A New Three Phase Triangle Core Measurement Type Voltage Transformer

O. Ozgonenel[1], B. Cepken[2], B. Cisal[2]
1. Electrical and Electronic Engineering, Ondokuz Mayis University, Samsun, Turkey
2. ESITAS, Hilal Mah. Paşaköy Cad. No:28 Sancaktepe 34791, İstanbul, Turkey
Corresponing author: okanoz@omu.edu.tr

Abstract

Measurement transformers are special transformers that are used to reduce both current and voltage at certain rates in alternating current installations and are a special application of transformers designed to measure current or voltage. Since they are widely used in distribution systems, minimizing core losses are crucial for effective and reliable distribution systems.
Therefore, this paper presents a different core type for measurement type voltage transformer. The new type transformer is tested magnetically and performance curves proof that the new type transformer is cost effective and has low core losses, less noiseness, and sound short-circuit resistant.

Keywords: Triangle core, low core loss, medium voltage, measurement transformer

Introduction

Reliability and stability of power systems depend on the operation of all system components within specified limits. Voltage measurement transformers take an important place among the power system components and perform their protection and measurement tasks where they are connected. Voltage measurement transformers are measurement transformers that reduce the primary circuit voltage, which is at a high level in the system to which they are connected, to the measurable low levels for the measurement and protection devices connected to the secondary circuit. The purpose of the new core design is envisaged to save weight and space, reduce the volume, reduce harmonic content and magnetic stray losses and naturally increase energy efficiency. This paper simply propose a three phase dry-type voltage measurement transformer based on triangular wound cores. In the literature, there are many modelling methods and procedures based on E-I Core transformers as well as triangular type distribution transformers. However, this paper presents to design and implementation of three phase voltage measurement transformer based on triangular core. In the proposed transformer no-load losses, magnetic stray losses and harmonics are studied. The modelling outcomes are then compared to real time data provided by ESITAS Company.

The final product is dry-type epoxy cast resin measurement type voltage transformer and includes many technical improvements. Dry type voltage measurement transformers are manufactured in two ways. The first of these are phase-to-phase voltage transformers and the second to phase-to-ground voltage transformers. It states that phase-phase voltage transformers can be used at voltages up to 24kV in the 40 / b sub-paragraph of the Electric Power Current Regulation, and that the phase-to-ground voltage transformers should be used for voltages above this voltage. Phase-phase voltage transformers are connected between two phases in the network. Since they are connected between two phases, these voltage transformers have two bushings. Primary windings are removed from these bushings. In this type of voltage transformers, medium voltage networks that draw balanced load, voltage measurement is completed by using two phase-phase voltage transformers. In this connection, phase-to-ground voltages cannot be measured. Useful aspects of this type of voltage measurement transformers are as follows:
a) Its cost is lower than that of phase-to-ground (unipolar) voltage transformers.
b) Resonance hazard in phase-to-earth voltage transformers is not present in this type of transformers.

The crucial aspects are given as below.
a) Voltage transformer winding insulation faults cause two phase short circuit.
b) No voltage can be detected anymore.

Phase-to-earth voltage transformers can be used at any voltage level above 1kV. The input end (polarity end) of the primary winding is connected to the phase conductor of the network. The output end (non-polarity end) of the primary winding is connected to ground. In three-phase systems, one is connected to each phase and used for measuring the phase-to-ground voltage. Useful aspects of this type of transformers are:
a) They are manufactured more reliable.
b) Interior insulation requires less material.
c) Provides residual voltage measurement in earth leakage.

The crucial aspects are;
a) In small networks, due to voltage increase, impedance decreases and resonance is exposed to excessive voltage. In this case, it now causes serious error in voltage detection.
b) Compared to two phase-to-phase voltage transformers, 3 voltage transformers are a more cost-effective solution.

Theory

In the proposed paper, it is aimed to design and manufacture a more efficient measurement transformer by combining the beneficial aspects of both types of voltage measurement transformers. It is also tried to be eliminated with this new type of transformer in the winding directions.

Today, it is possible to come across triangular core transformer designs as an innovative product in medium voltage (MV) level distribution transformers. However, this type of measurement transformer sample was not found in the bibliography scan. Consequently, the use of all useful aspects of the triangle core concept in voltage measurement transformers constitutes the main innovative aspect of our project. Another gain is the design and manufacture of a three-phase voltage measurement transformer in the same mold. Voltage transformers are generally manufactured using planar sheet plates, whether for distribution or measurement purposes. Reducing the magnetic resistance (reluctance) is very important considering the concepts of loss and accuracy in this type of transformers. Providing symmetry of each flux distribution in the core legs is important for saturation. In contrast, in the triangle-core transformer, three symmetrical legs are mounted in a triangle shape (see project images). It will be a measurement transformer with electromagnetically similar properties but with a symmetrical flux distribution feature. In a symmetrical three-phase design, the magnetic path length is shorter than conventional transformers. Therefore, the same measurement can be made with less magnetic material. When analyzed in terms of harmonics, it is stated in the related literature that these losses are less in triangular core transformers.

