POWER TRANSFORMER DESIGN, CONSTRUCTION AND FIELD ASSEMBLY

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Power transformers are the heart of every electrical transmission and distribution system. The power transformer concept was first conceived and developed in the late 1800's by Faraday, Maxwell, and Tesla, and put into common practice by people like Edison and Westinghouse. Since then, the basic concept of the transformer has remained the same for over 100 years, however, design and construction techniques have continually improved to increase both the overall efficiency and cost effectiveness of manufactured units. This paper will examine the basics of transformer design, construction and field installation focusing on details to ensure longevity of an installed unit.

In general, power transformers refer to liquid filled units and are loosely divided into 3 size categories, small power — under 10 MVA, medium power — 10 to 50 MVA, and large power above 50 MVA. These are not official categories as recognized by ANSI/CSA /IEEE, but are more often ranges referred to by consultants and manufacturers when specifying or building transformers. For example, a transformer manufacturer that builds units in the size range of 10 to 300 MVA will often have one plant facility that builds up to 50 MVA and then another plant that only builds units above 50 MVA and they will refer to these plants as their medium and large power assembly manufacturing facilities respectively.

INSULATION PRESERVATION SYSTEMS

A transformer's life expectancy is based on a number of factors, the most important of which is the quality of its insulation system over time. The oil used in power transformers is particularly susceptible to moisture and its insulating value is seriously reduced when even small amounts of water are present. In addition to this, the oil's insulating quality and performance as a cooling medium can be reduced by oxidization as well. It is, therefore, extremely important that the design of the transformer be such that it impedes the contact of the insulation system to the outside atmosphere, which contains both moisture and oxygen. Since the oil in the transformer will expand and contract with temperature and load, a number of systems have been developed to help preserve the overall insulation quality of the transformer. These designs include open style, sealed tank, conservator style, and automatic gas pressure.

Open style design refers to a tank design that is free breathing and vented to the atmosphere. There is an air or gas space in the main tank above the oil level. The insulating oil, inside the tank, expands and contracts with load and temperature, thus ultimately breathing in and venting to the outside atmosphere. This is an older style design normally used only in smaller size ranges. The benefits of this type was an initial lower cost base, but at the same time, this is the least effective method of protecting the transformer's insulating system.

In the sealed tank design, the core/coils and oil are completely enclosed in the main tank with no ventilation to the atmosphere. The gas space above the oil is normally 10 to 15 per cent of the volume of oil at 25°C and is made up of either dry air or nitrogen. This prevents any outside atmosphere from contact with the oil. This style offers better protection against the ingression of moisture and other contaminants that can have a negative effect on the integrity of the transformer's insulation system. Units of this style are often used in small to medium size designs with their top MVA size really being limited by the physical shipping height requirements of the main tank due to the fact that a gas headspace had to be incorporated above the oil. One drawback to this style is if a weld, flange or gasket develops a leak in the gas head space above the oil, this can lead to direct exchange with the outside atmosphere, which is not good for the oil. Overall this style offers a cost-effective advantage with good insulation protection.

The conservator- or expansion-type design has the main tank completely filled with oil and a smaller expansion tank positioned above the main tank, with about 5 to 10 per cent the volume of the main. As the oil expands and contracts with temperature and load, the atmosphere moves in and out through a

TABLE I — TRANSFORMER RATINGS AND COOLING METHODS

COOLING METHODS	C.S.A. DESIGNATION	A.N.S.I. DESIGNATION	B.E.S.A. DESIGNATION	RISE
Oil Immersed, Natural Circulation, Self-Cooled	ONAN	OA	ON	55/65
Oil Immersed, Natural Circulation, Water-Cooled	ONWF	OW	OW	55/65
Oil Immersed, Natural Circulation Forced-Air Cooled	ONAF	OA/FA	OB	55/65
Oil Immersed, Forced Oil, Water Cooled	OFWF	FOW	OFA	55/65
Oil Immersed, Forced Oil, Forced-Air Cooled	OFAF	OA/FA/FOA	ORB	55/65
Oil Immersed Natural Circulation, Forced Air Cooled, Second Stage of Forced Air Cooling	ONAF/ONAF	OA/FA/FA		

uni-directional moisture removing breather. Only a small surface area of the oil in the expansion tank has exposure to the atmosphere and the expansion tank is designed in such a way so that if moisture should get in, it remains trapped in the expansion tank and cannot be exposed to the paper/wood insulation and clamping system of the core and coils. This is the most cost-effective design in higher MVA units and also offers the easiest versatility in shipping because the main tank is totally immersed in oil with no top head space. Newer designs can also incorporate an air bag in the expansion tank which virtually eliminates any oil contact with the outside atmosphere.

