UDC 621.314.2

900kV UHV TESTING TRANSFORMER FOR CENTRAL RESEARCH INSTITUTE OF ELECTRIC POWER INDUSTRY

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I. FORWARD

Power transmission at a voltage of 750 kV is already in operation in America, Canada and the Soviet Union, and 1,000 – 1,500 kV is being studied as the next transmission voltage.

On the other hand, Japan greeted the age of extra-high-voltage power transmission by adopting 500 kV for its main power transmission system in 1973. However, it is estimated that the increased demand for electric power and the construction of power plants in remote areas will stretch 500 kV power transmission to its technological limits. UHV power transmission is expected to be initiated in the 1980's to meet the need for long-distance high power transmission and to improve the efficiency of power transmission routes. For this reason, a UHV Power Transmission Special Committee consisting of professors and specialists, government agencies, power companies, and manufacturers has been established to undertake full-scale research and development of UHV power transmission.

On phase of this research and development concerns counter-measures against contamination of UHV insulators. Artificial contamination tests for UHV insulators are to be conducted by the Central Research Institute of the Electric Power Industry to study this problem.

The 900 kV UHV testing transformer recently completed by us as the test power source for this research can continuously generate 900 kV to ground. This transformer is one of a very few in the world capable of generating such a high voltage. Furthermore this transformer was completed not only for use as a testing transformer, but also as a prototype of $1,550/\sqrt{3}/525/\sqrt{3}/66$ kV UHV transformer.

This report outlines this transformer and describes our development of UHV transformer.

II. SPECIFICATIONS

Table 1 shows the specifications of this transformer as a testing transformer. Since the transformer has a 900 kV continuous rating, it can be considered that it is the same as a power transformer and has a rated voltage equivalent to a system voltage of 1,550 kV ($= 900 \times \sqrt{3}$).

Moreover, since its impedance is selected low enough to obtain highly reliable data in insulator contamination tests, its actual capacity is several times greater than 2,000 kV to increase the short circuit strength of the winding. Considering this transformer as a UHV autotransformer, its essential specifications are as follows.

Type: Outdoor, single-phase, 50 Hz, autotransformer

Table 1 Specifications of transformer

Number of phases	Single-phase
Rating	Continuous
Frequency	50 Hz
Rated voltage	66/900 kV
Rated capacity	2,000kVA
Cooling system	Oil immersed self-cooled
Impedance	1.92% (2,000 kVA base)

