

# Calculation of the Current Transformer Accuracy Limit Factor

## Application Note



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## **1. Scope**

This document describes the calculation of the actual accuracy limit factor ( $F_a$ ) for protection-type (P) current transformers (CT). First, the calculation of the actual burden of the CT, including connection wires and protection relay impedance, is presented. Then, two alternative methods for calculating  $F_a$  are shown. All calculation principles and equations are illustrated with an example.

The rules presented are generally used and apply, for example, to protection calculation of SPACOM and RED 500 series protection relays.

**KEYWORDS:** current transformer, accuracy limit factor, accuracy limit primary current.

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## 2. Introduction

The rated accuracy limit factor ( $F_n$ ) is the ratio of the rated accuracy limit primary current to the rated primary current. A protective current transformer type 5P10 has, for example, the accuracy class 5P and the rated accuracy limit factor 10. For protective current transformers, the accuracy class is determined by the highest permissible percentage composite error at the rated accuracy limit primary current specified for the accuracy class concerned, followed by the letter “P” (referring to protection).

The CT accuracy primary limit current defines the highest fault current magnitude at which the CT will meet the specified accuracy. Beyond this level, the secondary current of the CT will be distorted, and this may have severe effects on the performance of the protection relay.

In practise, the actual accuracy limit factor ( $F_a$ ) differs from the rated accuracy limit factor ( $F_n$ ) and is proportional to the ratio of the rated CT burden and the actual CT burden.

For the reliable and correct operation of the protection relays, the current transformer (CT) has to be carefully chosen. The distortion of the secondary current of a saturated CT may endanger the operation, selectivity and co-ordination of the protection. A correctly selected CT, on the other hand, enables fast and reliable protection.

### 3. Technical implementation

#### 3.1. Calculation of the CT burden

The actual burden is formed by the resistance of the pilot conductors and the protection relay(s).

##### 3.1.1. Resistance of a conductor

The resistance of a conductor (with a constant cross-sectional area) can be calculated from the equation:

$$R = \rho \times l / A \quad (1)$$

where  $\rho$  = resistivity of the conductor material (given typically at +20°C)  
 $l$  = length of the conductor  
 $A$  = cross-sectional area

If the resistivity is given in  $\mu\Omega\text{m}$ , the length in metres and the area in  $\text{mm}^2$ , the equation 1 will give the resistance directly in ohms. The resistivity and temperature coefficient for copper is given in table 3.1.1.-1

**Table 3.1.1-1 Resistivity and temperature coefficient for copper (Cu)**

Material	Resistivity $\rho$ (+20°C)	Resistivity $\rho$ (+75°C)	Temp. coefficient $\alpha$
Copper	0.0178 $\mu\Omega\text{m}$	0.0216 $\mu\Omega\text{m}$	0.0039 1/K

##### 3.1.1.1. Resistance at higher temperatures

The resistance is temperature-dependent: when the temperature rises, the resistance will increase. Therefore, the resistance of a conductor should be calculated at the worst-case temperature. Normally +75°C is used for calculations.

For pure metals like copper and aluminium the dependence is almost linear in quite a wide temperature range (-50...+200°C). The resistance at a certain temperature  $T_2$  is calculated as follows:

$$R_2 = R_1 \times [1 + \alpha(T_2 - T_1)] \quad (2)$$

where  $R_1$  = resistance at temperature  $T_1$   
 $\alpha$  = temperature coefficient of the conductor material  
 $T_1, T_2$  = temperatures in Kelvin (20°C = 293.15 K)

The resistance per cable length at +75°C for copper is given in the table 3.1.1.1-1 and in the figure 3.1.1.1-1.