As a result, it is a product that is less costly than similar products, requires less insulation, high accuracy, less noise level, low harmonic measurement and more importantly not affected by ferroresonance effects. On the other hand, it is also possible to measure the inter-phase and ground voltages required by the three-phase connection at the same time. In addition, there will be significant improvements in the production process (number of products per unit time).

Simulation

A number of preliminary preparations have been completed. These preparatory works are given below as below.

a) 2D and 3D CAD models of current resinous voltage transformers have been prepared.
b) These models were transferred to COMSOL environment and necessary graphical operations were made on the models.
c) In the next step, the electrostatic analysis of the existing voltage transformers were conducted for both normal operating conditions and lightning pulse voltage analyses and compared with the real-time test results of the company.
d) After these two results were seen to be compatible, triangular core transformer models were created related to the proposed project subject and similar studies were carried out.
e) Electrostatic analysis has been performed in computer simulations especially according to IEC60076-3 standard.
f) These analyses will be carried out in more depth and the most appropriate body structure and design principles will be decided.

Design parameters are given in Table 1.

Table 1: Font sizing used in this template

Item	Value	Definition
Np	27000	Number of Turns - Primary
Ns	82	Number of Turns - Secondary
d1	0.12 mm^2	Primary Cross Section
d2	3 mm^2	Secondary Cross Section
U1	31.5 kV	Primary Voltage
f	50	Frequency
Rp	10 Ohm	Primary Resistance
Rs	10 kOhm	Secondary Resistance
Fs	2000 Hz	Sampling Frequency
t-end	0.04 sec	End of Simulation

The core material is selected as M5 laminated sheet and its BH curve is seen in Figure 1.

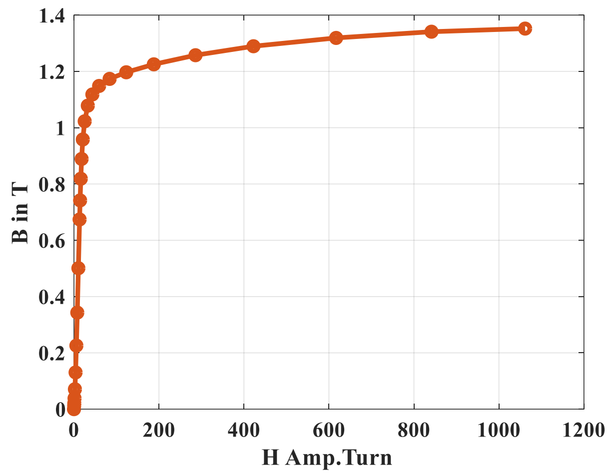

Figure 1. BH curve of M5 type core material

The complete 3D model of is given in Figure 2. The surrounding environment is selected as air in spherical shape. The model is designed on a scale 1:1.

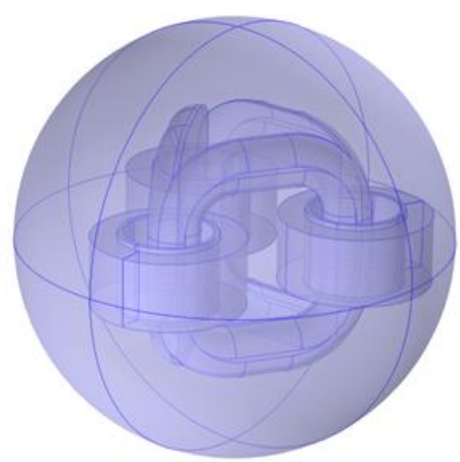

Figure 2. 3D model of triangular core measurement transformer

On the model open circuit and short circuit tests have been done and then ratio tests are performed. Magnetic field and electrical circuit physics are chosen to complete analysis. Time dependent study is chosen to see transient performances on the proposed model.

Maxwell's equations are used as the basis for the derivation of the mathematical model:

$$\nabla \times H = J \quad (1)$$

$$B = \nabla \times A \quad (2)$$

$$J = \sigma E + J_e \quad (3)$$

$$E = \partial A / \partial t \quad (4)$$

where A is the cross sectional area, H the magnetic field, E the electric field, J the current density, B the magnetic flux density, D the electric flux density.

Ampere law is applied to M5 type triangular core and BH curve is selected as magnetization. Three phase electric circuit is applied to model and to calculate circuit current External I vs U is used for all windings. In COMSOL environment application builder is used for open circuit and short circuit tests.