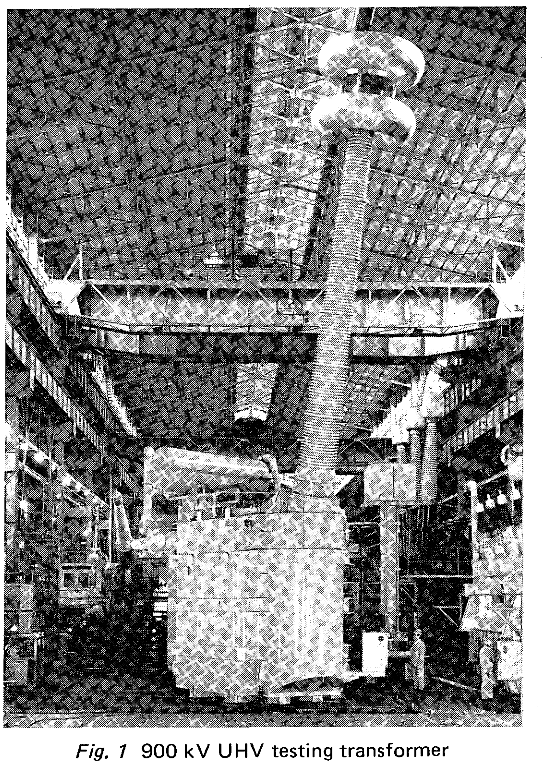


Fig. 1 900 kV UHV testing transformer

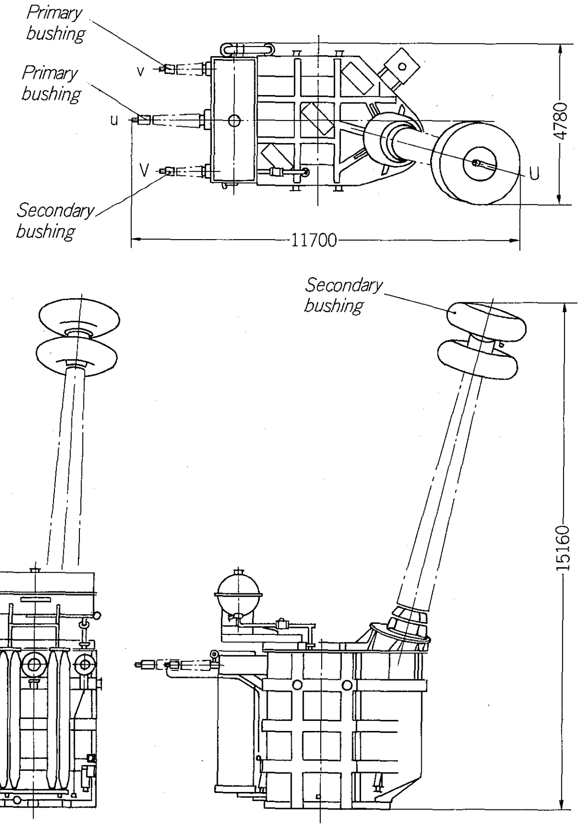


Fig. 2 Outline of 900 kV UHV testing transformer

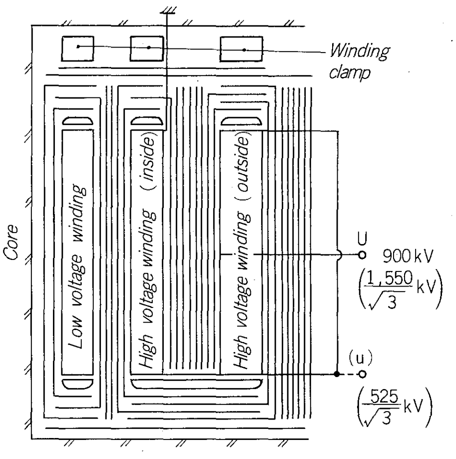


Fig. 3 Arrangement of windings

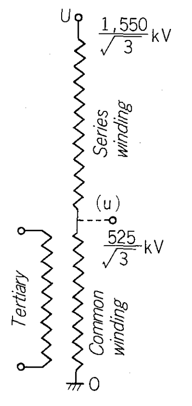


Fig. 4 Connection diagram

Voltage:	$\frac{1,550}{\sqrt{3}} / \frac{525}{\sqrt{3}} / 66$ kV
Capacity:	20/20/10 MVA
Impedance voltage:	:12% (primary-secondary 20 MVA base).

Moreover, the winding construction of actual UHV transformer is adopted unchanged, so that the experience gained in manufacturing this transformer can serve effectively in the design and manufacture of UHV transformers in the future.

As described above, this transformer was designed by assuming an autotransformer that will connects UHV system and 500 kV systems. Its primary AC 1,550 kV voltage exceeds the level of the UHV power transmission voltage planned for use in Japan.

Fig. 1 shows an exterior view of this transformer and *Fig. 2* shows its outline.

III. CONSTRUCTION AND FEATURES

Since this transformer has a continuous rating, its insulation level must be maintained at a level equal to that of power transformers. Therefore, it was designed to have an insulation strength equal to that of an AC 1,550 kV UHV power transformer. The following introduces the construction features and the outline of insulation design of this transformer.

1. Winding Arrangement and Construction

The winding arrangement of this transformer consists of a low voltage winding at the inside and high voltage windings divided into two at the outside, as illustrated in *Fig. 3*. The high voltage windings consist of inner high voltage windings consist of inner high voltage winding (corresponding to common winding) and outer high voltage winding (corresponding to series winding). The high voltage terminal (U) is led out from the center of the outer high voltage winding. Thus, the winding construction of the UHV power autotransformer has been adopted directly to this transformer. If the connection point (u) is led to the outside as shown in *Fig. 4*, the construction is identical to that of a single-phase, $1,550/\sqrt{3} / 525/\sqrt{3} / 66$ kV UHV autotransformer.

