Recent Trends in Ultralarge-capacity Three-phase Transformer Technology

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OVERVIEW: Large capacity transformers have evolved to meet the changing needs of electric power companies. For example, the need to reduce the transportation cost to the site and the trend towards smaller installation spaces have led to the introduction of on-site assembly technology. In addition, plans to double the voltage rating will increase considering future long-distance transmission, and the need for a routine supervisory system will grow as transformer operating conditions become severe due to extended operating life of equipment, overload operation, etc. Hitachi is meeting these needs with its computer analysis technology and verification testing using trial production. The result of our efforts is highly efficient large capacity transformers. In particular, we have just completed delivery of a 281.25-kV (525-kV) 1,060-MVA double-rating voltage transformer for the Hitachinaka Power Station of Tokyo Electric Power Co., Inc., as well as Hitachi's first-ever on-site assembly of transformers (500 kV 1,000 MVA) for the Chizu Substation of the Chugoku Electric Power Co., Inc. Hitachi uses the newest diagnostic technology for its apparatus supervisory system and provides rational maintenance and support.

INTRODUCTION

THE market for large capacity transformers is highly dependent on the needs of the electric power companies to which they are supplied. Consequently, with cost-effectiveness as the driving concern there has been a doubling of the voltage specification and extension of the operating voltage range for the future long-distance transmission. Moreover, there are transportation restrictions especially regarding substations in mountainous areas, etc., for which the introduction of an on-site assembly system is seen as a solution to this problem while also minimizing

Fig. 1—View of Shop Test of 281.25-kV (525-kV) 1,060-MVA Double Rating Voltage Transformer.
The shop test would be carried out by using test bushings, although the secondary side was connected with power cable. The test was first carried out in the 525-kV connection state and was repeated after changing to the 281.25-kV connection.

installation space. Of equal importance is the need for stable operation over long period. Thus preventive maintenance is a necessary aspect of controlling the investment in the equipment. This paper reviews Hitachi's efforts to meet the challenges described above. In particular, we discuss our 281.25-kV(525-kV) 1,060-MVA double-rating voltage transformer for power stations and our 500-kV 1,000-MVA site-assembled transformer for substations. We also discuss the latest apparatus supervisory system we provide, which can support preventive maintenance systems.

HISTORY OF HITACHI'S LARGE-CAPACITY TRANSFORMERS

The historical trend in Hitachi's transformer technology is shown in Fig. 2. Hitachi established 500-kV transformer insulation design technology in the 1970s. This eventually led to a UHV (ultra-high voltage) insulation design technology, and to a practical UHV transformer in 1993. Moreover, the evolution of computer analysis technology has led to significant efficiencies. For instance, the optimum core design can be found by magnetic flux distribution analysis and a high-accuracy stray loss evaluation is also possible through detailed magnetic field analyses. The result is the present low-noise, high-efficiency transformer technology. Development of a double-rating voltage transformer started with the 250-/154-(77-)/22-kV 300-MVA transformer in 1973. Larger capacity ones, the 225-kV (520-kV) 730-MVA transformer and 220-kV (500-kV) 250-MVA transformer, were supplied in 1994 for the Reihoku Power Station of Kyushu Electric Power Co., Inc. On-site assembled transformers for substation began in 1989 with the 220-kV 250-MVA site-assembly transformer. The technique used in 1989 is similar to the present one. The 500-kV 1,000-MVA site-assembled transformer was completed in 2000.

LARGE CAPACITY DOUBLE-RATING VOLTAGE TRANSFORMER

Specification

The specification of a double-rating voltage transformer for the Hitachinaka Power Station of the Tokyo Electric Power Co., Inc. is shown in Table 1. The feature of this transformer is that capacity is

