Voltage Transformers

An Online Continuing Education Course for Engineers

Course Number: E-2045

Credit: 2 Hours / 2 PDH / 2 CPD

Voltage Transformers

Velimir Lackovic, Electrical Engineer

Introduction

There are two types of voltage transformers, magnetic voltage transformers (VT) and capacitive voltage transformers (CVT). The magnetic voltage transformers are most economical for voltages up to about 145 kV and the capacitive voltage transformers for voltages higher than 145 kV. A CVT can also be used together with the Power Line Carrier (PLC) devices that are used for communication over the high voltage transmission circuits.

Voltage transformers are together with current transformers known as instrument transformers. Voltage transformers are in most situations connected between phase and ground. The standard that describes voltage transformers in details is IEC 186.

The main functions of instrument transformers are:

- To transform currents or voltages from a high value to a value that can be easily handled by protection relays and instruments.

- To insulate the metering circuit from the primary high voltage.

- To give standardization possibilities for instruments and protection relays to a few rated currents and voltages. Instrument transformers are specific types of transformers used for voltage and current measurements.

For the instrument transformers, the typical engineering laws that are also used for power transformers can be applied.

For a short-circuited transformer, the Equation (1) can be used:

$$\frac{I_1}{I_2} = \frac{N_2}{N_1} \qquad (1)$$

For a transformer in no load the Equation (2) can be used:

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} \qquad (2)$$

Equation (1) shows the current transformation in proportion to the primary and secondary turns. Equation (2) shows the voltage transformation in proportion to the primary and secondary turns. The working principle of the current transformer is based on Equation (1) and ideally, a short-circuited transformer where the secondary terminal voltage is zero and the magnetizing current is negligible.

The working principle of the voltage transformer is based on Equation (2) and is ideally a transformer under the no-load condition where the load current is zero and the voltage drop is created by the magnetizing current and is therefore negligible. In reality, the ideal conditions are not met as the instrument transformers are loaded with burden in the form of protection relays, instruments, and cables. This creates a measuring error in the current transformer due to the magnetizing current and in the voltage transformer due to the load current voltage drop.

The vector diagram for a single-phase instrument transformer is presented in Figure 1.

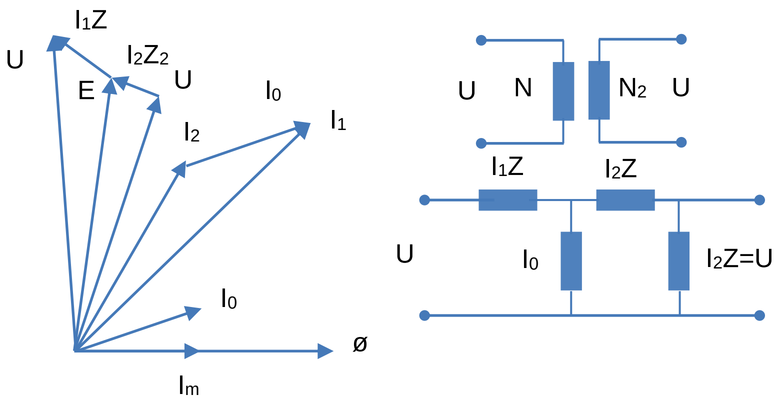

Figure 1. Instrument transformer operating principle

The turn ratio of the given instrument transformer is 1:1 to simplify the representation. The primary terminal voltage is U_1. The vectoral subtraction of the voltage drop I_1Z_1

from U_1 gives the electromagnetic force E. E is also the vectoral sum of the secondary terminal voltage U_1 and the secondary voltage drop I_2Z_2. The secondary terminal voltage U_2 can be written as I_2Z where Z is the burden impedance.

The electromagnetic force E is created by the flux Ø that lags E by 90°. The flux is caused by the magnetizing current I_m which is in phase with Ø. I_m is the no-load current I_0 reactive component and is in phase with E.

