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Step-up Transformers

The vast majority of installed transformers are used to distribute power to industrial, commercial, and residential loads. As such they step voltage down from a distribution level (typically 35 kV or lower) to 600 V class. Conventional distribution transformer construction is adequate since loading tends to vary modestly over the life of the transformer. This paper will explore the load requirements that step-up transformers must accommodate and the resultant electrical and mechanical design changes necessary to insure dependable long term performance.

All transformers use electro-magnetic induction between the energized input winding and the magnetically coupled output winding. When the transformer is energized, there is a short period of higher than normal inrush current as the magnetic field is established and current flows in both windings. Protective fuse designers use the rule of thumb that the inrush current should not exceed 12 X normal for 0.01 second. Transformer designers limit the inrush current so as not to exceed the fault current rating of the device. The higher the normal current, the more important this issue becomes.

As is the case with all transformers, the lower voltage winding has the highest rated current. Most distribution transformers convert high voltages as supplied via a generation or transmission source to a lower voltage utilized by the load. With step-up transformers however, the transformer is being energized with a lower voltage to provide a higher voltage. Given the fact that voltage and current are inversely proportional, it is at the same time being energized by the higher current winding thereby requiring that the design be focused on managing the effects of injecting multiples of the highest rated current during inrush. When the difference between HV and LV is small, the difference in HV current and LV current is also small and the issues are not as critical. Such is the case with interties between distribution circuits of similar voltages. Where it becomes critical is when a step up transformer is used with a relatively low voltage source.
The preceding illustrates the basic components of a coal fired steam generation plant. Regardless of type of power generation (coal, water, natural gas, nuclear...), the power is produced at a relatively low voltage but high current and fed into generator step-up transformers (GSU). The high voltage output of the transformers feed transmission/distribution lines for delivery downstream.

Generator step-up transformers present challenges because when connected directly to generators they can experience more severe operating conditions than normal substation step-up transformers experience. Specifically....

1. When a fully loaded generator suddenly loses its load, it tends to over-speed for a period of time until it can make the necessary adjustments for the lost load. This over-speeding causes the output voltage of the generator to increase which is then applied to the transformer. If the transformer core is not sized correctly, the generator over voltage could put the transformer core in saturation.

2. When a fault occurs on the output side of the transformer, the time it takes for the field of the generator to trip and for the generator to coast down creates forces and fault energy to be absorbed by the transformer during this coast down time. The energy the transformer must absorb is larger than would be seen by a typical substation transformer.
The first condition (core saturation) can be managed by reducing the induction level of the transformer core. Depending on the installation specifics, Pacific Crest Transformers may adjust the design to accommodate over-voltages ranging from 5 to 20 percent of transformer rating. Preventing core saturation minimizes short term over-currents which reduces coil heating.

The second condition (faults) can result in significant heating as well as mechanical stress in the core/coil assembly. Round coils and 360 degree coil cooling may be incorporated into the design to minimize the impact.

In the past, step-up transformers were primarily employed in power generation facilities and distribution substations. Renewable power however has resulted in their exponential growth. Wind energy is presently responsible for the majority of this new demand. To the right is a picture of a wind farm installation. At the base of each turbine tower is a 3 phase padmount step-up transformer which is connected to the turbine generator located in the nacelle.

A typical wind farm may be comprised of 100 or more turbines. The input to each transformer is typically 480 to 690 volts. The high voltages range from 13.8 to 46 kV. The transformer outputs for the entire wind farm are fed to a collective step-up transformer which steps the voltage up to a transmission voltage level.

Today’s step-up transformers may range from a few hundred kVA though several hundred MVA. The demands on the electrical and mechanical design typically exceed those of their
step-down counterparts. As mentioned earlier, the 2 key areas of concern are core saturation and fault management.

Core saturation issues can be managed via a lowering of flux density in the core design. Lower flux density equates to additional core steel which in turn equates to higher material content.

The proper management of coil heating and mechanical stresses due to faults however, may require significant change to the core/coil design. Thus, PCT enhances the capability of the transformer to handle these additional factors with enhanced cooling and round coil construction.

Under high inrush and fault conditions substantial mechanical forces are exerted on the coils. Round coil construction equalizes these forces minimizing the possibility of coil movement that can lead to ruptures in the insulation which can subsequently lead to short circuits within the windings.

Conventional distribution transformers are routinely designed with rectangular coils and 5 legged formed cores. Although quite adequate for distribution loads, extreme coil heating can occur when subjected to continuous inrush loading because the cooling ducts on rectangular coils are located in the front and rear of the coils while their sides
are surrounded and essentially enclosed by iron cores. The hot spot in each coil is therefore found on the sides. As the cooling oil flows from bottom to top of each coil, the heat is drawn from the sides only by convection. Since distribution loads tend to be relatively stable, in most cases, this type of cooling is more than adequate. Generator step-up transformers however, can be subjected to frequent thermal cycling as a function of varying loads. This can cause repeated thermal stress on the winding, clamping structure, seals and gaskets. Repeated thermal cycling can lead to nitrogen gas absorption into the hot oil and then released as the oil cools, forming bubbles within the oil which can migrate into the insulation and windings to create hot spots and partial discharges which can damage insulation. The thermal cycling can also cause accelerated aging of internal and external electrical connections. Round coil construction design allows for the addition of 360° oil cooling ducts resulting in dramatically improved cooling characteristics.

Although the cooling advantages are significant, the ability to manage fault currents makes round coil construction the best option when the transformer is to be employed in a generator step-up application. Under fault conditions the radial and axial forces are exerted on the coils. Round coils manage the radial forces since they are equalized throughout the circumference of each coil. A failure to manage axial forces during a fault can result in telescoping of the coils resulting in transformer failures. Round coil construction coupled with cruciform coils provide for the capability of adding pressure plates to the top and bottom of each coil to constrain axial forces.
The preceding image shows the lower plates installed on the core legs. The pressure plates are constructed with routered slots to provide a path for the insulating fluid to flow freely throughout the coils to efficiently cool winding conductors and minimize insulation heating.

Once the coils are installed on the core legs, the top pressure plates are added to the assembly. The top yoke of the core is then installed.

After the top core frame is installed, the upper and lower pressure plates are secured with all-thread rods which apply even pressure to the top and bottom of the coils to contain the axial forces.

In addition to providing a means of securing the coils, the core frame is used to provide pressure
to the core laminations, which increases efficiency and reduces noise due to vibration.

The role of step-up transformers in the industrial market is extremely important since their performance can directly impact the entire electrical supply of the operation. To guard against the possibility of an extended disruption in power supply for critical operations, the use of a back-up power supply should be considered. The cost for the initial investment could prove to be easily offset by the prevention of just one outage.

As with all products produced by Pacific Crest Transformers, strict attention is paid to the details as pertains to the application and duty cycle for the transformer to be provided. Specific design parameters are utilized for specific needs. There is far more to specifying a liquid filled transformer than mere kVA and voltages. Although all transformers must meet ANSI construction and test standards, the optimum design needs to take into consideration the application and operating environment of the installed transformer to insure optimum performance as well as long term operation.