multi-Valve Unit.*
*The size per unit of electrical capacity was reduced to 60% of that of a conventional thyristor valve with 8-kV, 3,500-A direct-light-triggered thyristors.*

methods to control the loss of the thyristor valves and atmospheric conditions were developed for this project, which reduced the amount of cooling water needed.

## CONVERTER TRANSFORMER

Converter transformers for the two converter stations, the Anan converter station and the Kihoku converter station, were also supplied. The specifications of the transformers are shown in Table 4. Except for the audible-noise level, the electrical performance of the two transformers is the same. In 12-pulse conventional converter stations, converter transformers are arranged separately in a 6-pulse configuration; in the Kii-Channel HVDC system, each converter transformer has triple coils for two DC terminals (see Fig. 7).

For the Kihoku converter station, a structure with three sets of single-phase 4-legged coils was used because of the transportation restraints. The 4-legged coils are arranged in a 6-pulse operation on each main core. For the Anan converter station, six sets of single-phase center cores were used because of the weight limitations.

Before manufacturing the converter transformers, several tests were carried out using a prototype model. To evaluate the insulation, the DC dielectric materials were tested for one year. With the help of computer simulation using a DC electric field, a number of characteristics of insulators were analyzed and highly reliable converter transformers were manufactured. Some specific problems of converter transformers, such as magnetization loss, audible noise, and conducting loss caused by harmonic currents, were investigated by using computer simulation.

## CONTROL AND PROTECTION PANELS

HVDC control and protection panels are important for HVDC systems. The performance and reliability of the Kii-Channel HVDC system should be especially high because it is a bulk transmission system. The configuration of the control system for the Kii-Channel HVDC system is shown in Fig. 8. It has the following features;

(1) supervisory substation control for the human interface and monitoring;

(2) HVDC master control for system control and protection;

(3) converter control for the converter-unit sequence and converter-triggering pulse generation.

Hitachi is responsible for the HVDC master control system and converter control system for both the converter stations and for the substation control system for the Kihoku converter station (see Fig. 9).

(1) Supervisory substation control for the human interface and monitoring

Because the HVDC system consists of many pieces of equipment, there was a strong need for a system that would assist in human operation and monitoring of the system. A high-speed analyzing system was introduced to look for defects in the HVDC system; it analyzes waveforms and generates a transient analysis of the system faults.

(2) HVDC master control for system control and protection

The HVDC master control system consists of a power-system controller and a converter-station controller. The power-system controller enables the power system to be stable and ensures continuous DC operation during AC faults and power modulation. The converter-station controller enables power sharing

TABLE 4. Specifications of Converter Transformers for Kii-Channel HVDC, Phase I

| Capacity | Anan converter station | Kihoku converter station |
|---|---|---|
| Capacity | 872 MW/436 MW/436 MW | |
| Voltage | 500 kV/110 kV/110 kV | |
| Impedance | 16% | |
| Connection | YNy0d1 | |
| Audible noise | 70 dB | 60 dB |

*Fig. 7— 872-MVA Converter Transformer (Kihoku Converter Station).*
*The size was reduced by using triple coils for two DC terminals.*