Instrument Transformer Measuring Error

The voltage transformer is typically loaded by impedance consisting of protection relays, instruments, and the cables. The induced electromagnetic force E needed to achieve the secondary current I_2 through the complete burden Z_2+Z, needs a magnetizing current I_0 which is taken from the primary side voltage. The I_0 is not part of the voltage transformation and instead of the rated ratio K_n:

$$\frac{U_1}{U_2} = Nominal\ ratio\ K_n \qquad (3)$$

The real voltage ratio K_d is expressed as:

$$\frac{U_1 - \Delta U}{U_2} = Real\ ratio\ K_d \qquad (4)$$

where

U_1 is the rated voltage of the primary

U_2 is the rated voltage of the secondary

The measuring error ε is expressed using the Equation (5):

$$\frac{\frac{U_1}{U_2} - \frac{U_1 - \Delta U}{U_2}}{\frac{U_1}{U_2}} \times = \frac{\Delta U}{U_1} \times 100 = \varepsilon(5) \qquad (5)$$

where

U_1 is the voltage of the primary

U_2 is the voltage of the secondary

The reproduction error will appear both in magnitude and phase. The magnitude error is known as voltage or ratio error. According to the definition, the voltage error is positive if the secondary voltage is bigger than the rated voltage ratio would give. The phase angle error is known as phase error or phase displacement. The phase error is positive if the voltage of the secondary is leading the primary.

According to the Figure (1), it can be written:

$$\Delta U = \Delta E_1 + \Delta E_2 \quad (6)$$

$$\Delta E_1 = I_1 Z_1 \quad (7)$$

$$\Delta E_2 = I_2 Z_2 \quad (8)$$

If $Z_1 + Z_2 = Z_k$ and $I_1 = I_0 + I_2$ it can be written

$$\Delta U = I_0 Z_1 + I_2 Z_k \quad (9)$$

Therefore, the voltage transformer is dependent on the voltage U and the flux density and magnetizing curve, and partly on the load current. The magnetizing current that creates the measuring error is dependent on several different factors as presented in Figure 2. The induced electromagnetic force also determines the transformer capability to carry the burden.

For the no-load voltage drop $I_0 * Z_1$, the following relations are valid:

$$I_0 = f(B) \quad (10)$$

$$I_0 Z_1 = f(B) * R_1 + jf(B) * X_1 \quad (11)$$

To achieve a low voltage drop, the following steps need to be taken:

- The primary winding is wound with a wire with a big cross section

- A low induction is applied

- The reactance is kept low

This means that a big core cross section must be used so that a high number of primary turns is avoided since the reactance has a square dependence on the number of turns. The load dependent voltage drop I_2Z_k is expressed with Equation (12).

$$Z_k = R_1 + jX_1 + R_2 + jX_2 \qquad (12)$$

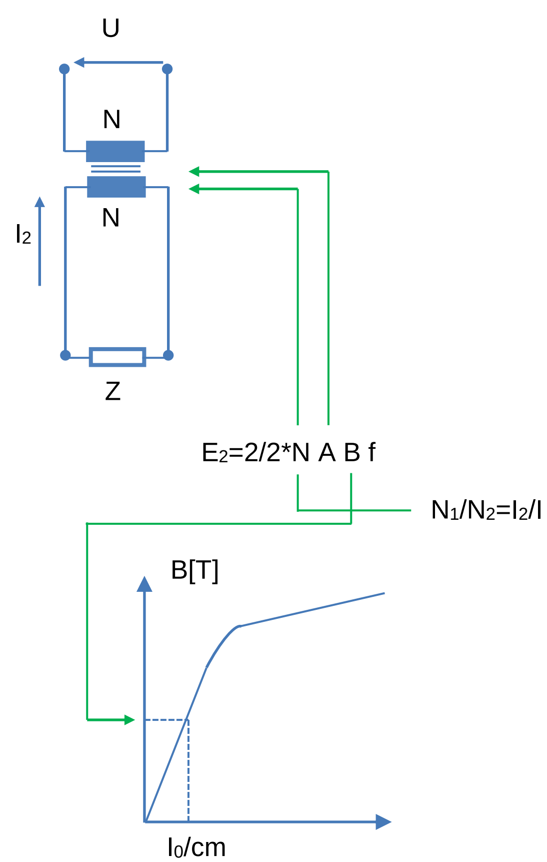

Figure 2. The factors affecting the voltage transformer output and magnetizing current

To maintain a low voltage drop due to the load current, the impedances of the primary and secondary have to be kept as low as possible which in reality means that a winding with a big cross section on the wires is used and the coils are made as compact as possible to decrease the leakage flux.