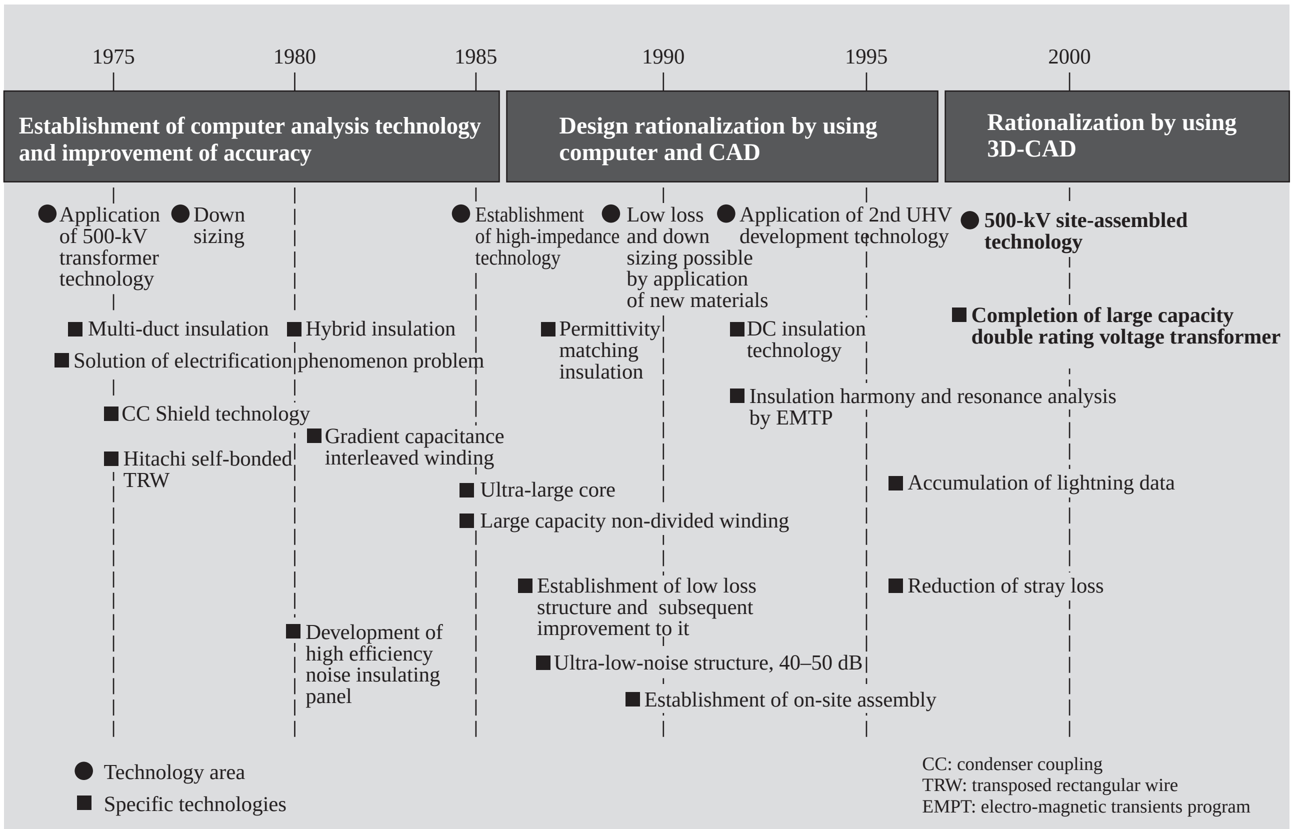


Fig. 2—Historical Trend in Hitachi's Large-capacity Transformer Technology.
Hitachi has developed high-reliability transformers by accumulating test data from trial productions and applying computer analysis that has evolved over time.

TABLE 1. Specification of 281.25-kV (525 kV) 1,060-MVA Transformer
The short-circuit impedances under both operating voltages are equal.

Item	Specification
Type	Three-phase ODAF
Capacity	1,060 MVA
Voltage	Primary: 18.525 kV Secondary: F287.5-R281.25-F275 kV (F550-F537.5-R525-F512.5 kV)
Frequency	50 Hz
Connection	Primary: Delta Secondary: Star
Insulation level	Primary: AC 50 kV LI 150 kV Secondary: AC 330 kV LI 950 kV (AC 635 kV LI 1,300 kV)
Impedance	14% (both 281.25-kV and 525-kV connections)

ODAF: direct oil forced-air cooled type
LI [LIWL: lightning impulse withstand level]