The gas regulation design is very similar to the sealed tank design with the exception that the air space above the oil is kept at a positive pressure at all times by a gas regulation system. With this style, as long as the gas bottle and regulation system are intact, a positive pressure is automatically maintained on the tank, allowing no atmosphere to oil contact. This system is quite reliable, however, it does come with a higher initial price tag and maintenance cost factor.

NAMEPLATES AND RATINGS

The nameplate on a transformer contains an assortment of information about the unit itself. It is full of acronyms and abbreviations that refer to the style, type, rating, voltage class and construction details of that particular transformer. There are different standards worldwide which govern the design criteria for power transformers, the standard(s) that a particular unit is designed to will be labeled on the nameplate. While all these standards have their similarity, they are

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all unique and, as such, use different acronyms or abbreviations for particular terms.

Table I refers to various transformer ratings and cooling methods. This illustrates how various regulatory bodies use slightly different designations to refer to the different ratings.

Transformers all have an MVA rating which is defined as the rated output that the transformer can deliver continuously or for a specified time at rated secondary voltage and frequency without exceeding its specified temperature rise limitations. This rating is sometimes referred to as the OA or ONAN rating. The rated output of the transformer may be increased with the addition of cooling stages. These cooling stages can be in the form of forced air, forced oil, water cooled, or any combination of these. Table II lists the various types of cooling stages and their associated loading capacities above the base OA or ONAN rating.

TRANSFORMER CONSTRUCTION

Transformer design/construction can be divided into three categories: the tank, the core and the windings. The design of each of these components depends on a number of factors, and together with the other accessories, they form the basis for the finished product.

The tank is made of high-quality shot-blasted steel with horizontal or vertical re-enforcing stiffeners for added mechanical strength to withstand operating and filling pressures. It is then coated inside and out to prevent the spread of corrosion. The base design may be a skid style or flat style depending on installation requirements.

The magnetic core consists of thin silicone steel sheets stacked into piles until the desired cross section is achieved to meet the magnetic circuit design. Once this operation is complete, these steel sheets on the laminations are strapped together, generally with epoxy fiberglass bands. These bands have a high tensile strength and are capable of withstanding hotspot temperatures up to 130° C. The whole core assembly is then clamped, stood vertically and ready for the windings to be installed.

The transformer windings are either copper or aluminum and use insulating materials which perform both mechanical and electrical functions. The insulated wire or strap is wound onto a cylinder core on a special winding machine. The LV winding is normally wound on the inside and the HV on the outside. This is to minimize the insulation required from the live winding to the grounded core. Once the windings are complete, they are tested, dried, sized and placed on the core assembly. An insulating tube and spacers are placed over each core leg before the winding is lowered into place. This provides electrical and mechanical strength as well as ensures the winding is as close to the axial center of the core leg as possible. After all three windings are in place, the top core steel is inserted and the entire core and coil assembly is clamped into place. The unit will then be sent to the oven or autoclave for an initial dryout before installation and fitting in the tank.

TRANSFORMER ACCESSORIES

Other accessories such as bushings, radiators, protective devices, gauges, tap changers, etc. are all installed on the transformer in the factory after it has been through its initial dryout process and fitted into the tank. After these accessories have all been installed, the transformer will have a final vacuum dryout and first oil filling at the factory.

Once this first filling is complete, the unit will move to the test bay where factory testing takes place to CSA/ANSI standards. These tests are designed to verify the mechanical strength and electrical integrity of the transformer and guarantee the losses that the manufacturer has designed against. Once the unit has passed factory tests, it is dressed down for shipment to a customer's site. This involves removing the oil and backfilling the unit with a dry gas (air or nitrogen) to minimize the possibility of moisture ingression. All accessories that cannot be left on for shipping such as bushings, radiators, conservator etc. are removed and packed to be sent to site for the field installation.