The high voltage windings are the special interleaved disk (high-ser-cap) winding which we have manufactured in great numbers, including the windings of 500 kV transformers. This winding has been adopted as the standard winding for extra high voltage by Trafo-Union in West Germany, with whom we have a technical cooperation. For example, it is adopted in 415 kV 1,020 MVA (BIL 1,550 kV) transformers, $735/\sqrt{3}$ kV 200 MVA (BIL 2,150 kV) transformers, and numerous other extra high voltage transformers. It is also used in the 1,200 kV prototype autotransformer for future UHV power transmission.

The features of this special interleaved disk winding are:

(1) Small voltage distribution between coils, excellent lightning impulse characteristic, and high insulation reliability.
(2) Good winding space factor and small shipping dimensions and installation space.
(3) Good winding cooling efficiency.
(4) Mechanically high strength.

These features make it perfect for UHV high capacity transformers.

2. Insulation Design

The condition of $1{,}550/\sqrt{3}$ kV continuous operation was taken into consideration in the insulation design of this transformer, AC 1,600 kV 1 minute test voltage and BIL 3,000 kV were set as the design target level.

Grasping the magnitude of the voltage generated at the windings, leads and their surrounding area; especially the voltage generated at high voltage parts, and the distribution of the electric field, and adopting the optimum insulation construction using insulation material suitable to these voltages and electric fields, are extremely important in the insulation design of an extra high voltage transformer. We have adequately absorbed the insulation design technology of Trafo-Union and are continuing our own research and development to improve reliability still further and have established extra high voltage interleaved disk winding design and manufacturing techniques. The insulation design techniques used in developing the extra high voltage interleaved disk winding taken by us are illustrated in *Fig. 5*. These insulation technologies are adequately incorporated into the design of this transformer. Basically, the generation voltage was accurately known by analyzing the voltage oscillation of the winding with a computer and the insulation strength was checked by actually measuring with an analyzer model.

Especially detailed analysis of the electric fields was made through the electronic computer field mapping technique developed by us. *Fig. 6* shows analysis of the voltage distribution of the high voltage winding. This shows the computation of the voltage distribution to ground of each part of the windings. *Fig. 7* is an example of field mapping around the center of the high voltage winding.

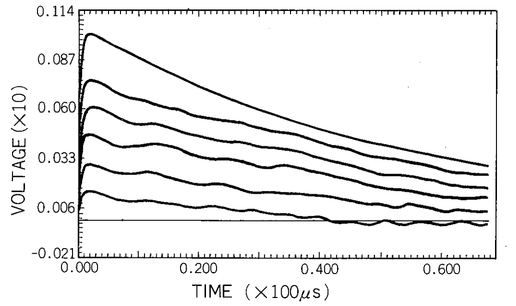


Fig. 6 Voltage distribution of HV windings

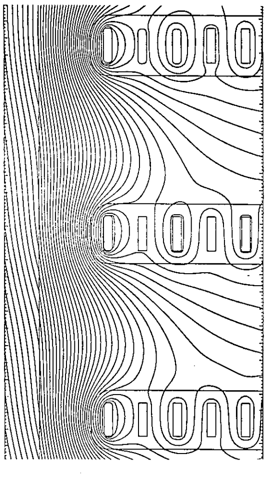


Fig. 7 Electric field mapping of winding

3. Insulation Construction

The multilayer oil gap construction divided by insulation barriers, which is widely used by European transformer manufactures, especially Trafo-Union of West Germany, is adopted to improve the insulation strength of this transformer. The precision of the oil gaps between barriers is the