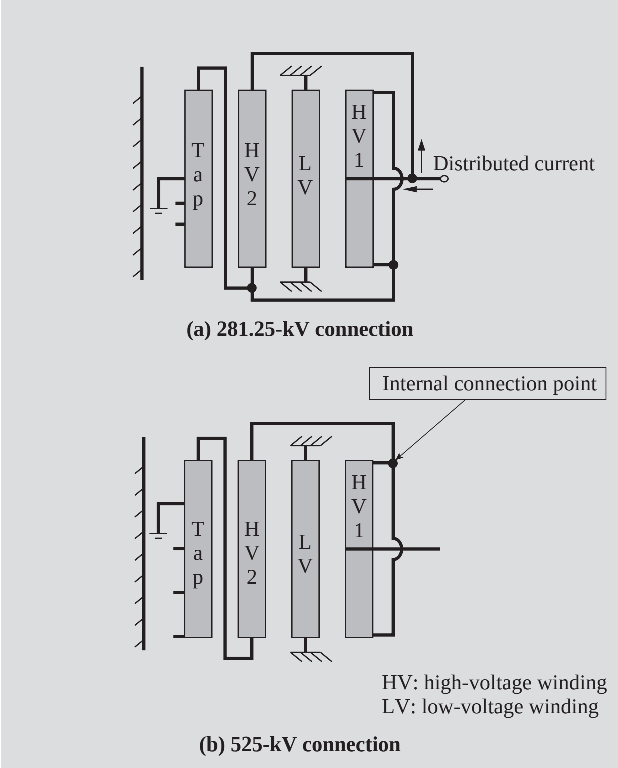


Fig. 3—Winding Arrangement of Double Rating Voltage Transformer.
The high-voltage windings are used in parallel for the 281.25-kV connection and in series for the 525-kV connection.

maximized as the double-rating voltage transformer and moreover the short-circuit impedances under both operating voltages (281.25 kV and 525 kV) are equal.

Structure

The high voltage winding consists of two windings. Two high-voltage windings are used in parallel for the 281.25-kV connection and are used in series for the 525-kV connection. By changing the internal lead line, the connection can be changed. The composition of the windings is shown in Fig. 3.

Core

The three-phase five-legs core of the conventional large capacity transformer was adopted. The optimum joint structure was used to ensure the magnetic flux would be uniform and the local loss would not become concentrated. The cross-sectional ratio of the up-and-down yoke and side yoke was also optimized.

Winding

The windings are arranged in the order of tap winding, high-voltage winding 2, low-voltage winding, and high-voltage winding 1 from the inner side. In order to make the short-circuit impedance the same for both operating voltages, the current distribution needs to be made the same. For the parallel 281.25-kV connection of the high-voltage winding 1 and 2, the low-voltage windings among the high-voltage windings 1 and 2 are connected so that current distribution ratio can be about 50%. Furthermore, analysis of the main gaps ensured that the impedance between each high-voltage winding and the low-voltage winding would be almost equal. To design the insulation of the high-voltage windings, the generating voltages between coils and an internal connection point were analyzed using EMTP (electro-magnetic transients program). The EMTP analysis was carried out not only for standard waves but also for long-tail waves, and attenuation oscillating waves. A low-voltage helical winding consisting of many parallel transposed rectangular wires was adopted, and it was designed to control circulating current by using the optimum transposition method.

Reliability Verification

To verify the reliability of the transformer, the current distribution ratio of the two high-voltage windings and the voltage distribution characteristics of the windings in air against low-voltage surge were checked in the manufacturing stage. It was found that there were no problems regarding performance. In the shop test, the connection was changed after the test for the 525-kV connection and the test for the 281.25-kV connection was carried out. Good results were obtained for both connection states.

Fig. 4—500-kV 1,000-MVA Site-assembled Transformer for the Chizu Substation of the Chugoku Electric Power Co., Inc.
The first-ever on-site assembly of a 500-kV transformer for Hitachi.

500-KV SITE-ASSEMBLED TRANSFORMER

Completion

Hitachi's first-ever on-site assembly of a 500-kV transformer (500 kV 1,000-MVA) was done at the Chizu Substation of the Chugoku Electric Power Co., Inc. in 2000 (see Fig. 4). Transportation costs have been reduced, and also, installation space could be reduced to about 50 to 60% compared with three units of the conventional single-phase transformer.

Main Features of On-site Assembly Technology

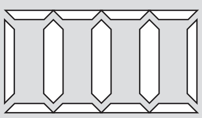
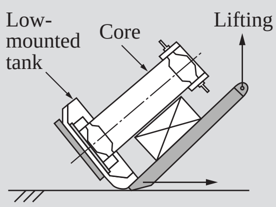
The main features of the technology applied to the 500-kV site-assembled transformer are as follows:

(1) The main leg non-division method is adopted for the core. This minimized the transportation size and mass, without deteriorating the core characteristics (see Table 2).

(2) All windings of the same core leg were transported as one unit. Windings were covered with film to prevent them from absorbing moisture and protect them against dust.

The number of divisions of the tank was determined taking into account the transportation restriction of a low floor trailer. A low-mounted tank simplifies assembly of the core and reduces the force of lifting. It also simplifies the core assembly work that has to be done on site (see Table 2).

