by
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Advanced Site Assembly (ASA) Technologies for UHV Transformers

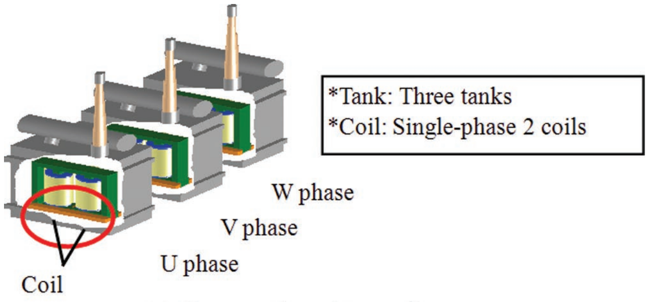
Much electric power infrastructure, e.g., substations, was built in Japan in the period from the late 1960s through the 1970s as a result of the enormous growth in the economy. Consequently, devices installed in such substations have now exceeded their 30-yr design life expectancy and should be replaced in due course. Because more than 70% of the Japanese land surface is mountainous, many pieces of large-capacity electric apparatus such as UHV (ultra high voltage) power transmission equipment must be built in mountainous areas. The largest related problem is transportation of transformers, the heaviest main component in substations. In the case of 3-phase transformers of the 3,000-MVA class for UHV transmission, the transportation weight of a transformer unit is 210 tons, even if a 3-phase transformer bank is configured as 3 single-phase transformer units. Transportation of such equipment involves an enormous amount of planning and is costly. Railroad companies often terminate the operation of their lines in rural areas, because it is getting very difficult to maintain such lines due to the continuing decrease in the number of passengers. In urban areas, on the other hand, railway schedules are usually congested, and railway transportation by special freight train has become difficult in recent years. In regard to road transport, there are major restrictions concerning bridge pier strength, tunnel dimensions, mountain road strength, and heavy load passage that significantly affect transformer design.

Under these circumstances, manufacturers have developed transformers that can be disassembled for shipment and assembled at the site. Tokyo Electric Power Company and Toshiba Corporation, both in Tokyo, have jointly developed a 3-phase, all-in-one 500-kV transformer, using Advanced Site Assembly (ASA) technology to enhance dust/humidity control while large coils and cores are disassembled and reassembled. Revised maximum temperature and system back impedance specifications, and new technologies, were employed to enhance transformer winding capacity and short-circuit strength. Measures were also devised to reduce winding weight and thus transportation weight for each unit. As a result, the largest leg capacity for a substation transformer (500 MVA) was realized, using much less material and incorporating a compact, environment-friendly, and low-loss design.

Two important factors strongly influenced the development of a new ASA transformer for 500-kV substations:

(a) Due to the recent sharp increase in the price of silicon sheet steel and copper wire, materials account for approximately 50% of the initial cost of 500-kV transformers. Procurement lead time is also getting very long for materials. It follows that the amount of material used for the basic structure of the transformer should be minimized. Therefore, the development target was set at 3 phases in a tank with one coil/phase, as shown in Figure 1.

(b) Given the increasing difficulty of rail freight transportation, road transportation is preferred. Thus, transformers must be disassembled for shipment and reassembled at the site. A reduced transportation weight of 45,000 kg including a trailer was targeted so that less-expensive, general-purpose trailers could be used, with fewer road travel restrictions.



(a) Conventional transformer

(b) Newly developed transformer

Figure 1. Comparison of schematic configurations between conventional and newly developed 500-kV transformers.

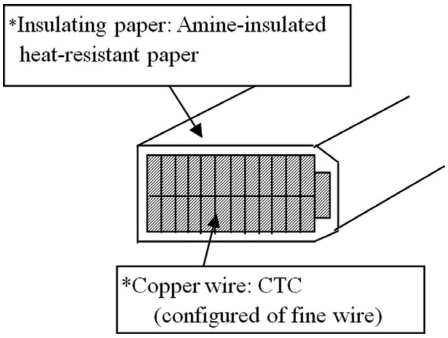


Figure 2. Technologies applied to coils (copper wire/insulating paper).