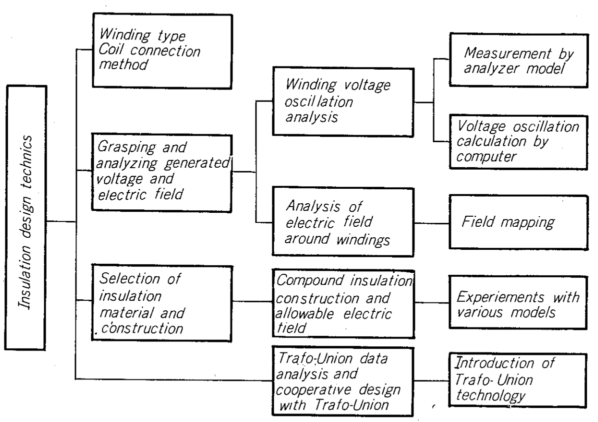


Fig. 5 Insulation design technics

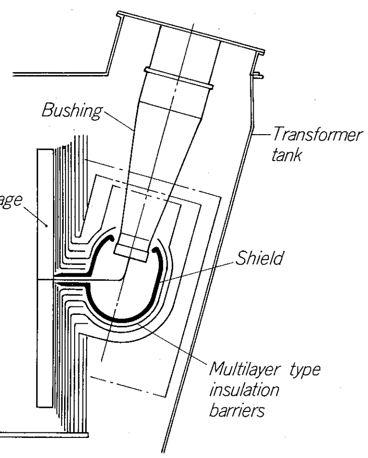


Fig. 8 Insulating construction for bottom part of 900 kV bushing

most important point in using this multilayer insulation barrier system. As shown in *Fig. 3*, multiple concentric barriers are provided where the high voltage winding faces other windings, tank and core return legs. The oil gap has been divided by L-type insulation barriers at the top and bottom ends of the high voltage winding. Moreover, the 900 kV terminal does not adopt the conventional lead arranged between the winding and tank, but is constructed by directly connecting it to the bottom of the bushing at the center of the outer high voltage winding as illustrated in *Fig. 8*. The shield for electric field damping of this part is combined directly with the winding, and the high voltage winding is made a single assembly with the shield by using a pulp molded insulation barrier.

4. 900 kV Bushing

The 900 kV bushing is a stable quality, high internal corona starting voltage oil immersed condenser bushing made by NGK Insulators Ltd. in Japan. An 8 m insulator the largest currently being manufactured, is used. Since this bushing is installed in the test hall in artificial fog, we have studied the dielectric strength and atmosphere corona characteristics in the fog. We have made atmosphere insulation characteristics comparison tests in various air shields in cooperation with NGK (*Table 2*).

From the results of these tests, we adopted the double ring air shield construction shown in *Fig. 1*. The various characteristics in the fog were obtained and valuable data on future UHV air insulation techniques were obtained through these basic experiments. This test was performed by suspending the test shield ring in space about 7.5 m from the floor.

IV. INSULATION TEST

Table 3 shows the results of the insulation test of the insulation test of this transformer. Excellent results were obtained for all items and the propriety of its insulation design was confirmed.

The induced withstand voltage test was performed at 1,000 kV for 5 minutes and the long-term withstand test was performed at 900 kV for 10 hours. These test voltage corresponds to $1{,}200/\sqrt{3} \times 1.44$ and $1{,}200/\sqrt{3} \times 1.3$ in the system voltage 1,200 kV UHV transformer.

During the induced withstand voltage test and long-term withstand test, ERA meter was connected to the high voltage bushing PF tap and the corona discharge was measured. No corona discharge was detected (external noise 10 pC or less).

Moreover, a corona discharge test at 900 kV for 2 hours was performed at the site and good results were obtained. This transformer has been operating satisfactorily as a power source for insulator contamination test.

Table 2 Electrical characteristics of shield ring

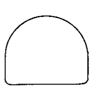
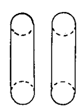
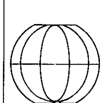
Item \ Shield ring shape			Spherical 	Double ring 	Globe 
Wire and withstand voltage	Dry	F.O.	1,330 kV	1,390 kV	1,125 kV
		1 minute withstand voltage	1,198 kV	1,270 kV	956 kV
		60 minutes withstand voltage	1,131 kV	1,200 kV	956 kV
	In fog	F.O.	1,166 kV	1,238 kV	1,228 kV
		1 minute withstand voltage	991 kV	1,114 kV	983 kV
		5 minutes withstand voltage	933 kV	990 kV	921 kV
Visible corona	Dry	Flash	Not generated	Not generated	965 kV
		Streamer	1,330 kV	1,390 kV	1,103 kV
	In fog	Flash	692 kV	538 kV	540 kV
		Streamer	917 kV	888 kV	934 kV

Table 3 Insulation test results

Test item	Voltage	Test result
Lightning impulse test	1,550 kV	Good
Induced withstand voltage test and partial discharge measurement test	1,000 kV for 5 mins	Good Partial discharge 10pC or less
Long-term withstand test and partial discharge measurement test	900 kV for 10 hours	Good Partial discharge 10pC or less