TABLE 2. Features of Site-assembled Transformer
The optimum division method is adopted for each part.

	Core division method	Low-mounted tank serves as both a tank and a mount for the core
Contents	Main-leg non-division method 	

Transportation Test

Prior to full-scale manufacture of the 500-kV 1,000-MVA transformer, trial production of the 500-kV 1,000/3-MVA transformer was carried out. To determine the optimum safe division of the winding and core, a run test, bad-road test, sudden blast-off and sudden braking test with a vehicle acceleration of more than 29.4 m/s^2 were carried out, and a fall test using a wrecker was also carried out. These tests showed that the units would remain undamaged in typical mishaps. Moreover, an electrical characteristic test was carried out before and after the transportation test, and it showed that there was no change in characteristics. The transportation test is shown in Fig. 5. Tests carried out after transportation and assembly revealed no differences compared with electrical characteristics measured before transportation.

PREVENTIVE MAINTENANCE SYSTEM

Preventive maintenance for the substation can be enhanced with the supervisory equipment for oil level, oil temperature, diagnosis of unusual events, etc. An example is the operation supervisory technology of the on-load tap changer, which is much more troublesome than other transformer parts.

Fig. 5—Transportation Test.
An electrical characteristic test was carried out before and after the transportation test.

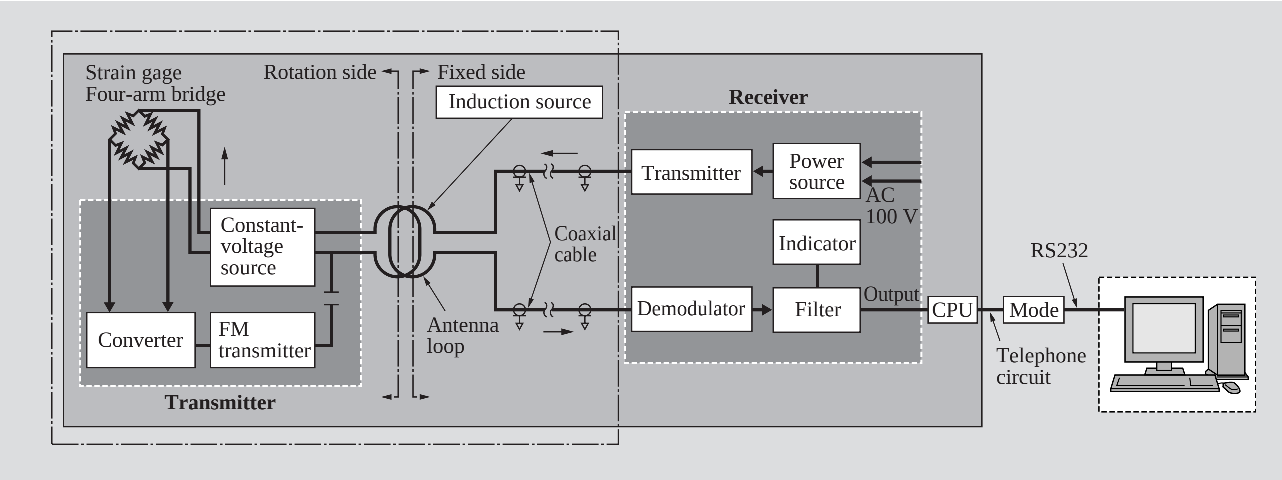


Fig. 6—Measuring Driving Torque of On-load Tap Changer.
Detecting fault phenomena and locating fault locations are possible.

Torque Supervisory System of On-load Tap Changer

Hitachi has created supervisory equipment that can diagnose unusual states of the on-load tap changer at an early stage by detecting driving torque, operation time, motor current, etc. In the measurement system shown in Fig. 6, a torque sensor and a torque measurement value are transmitted to a distant central control room by using a telephone circuit. Locating the fault position in addition to detecting the fault phenomenon is also possible through accumulation of the transmitted torque data. Moreover, abnormalities originating in deformation of the tap changer drive system, jams between a shaft and bearings, and wear are detectable by analyzing the trend and pattern of the driving torque data.

CONCLUSIONS

A large-capacity double rating voltage transformer and a 500-kV site-assembled transformer were described as examples of transformers reflecting the latest needs of electric power companies. The need to control equipment investment is a serious concern for electric power companies. Hitachi is committed to improving the design, manufacture, and maintenance resume of our transformers, which we believe to meet our customer needs.

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