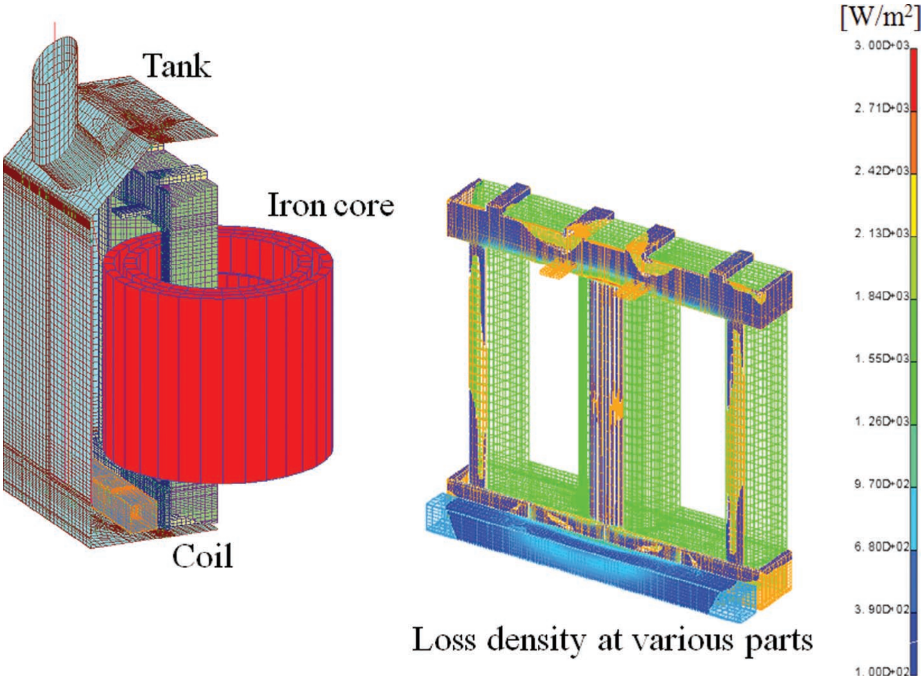


Figure 3. Magnetic-field analysis model and examples of local heat-loss densities.

To achieve these targets, the following measures were needed:

(1) Enhanced winding capacity

The amount of heat generated within the new enhanced winding capacity coils will be approximately 1.7 times that in the existing types because the capacity has been doubled. Possible countermeasures against increases in current and temperature are (a) to increase the cores of the copper wires in the coil proportionally to the increase in current, thereby reducing the current density, or (b) to increase the circulation rate of the coil-cooling oil. The former is not acceptable because it would increase the weight of the coil. The latter has the disadvantage of static charge build-up due to friction between the insulation and the oil, increasing with the second or third power of the oil circulation rate. An effective and acceptable countermeasure is to wrap amine insulation paper around the copper wire of the coils, as shown in Figure 2. This paper resists thermal degradation and offers the required insulation performance. Therefore, the allowable coil temperature can be raised by 10K above the temperature specified in a JEC (Japanese Electrotechnical Committee) standard.

To reduce the heat generated in the coil, it was decided to use a continuously transposed cable (CTC) composed of bundled and continuously twisted thin square-shaped plane conductors to reduce eddy-current losses. In this way, heat generation due to eddy-current loss (intersection of leakage flux) was reduced because the eddy-current loss is proportional to the square of the wire diameter.

Finally, a new 3D magnetic-field analysis technology was developed. Because the leakage flux from the coil increases as the current increases, heat generation and local overheating tend to occur where the leakage flux intersects with the tank or core (see Figure 3). The new technology facilitates a detailed understanding of the temperature differences between the coil and the core, and a new magnetic shield has been developed that effectively reduces leakage flux and local overheating.