The Measuring Error Change with the Voltage

The no-load error I_0Z_1 changes with the voltage following the transformer magnetizing curve. The primary impedance Z_1 can be considered as a constant. The voltage drop that depends on the load is proportional to U_2 as $I_2 = U_2/Z$ where Z is the connected burden and Z_1 and Z_k are constants. Therefore, the relative voltage drop is constant. Turns correction is typically used on voltage transformers to reach high accuracy. The high number of turns provides a possibility to regulate in small steps. According to IEC 186 a voltage transformer needs to fulfil its accuracy cl… s between 25 and 100% of rated burden. Turns co… sitive error $+\varepsilon_{max}$ at a burden of … ted burden. This is presented in …

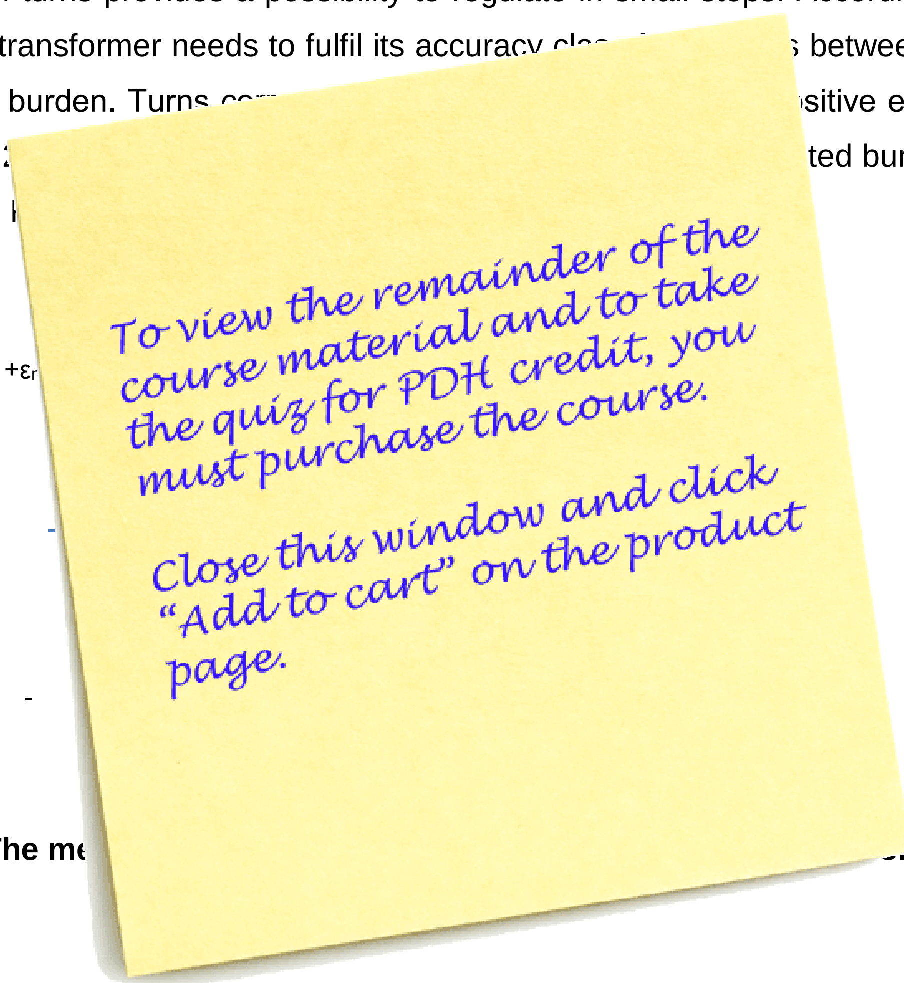

Figure 3. The me… nstant