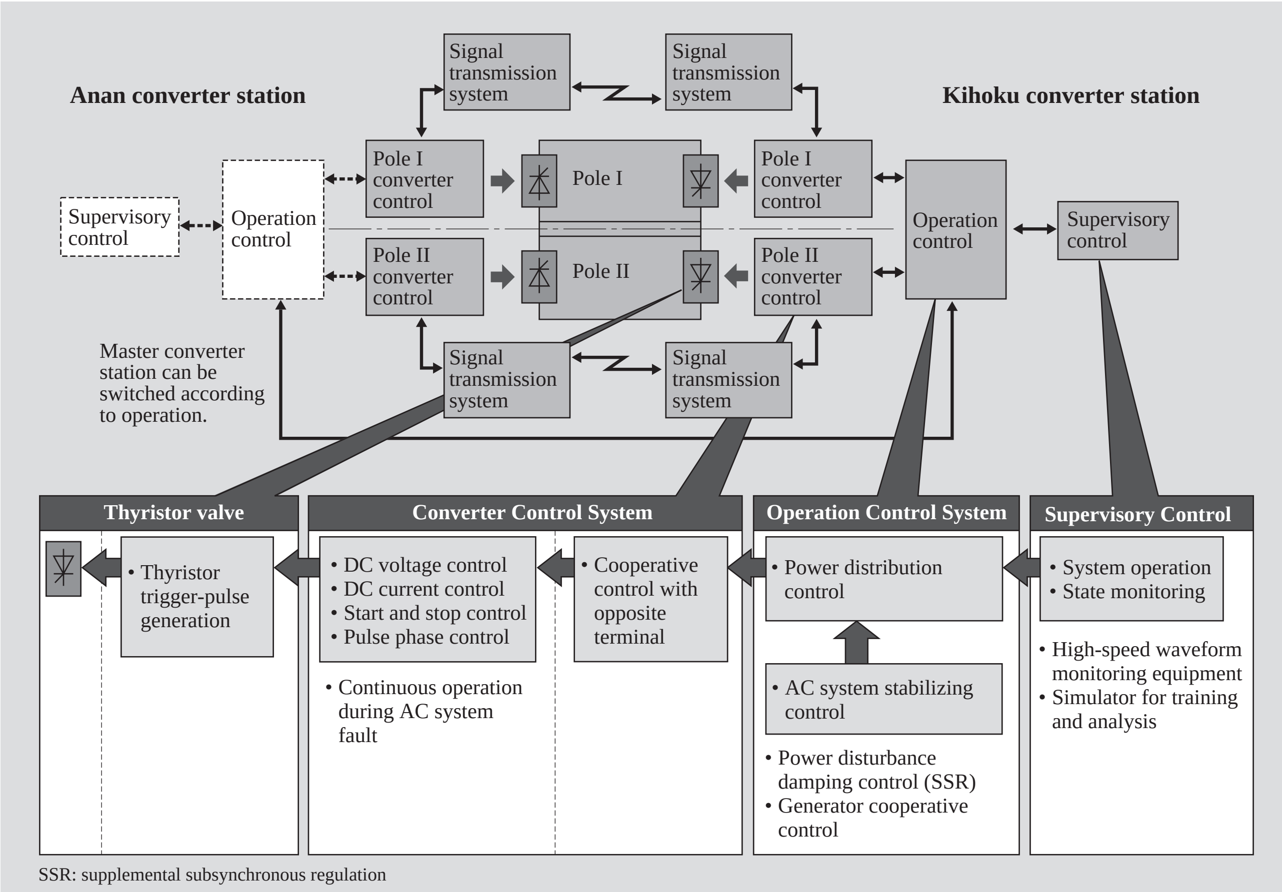



*Fig. 8— Configuration of Control & Protection System for the Kii-Channel HVDC.*
*Reliability was improved by installing dual operation control system at both the converter stations and master/slave switching. Dual systems were introduced to further improve reliability.*

*Fig. 9— Substation Control System of the Kihoku Converter Station.*

between the poles, quick recovery from DC-system faults, and over-load operation during power-system emergencies.

(3) Converter control for the converter-unit sequence and converter-triggering pulse generation

A converter-triggering pulse is generated by the firing of a thyristor valve in accordance with the power reference from the HVDC master control system. Regarding the hardware, Hitachi's MPU "SH3," which is highly effective in high-speed sampling and calculations, satisfies the system requirements.

## CONCLUSIONS

In this paper, we described the work, technologies, and products of the largest HVDC system in Japan, the Kii-Channel HVDC project, which has been in commercial operation since June, 2000.

The research and experience we have had in the planning and construction of the Kii-Channel system should be applicable to the construction of power systems in the future.

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