(2) Improved mechanical strength

If the leg capacity of a coil is doubled, the magnetic mechanical force applied to the coil will increase by a factor of approximately 1.6. The mechanical strength of the coil must, therefore, be dramatically increased. First, the dynamic analysis of coil deformation was revised by conducting model tests to examine the tensile strength of the conductor wire and free buckling of the winding. Second, it was decided to use wire with 20% greater strength.

(3) Improved transportation and assembly methods

The ASA method of disassembling transformers for shipment and reassembling them at the site was implemented for large transformers by designing jigs and tools to reduce the transportation weight (see Figure 4) and by developing technologies for control of dust and humidity.

First, it was decided that aluminum (not iron) tanks would be used for transporting coils to reduce weight. This mea-

Figure 4. Transportation of a coil.

sure, along with those mentioned earlier, reduced the transportation weight including the trailer to 45,000 kg. Second, the method of inserting coils was changed. The assembly on site must be conducted in a dust-proof house (see Figure 5) that can offer the same humidity and dust control as the factory. In the past, it was necessary to open the roof to lower the coil into the core by a crane. It was, therefore, decided that a gantry crane would be used so that the roof could remain closed (see Figure 6). In this way, risks associated with sudden changes in weather and time schedules could be avoided.

According to Toshiba, the mentioned techniques, applied to 500-kV transformers, have reduced the amount of copper wire by approximately 50%, total energy losses by approximately 20%, weight by approximately 35%, and installation area by approximately 40%. A 500-kV and a 1,000-MVA transformer, manufactured and installed as described earlier, have operated smoothly since completion of construction in June 2008 at the Shintokorozawa Substation (see Figure 7). The basic specifications/structure of a newly developed 500-kV transformer are given in Table 1. Three other 1,500-MVA transformers are scheduled to be installed at the Shinkoga Substation during 2010 and 2011.

This article was written with the help of Dr. Takayuki Kobayashi of Tokyo Electric Power Company and Mr. Yoshihito Ebisawa of Toshiba.

Figure 5. All-weather, dust-proof house.

Table 1. Basic Specifications of a Newly Developed 500-kV Transformer.

Item	Specifications/structure
Overall structure	1 tank/3-phase batch; 1 coil/single-phase
Rated voltage	525, 275, 63 kV
Rated capacity	1,500, 1,500, 450 MVA
Short-circuit impedance	14% (primary/secondary)
Test voltage (primary)	LI: 1,300 kV, 1,550 kV; AC: 475, 635, 475 kV
Temperature rise limit	Maximum oil temperature: 60K; Winding (average): 70K
Short-circuit current	63 kA (taking the system impedance into account)
Transportation/assembly method	Disassembled for transport, reassembled at site; transport weight: maximum 45,000 kg including a trailer

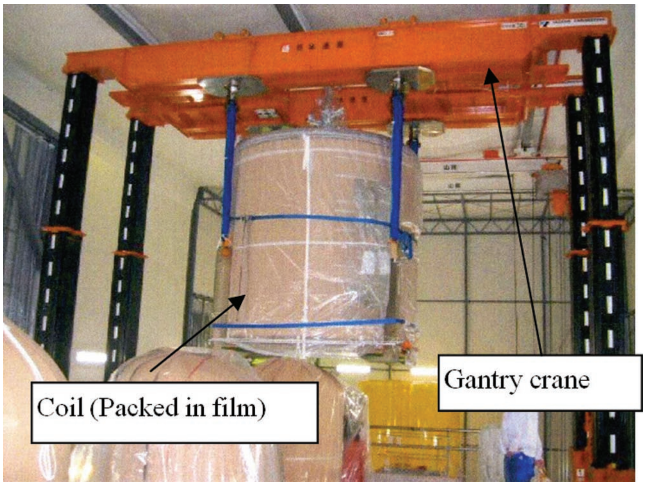


Figure 6. Coil insertion by a gantry crane.

Figure 7. Transformer No. 2 in Shintokorozawa Substation