V. DEVELOPMENT OF UHV TRANSFORMER

1. Subject of UHV Transformers

Since UHV transformers are used for long distance high power transmission, their unit capacity must be greater than that of other transformers. Moreover, UHV transformers are highest voltage devices and the proportion of space occupied by the insulation is larger than that of a 500 kV transformer, and the exterior dimensions of the transformer are also larger. The use of transformers having a bank capacity of 3,000 MVA in Japan as UHV system and 500 kV system connection transformers is expected. However, since the shipping limit is small, because of the narrow gauge of Japanese railroads, and UHV substations are expected to be located in mountainous regions, a new system that meets current transportation means, such as split type

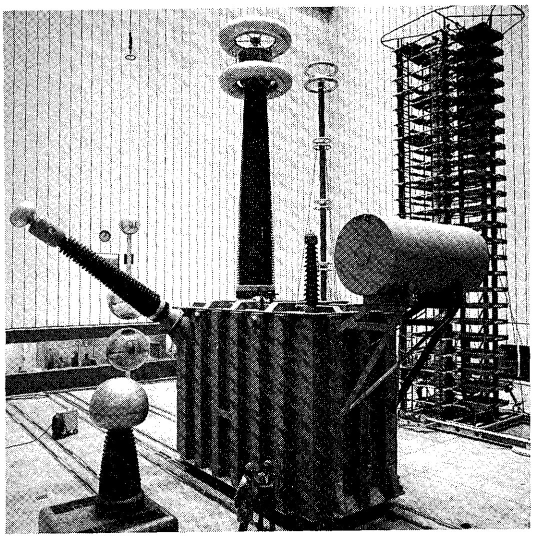


Fig. 9 UHV transformer (TU)

Table 4 Specifications of UHV transformer (TU)

Type	Outdoor, auto-transformer
Number of phase	Single phase
Frequency	50 Hz
Rated voltage	$\frac{1,200}{\sqrt{3}}/\frac{525}{\sqrt{3}}/30$ kV
Rated capacity	$\frac{800}{2}/\frac{800}{2}/\frac{240}{2}$ MVA

system, must be studied.

Moreover, reducing the dimensions by rationalization of the insulation material and construction is an important subject. We are conducting new research on the development of a highly reliable UHV transformer that can be transported by rail and requires little on-site work.

2. Trafo-Union UHV Transformer Technology

As previously mentioned, we have a technical co-operation with Trafo-Union of West Germany covering all types of transformers, and have introduced the newest Trafo-Union technologies through the long-term dispatch of design and manufacturing engineers and the cooperative development of important products.

Trafo-Union developed a 1,200 kV UHV prototype transformer having the specifications given in *Table 4* in 1968.

Table 5 Insulation tests results of UHV transformer (TU)

Test item	Primary	Secondary	Tertiary
Induced withstand voltage test (1 minute)	1,200 kV	680 kV	80 kV
Lightning impulse test	2,400 kV	1,550 kV	170 kV
Switching surge test	1,950 kV	(1,175 kV)	
Partial discharge test (1 hour)	1,040 kV $\frac{1,200}{\sqrt{3}}\times 1.5$	455 kV $\frac{525}{\sqrt{3}}\times 1.5$	

The rated capacity is 800/2 MVA, namely 1/2 phase of single phase 800 MVA (bank 2,400 MVA) transportable by rail in West Germany. It was constructed by parallel connection of 2 leg windings and 800 MVA can be obtained by parallel connection of 4 leg windings.

Trafo-Union conducted the insulation tests given in *Table 5* on this transformer and the excellent results proved the reliability of its insulation. Trafo-Union completed development of a 1,200 kV class UHV transformer in this manner and now can manufacture UHV transformers at any time.

We are conducting research on transformer construction with the transportation situation in Japan added to these Trafo-Union techniques.

VI. CONCLUSION

In view of the importance of UHV power transmission, we are researching and developing UHV power transmission equipment based on a powerful development organization. The completion of this 900 kV transformer has given us vital experience for the manufacture of UHV transformers in the future. Based on the experience gained through the manufacture of this transformer, we will undertake further research on UHV transformers and make efforts in rationalizing construction and improving reliability.

Finally, we wish to express our thanks to all those at the Central Research Institute of Electric Power Industry for their guidance in the design and manufacture of this transformer.