Table 2. Open circuit test procedure

```
with(model.component("comp1").physics("mf").feature("coil1"));
  set("CoilExcitation", "Voltage");
  set("VCoil", "V1n_f");
endwith();
with(model.component("comp1").physics("mf").feature("coil2"));
  set("CoilExcitation", "Voltage");
  set("VCoil", "V1n_f*exp(-j*2*pi/3)");
endwith();
with(model.component("comp1").physics("mf").feature("coil3"));
  set("CoilExcitation", "Voltage");
  set("VCoil", "V1n_f*exp(+j*2*pi/3)");
endwith();
with(model.component("comp1").physics("mf").feature("coil4"));
  set("CoilExcitation", "Current");
  set("ICoil", "0[A]");
endwith();
with(model.component("comp1").physics("mf").feature("coil5"));
  set("CoilExcitation", "Current");
  set("ICoil", "0[A]");
endwith();
with(model.component("comp1").physics("mf").feature("coil6"));
  set("CoilExcitation", "Current");
  set("ICoil", "0[A]");
endwith();
```

Table 3. Short circuit test procedure

```
with(model.component("comp1").physics("mf").feature("coil1"));
  set("CoilExcitation", "Current");
  set("ICoil", "I1n_f");
endwith();
with(model.component("comp1").physics("mf").feature("coil2"));
  set("CoilExcitation", "Current");
  set("ICoil", "I1n_f*exp(-j*2*pi/3)");
endwith();
with(model.component("comp1").physics("mf").feature("coil3"));
  set("CoilExcitation", "Current");
  set("ICoil", "I1n_f*exp(+j*2*pi/3)");
endwith();
with(model.component("comp1").physics("mf").feature("coil4"));
  set("CoilExcitation", "Voltage");
  set("VCoil", "0[V]");
endwith();
with(model.component("comp1").physics("mf").feature("coil5"));
  set("CoilExcitation", "Voltage");
  set("VCoil", "0[V]");
endwith();
with(model.component("comp1").physics("mf").feature("coil6"));
  set("CoilExcitation", "Voltage");
  set("VCoil", "0[V]");
endwith();
```

Magnetic flux density is seen in Figure 3 and current density distribution is given in Figure 4.

