The transformer becomes triangular – regaining symmetry

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Transformers using a triangular instead of a planar core configuration offer a number of advantages. Such dry-type transformers are now commercially available.

This new technology allows weight and space savings, reduces sound level, harmonic content and magnetic stray fields, and inherently improves energy efficiency.

The beauty of being triangular

Three-phase distribution transformers are usually constructed with planar cores, i.e. core legs and core yokes are coplanar. They can be built as either stacked or wound cores. In case of stacked cores, the legs and yokes are individually manufactured by stacking numerous straight sheets of electrical steel on top of each other. The many joints where legs and yokes connect have to be specially built in order to keep material consumption and the core magnetic resistance (reluctance) as low as possible, for instance using the step-lap technique.

Wound planar cores (Evans or 5-legged-cores) consist of several individual bodies with different shapes. The bodies are manufactured by winding thin electrical steel foils on a mandrel and cutting each layer for opening the core and inserting the windings on the legs. The gaps originating from this opening of the core bodies increase reluctance and no-load loss of the transformer. These planar core configurations introduce an asymmetric component for the three-phase AC system, because the outer phases exhibit different electromagnetic properties than the centre phase.

In contrast, wound triangular cores consist of three identical wound core rings. These rings are manufactured by continuously winding a lamination of electrical steel on a mandrel. The core rings are arranged in a triangle (Fig. 2) in order to assemble the three phase transformer core. All core legs, which are formed by two adjacent rings each, are positioned at the corners of the equilateral triangle and therefore lie on a circle. Their electromagnetic properties are identical and a magnetically symmetric transformer configuration is achieved as a result.

The symmetry of the core and the lack of joint areas of the triangular wound cores provide various benefits over planar core types. Improvements in manufacturing technologies nowadays allow the manufacture of triangular transformers in a competitive way, which also reaps benefits from the configuration.

Note that the poles of a generator, the element that generates electricity, are also arranged on a circle and have a symmetrical structure. The same is the case for electric motors. The triangular transformer configuration is therefore a more natural configuration than the planar one, and its introduction allows transformers to regain symmetry.

How to make a triangular core transformer

In order to minimise the required amount of materials, core legs ideally have a circular cross section. By continuously varying the width of the electric steel sheet while winding the core rings, an almost D-shaped cross section of the rings is obtained. When two D-shaped rings are
brought together, the core legs receive their circular cross section. That results in a high fill factor of core material for the cylindrical coils, which is important for a compact and cost-efficient structure.

Continuous winding means that the core cannot be opened to allow installation of the coils. The windings need therefore to be wound directly on the core (Fig. 3). Furthermore, casting of the coils with epoxy is done directly on the core. Although the processing on the core is slightly more complex from a handling point of view, exactly the same technology is used and the same quality is achieved as for regular vacuum cast coil dry-type transformers. ABB calls its triangular dry-type transformer "TriDry", combining the name of the form (triangular) and the type of the transformer technology (dry-type).

The benefits of being triangular

The symmetric structure and the lack of joints between core legs and yokes have an astonishing effect on the characteristics of the transformer. Each of the three legs is linked directly to the other two and the distances covered by the magnetic flux in the core are symmetrical and shorter. If the magnetic flux in the yoke of one of the core rings becomes too large, the remaining flux can make its way via the other core ring and even close back over the third core ring, providing a symmetric path. This behaviour together with the different footprint results in impressive advantages over conventional transformers.

The beauty of the triangular transformer technology is that it automatically combines all these advantages at the same time. If one can, for example, take advantage in an installation of the compact footprint, at the same time one also gets reduced sound, reduced losses, reduced magnetic stray fields and reduced harmonic content. With conventional transformer technology, it is difficult and costly to produce these characteristics at the same time.

Symmetry reduces losses and operation costs

Compared to a planar core, a triangular core has reduced weight. Together with the lack of joints, this leads directly to a reduction in no-load loss which is caused by the alternating core magnetisation due to the application of an AC voltage. This has an economic as well as an ecologic value. As no-load loss incurs constantly from the moment when the transformer is connected to the grid, it is crucial.

For a 1000 kVA transformer, the difference in no-load loss between a TriDry transformer and a usual dry-type transformer is 600 W, the equivalent to the power consumption of a hair dryer. This results in an annual energy consumption of 5300 kWh and related costs of R3200 at electricity costs of R0.60/kWh.
Symmetry enables compact installations

Due to the triangular shape, the transformer has a different and more compact footprint than a conventional transformer (Fig. 4). The total length of a distribution switchgear installation with transformer can therefore be reduced and the space is usable for other purpose. Together with typically 20% lower weight, these factors may be decisive for installations in buildings due to limitations imposed by the load-bearing capacity of elevators or floors.

Symmetry cuts magnetic stray fields

Technical equipment can react very sensitive to magnetic fields, either deliberately in case of a magnetic sensor or unintended where they can cause malfunctioning. This is the case in hospitals, for example, where the limit for magnetic stray fields is often just 0,4 μT, or in research facilities or data centres. Magnetic fields may also have negative impact on human bodies, especially in case of long-term presence, and some countries have introduced limiting values. Switzerland for example specifies a maximum value of 1 μT RMS for 50 Hz magnetic fields at working or living places.

Electromagnetic compatibility (EMC) and minimisation of magnetic stray fields is therefore of importance. Since dry-type transformers are often installed in buildings and very close to people and installations, it is especially of relevance. Triangular transformers show a reduction of magnetic stray fields, as shown in Fig. 5. The symmetrical structure causes the stray fields of the individual phases to automatically cancel each other out partly.

In the case of a 1000 kVA transformer, the required clearance distance to the triangular transformer for being below 1 μT is about 1 m less than for a planar transformer. This may for example allow to make full use of the floor directly located above the transformer installation. Calculated and measured magnetic stray fields are in good agreement (Fig. 6) [1].

Symmetry reduces noise

Transformer sound is often disturbing, especially if the transformers are located close to living or office areas. Due to the reduced core mass, the lack of joints, and the lower harmonics, the sound level of the transformer is reduced by 5 – 10 dB. This corresponds in human perception to only half the noise.

Symmetry reduces harmonics

The harmonic content of the excitation current, which is caused by then non-linearity of the B-H curve has been measured to be significantly lower (Fig. 7). Its reduction improves the overall power quality in the network.

Conclusion

The concept of a triangular transformer is not new as such. Ideas for different kinds of triangular configurations have existed for many years. However the commercial launch of the triangular transformer shows that transformer product innovation is possible even today. The transformer owes its astonishing array of technical advantages due to its symmetrical structure. Furthermore, it offers the other advantages of dry-type transformers, in particular their high safety and reliability. The dry-type triangular transformer thus makes a significant contribution to safety, compact installation, network stability, environmental protection, and low cost operation.

References


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