FIELD ASSEMBLY AND OIL FILLING

When a transformer leaves the factory, it is shipped by heavy haul trucks, rail and/or seaway vessel to site. There are generally three separate shipments made, the main tank c/w core and coils, the accessories that have been removed and packaged, and the insulating oil. The core and coils are the most critical part of the shipment and are normally monitored continuously from the plant to the final site via one or more three axis accelerometers (impact recorders). These devices are designed to measure sudden movement or 'jarring' in any direction that the transformer may experience during its shipment. This sudden movement, if excessive, could have a negative effect on the bracing of the core and coils.

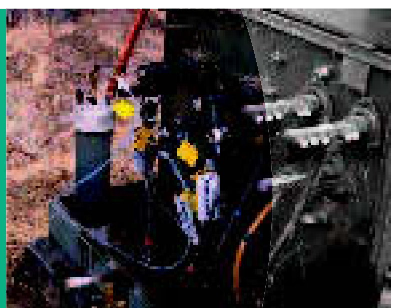

TABLE II — TRANSFORMER COOLING STAGES AND LOADING CAPACITY

TYPE OF COOLING	LOADING CAPACITY
ONAN	100 PER CENT
ONAN/ONAF	100/133 PER CENT
ONAN/ONAF/ONAF	100/133/167 PER CENT
ONAN/ONAF/OFAF	100/133/167 PER CENT
ONWF	125 PER CENT
OFWF	167 PER CENT

Once the unit gets to site, a receiving inspection is done on the unit which generally consists of a visual inspection, examination of the impact records and a test of the core ground insulation and shipping gas. These inspections and tests are completed before the unit is cut loose from the shipping deck, and give an indication of the received condition of the transformer. If there is any indication of movement or air leaks during shipment, normally an internal inspection is performed on the main tank, core and coils, before the unit is offloaded, to get a first-hand look at any potential shifting problems during transportation. If all tests are good, the unit is offloaded and the assembly process can begin.

Once the transformer is situated on its pad, all the accessories that were removed for shipment are reinstalled. This process is carried out in such a way as to minimize the introduction of moisture, atmosphere or foreign contaminants of any form into the main tank. Dry breathing air with a moisture content of less than 0.5 per cent is fed into the transformer at all times. It is best to try and complete the work when weather conditions are dry. Since the number one enemy of the insulation system is water, every attempt is made to keep moisture out. Caution is taken to try and not open up more than one accessory cover or entry hole at one time, to prevent cross ventilation of the outside air.

In some cases, it is necessary to make a confined space entry into the tank to either remove shipping blocks, make bushing connections inside the tank, or to perform a final internal inspection. Extra caution needs to be taken to ensure nothing is moved or bent inside the tank and that nothing is left or dropped in the tank when this work is being carried out. Even the smallest piece of foreign contaminant introduced, such as metal filing, etc., could have drastic effects on the longevity of the transformer.

After the assembly is completed, the unit is closed up and a pressure check is done to ensure that all flanges, welds, valves, etc. are sealed. A dew point test may be done on the unit at this point to give an indication of the relative humidity or general moisture content of the air and insulation system. Next, the final dryout of the unit begins by lowering the pressure with high capacity vacuum pumps to a level below the partial vapor pressure of water. This, in effect, boils off any surface moisture that has been introduced during the assembly and acts to further dry the paper/wood insulation and bracing system in the transformer. Once the prescribed amount of vacuum has been achieved and held, the oil filling begins.

The oil is heated and processed through a separate vacuum chamber and filter system into the transformer tank, while holding vacuum on the transformer tank at the same time. This is the most critical part of the procedure and must be monitored very closely. Oil processing speed, temperature, and vacuum all need to be monitored and kept within specific values to ensure that the process meets all manufacturing specifications. Loss of vacuum at any time on the main tank during this process will call for a complete shutdown and restart of the whole field dryout process. The entire procedure is run continuously until the transformer is filled with oil to the desired level. At this point, the transformer is ready to be final field tested and commissioned for startup.

SUMMARY

Transformer design and manufacturing techniques have remained similar for many years. Over time, improvements have been made in materials, design programs and testing techniques to allow for lighter and more efficient units to be produced.

The number one enemy of the transformer's insulation system is water. Proper procedures and handling for field installation has proven to be very critical in reducing moisture content and maximizing the life span of an installed unit.

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