**Table 3.1.1.1-1 Resistance per cable length (+75 °C) for copper**

Material	2.5 mm <sup>2</sup>	4 mm <sup>2</sup>	6 mm <sup>2</sup>
Copper	0.00865 $\Omega/\text{m}$	0.00541 $\Omega/\text{m}$	0.00360 $\Omega/\text{m}$

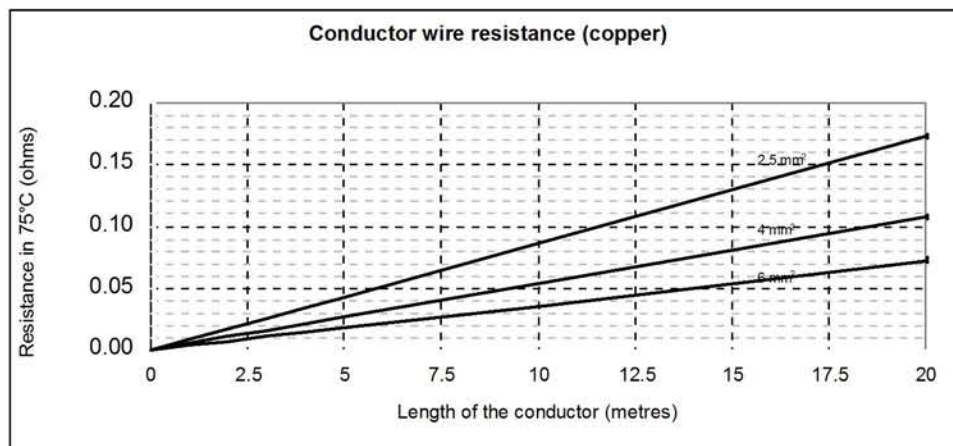


Fig. 3.1.1.1.-1 Resistance per cable length (+75°C) for copper (Cu).

## 3.1.1.2.

### 4- or 6-wire connection

If 6-wire connection is used, the total length of the wire, naturally, will be two times the distance between the CT and the relay. However, in many cases a common return conductor is used (figure 3.1.1.2-1). Then, instead of multiplying the distance by two, a factor of 1.2 is typically used. This rule only applies to the 3-phase connection. The factor 1.2 allows for a situation, where up to 20% of the electrical conductor length, including terminal resistances, uses 6-wire connection and at least 80% 4-wire connection.

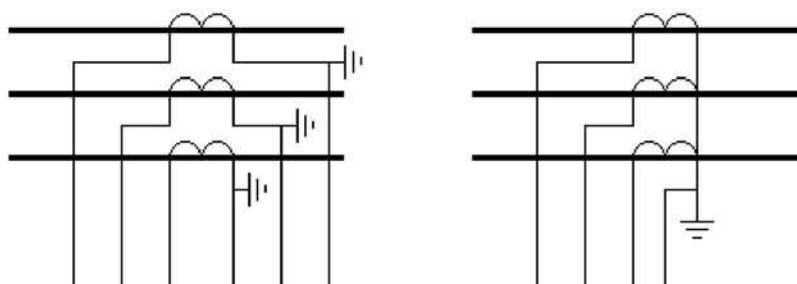


Fig. 3.1.1.2.-1 CT connections, 6-wire and 4-wire (common return conductor)

If, for example, the distance between the CT and the relay is 5 metres the total length is  $2 \times 5 \text{ m} = 10 \text{ metre}$  for 6-wire connection, but only  $1.2 \times 5 \text{ m} = 6.0 \text{ metre}$  when 4-wire connection is used.

## 3.1.2.

### Burden of the relay

The burden of the relay, i.e. the relay input impedance must be checked with the relay manufacturer (User's manual, Technical data).

For SPACOM relays, for example, the input impedance is less than  $0.020 \Omega$  for a 5 A input (i.e. burden less than 0.5 VA) and less than  $0.100 \Omega$  for a 1 A input (i.e. less than 0.1 VA).