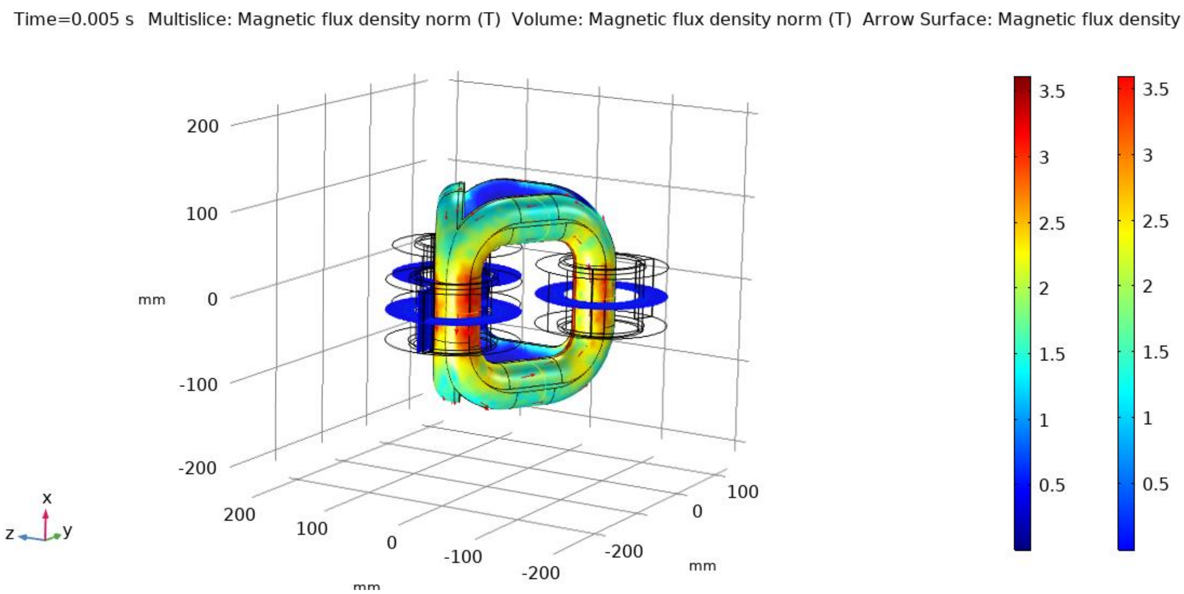

Figure 3. Magnetic flux density norm

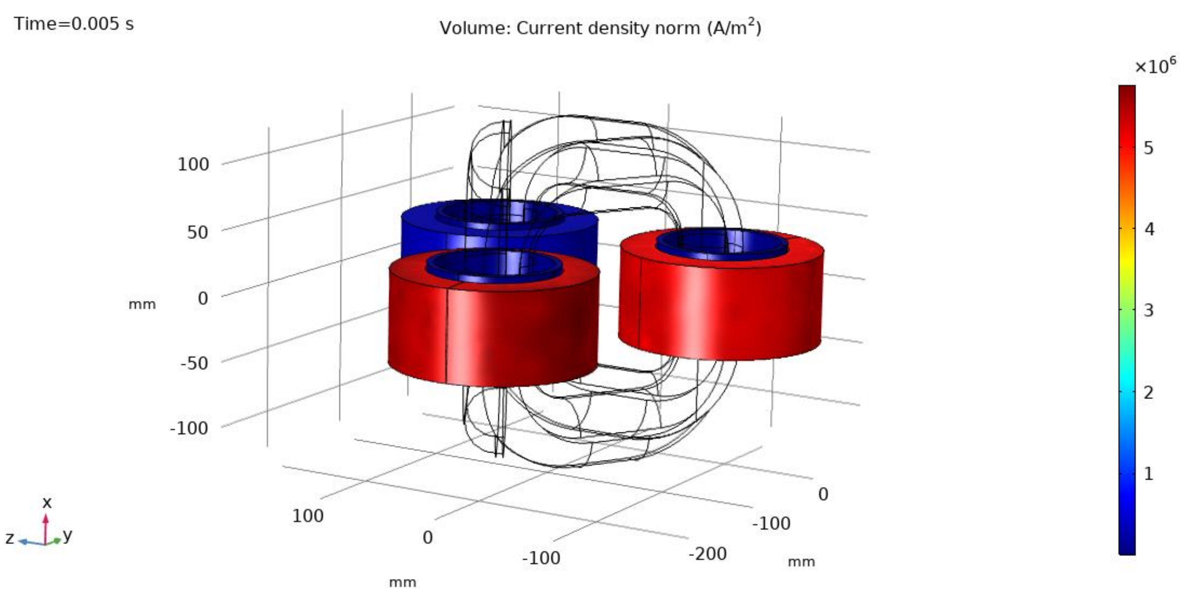

Figure 4. Current density norm

Finally, induced voltages is given in Figure 5.

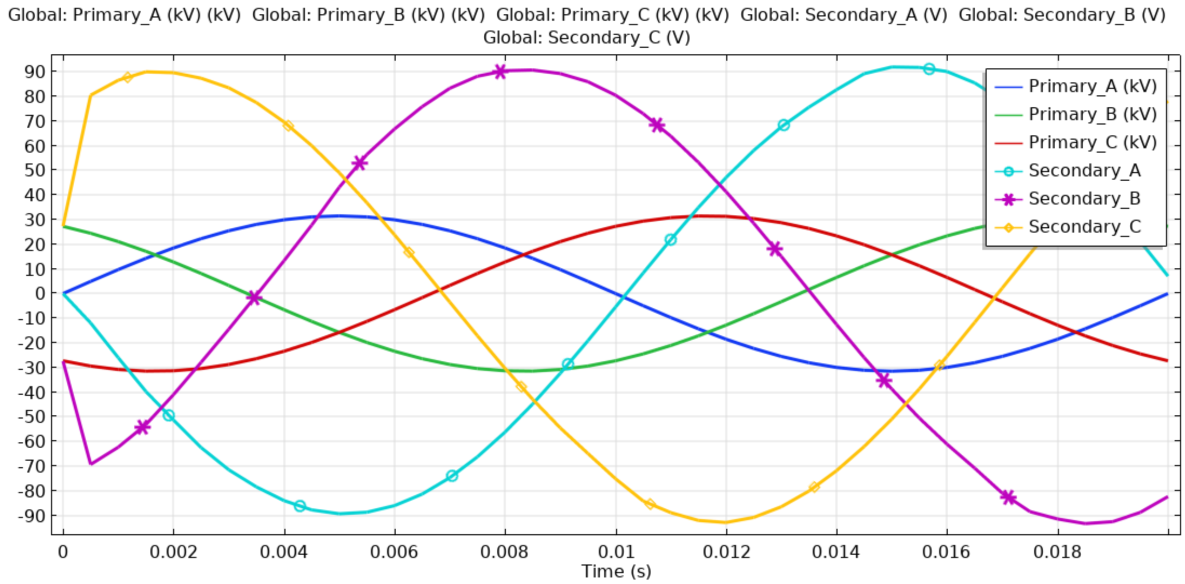

Figure 5. Induced voltages in primary and secondary sides

Conclusions

This paper proposed a new type voltage measurement transformer based on triangular core shape. On the proposed model FEA is performed its performance for both open and short circuit tests. Some useful advantages have been observed. Due to its symmetry the related losses and operation costs are reduced. 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 behavior together with the different footprint results in impressive advantages over conventional transformers.

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