### 3.1.3.

#### Example

The distance between the CTs and the protection relay is 15 metres, 4 mm<sup>2</sup> Cu conductors in 4-wire connection are used. The burden of the relay input is less than 20 mΩ (5 A input). Calculate the actual burden of the CT at 75°C:

Solution:

$$\rho = 0.0216 \mu\Omega\text{m} (75^\circ\text{C})$$

$$R = 0.0216 \mu\Omega\text{m} \times (1.2 \times 15 \text{ m}) / 4 \text{ mm}^2 = 0.097 \Omega$$

$$\text{Burden of CT} = 0.097 \Omega + 0.020 \Omega = 0.117 \Omega$$

#### Note for rated secondary current

As shown previously, the smaller the CT burden in voltamperes, the better (higher) the actual accuracy limit factor. When changing to 1A rated CT secondary current instead of 5 A, the burden in voltamperes will drop to a level of 1/25 of what it was.

### 3.2.

#### Calculation of the actual accuracy limit factor

The actual accuracy limit factor ( $F_a$ ) is calculated from the following equation

$$F_a \approx F_n \times \frac{|S_{in} + S_n|}{|S_{in} + S_a|} \quad (3)$$

where  $F_n$  = rated accuracy limit factor  
 $S_{in}$  = internal burden of the CT secondary coil  
 $S_n$  = rated burden of the CT  
 $S_a$  = actual burden of the CT

In equation 3, all burdens must be in VA, which can be calculated from the expression  $S = I^2 R$  by using the rated secondary current of the CT.

#### 3.2.1.

#### Example

The internal secondary coil resistance of the CT is 0.07 Ω, the secondary burden (including wires and relay) is 0.117 Ω and the CT is rated 300/5, 5P20, 10 VA. Calculate the actual accuracy limit factor  $F_a$ .

Solution:

$$F_n = 20 \text{ (CT data 5P20),} \quad S_{in} = (5\text{A})^2 \times 0.07 \Omega = 1.75 \text{ VA,}$$

$$S_n = 10 \text{ VA (from CT data),} \quad S_a = (5\text{A})^2 \times 0.117 \Omega = 2.925 \text{ VA}$$

$$F_a = 20 \times \frac{1.75 + 10}{1.75 + 2.925} = 50.3$$

Note: Often, as in this example, the power factor ( $\cos\phi$ ) of the CT is ignored.

## 3.2.2.

### Alternative method

There is also an alternative method for calculating  $F_a$ , that is, by first calculating the voltage on the CT secondary side, using the rated values:

$$U_{sat} = F_n \times I_n \times (R_{in} + R_n) \quad (4)$$

where  $F_n$  = rated accuracy limit factor  
 $I_n$  = rated secondary current of the CT  
 $R_{in}$  = internal resistance of the CT secondary coil  
 $R_n$  = rated resistance (burden) of the CT

This voltage (secondary limiting e.m.f.) is independent of the CT burden. Thus,  $F_a$  for the actual burden can be calculated as follows:

$$F_a = U_{sat} / [I_n \times (R_{in} + R_a)] \quad (5)$$

where  $R_a$  = actual resistance (burden) of the CT.

By using the values from the previous example, the solution will be:

$$U_{sat} = 20 \times 5A \times \left( 0.07\Omega + \frac{10VA}{(5A)^2} \right) = 47.0V$$

$$F_a = \frac{47.0V}{5A \times (0.07\Omega + 0.117\Omega)} = 50.3$$

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## **4. References**

IEC 60044-1. Instrument transformers – Part 1: Current transformers.

## 5. List of symbols

$\alpha$	temperature coefficient of the conductor material
$\rho$	resistivity of the conductor material
$A$	cross-sectional area
$F_a$	actual accuracy limit factor
$F_n$	rated accuracy limit factor
$I_n$	rated CT secondary current
$l$	length of the conductor
$R$	resistance
$R_I$	resistance at temperature $T_I$
$R_2$	resistance at temperature $T_2$
$R_a$	actual resistance (burden) of the CT
$R_{in}$	internal resistance of the CT secondary coil
$R_n$	rated resistance (burden) of the CT
$S_a$	actual burden of the CT
$S_{in}$	internal burden of the CT secondary coil
$S_n$	rated burden of the CT
$T_I, T_2$	temperatures in Kelvin ( $20^\circ\text{C} = 293.15\text{ K}$ )
$U_{sat}$	secondary limiting e.m.f.







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