CORE CROSS-SECTION CALCULATION AND ACCURACY CLASS CURVES OF INSTRUMENT CURRENT TRANSFORMER

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ABSTRACT

Instrument current transformers are important for protection of the energy system and for the billing of the energy sold, as well as for determining the current and voltage amplitudes in the generation, transmission and distribution processes of electrical energy. Incorrect measurement of current amplitude or angle in the system causes the applications, performed in the system, to be engaged at a wrong time and in a wrong way. In order to accurately measure the current and voltage information and maximize the efficiency of the system, it is very important to understand the transformer design criteria correctly. IEC standards specify all the technical specifications required for the design of the transformer. Taking into consideration the criteria given in these standards, the characteristics of the appropriate current transformer should be determined. In this paper, the design criteria of the current transformer is examined as suggested in the IEC standards, and the design procedure of the most optimal current transformer secondary is illustrated according to the technical specifications.

1. INTRODUCTION

Development of the material technology in recent years has also affected and developed the device production technology. This change is affecting and changing international standards. When the changes in IEC standards [1], [5] in the last decade is considered, the serious developments in the instrument transformers can be better understood.

The standards [1], [5] describe the minimum requirements that the manufactured equipment must have. Although the products have to pass the type and routine tests according to these standards [1], [5] the most challenging test of the equipment is the network itself which is always running. Products exposed to more severe conditions than those specified in the standards may be damaged during field operation. Precision to be shown in product selection and system design, and the use of protection devices in the right place and way will reduce the risks of damage to minimum level.Current Transformers are devices that:

- Converts high current to measurable low levels for measuring and protection devices,
- Isolates the measurement and protection circuits from the primary high voltages,
- Provides the standardization of measurement and protection devices.

In selecting the current transformers, the following parameters must be determined according to the relevant standards [1], [5].

- Current ratio
- Short circuit current, kA
- Highest system voltage, kV
- Operating frequency, Hz
- The number of secondary windings
- Rated burden for each secondary, VA
- Accuracy class for each secondary
- Required international standard

2. MATERIALS USED IN MAGNETIC CORES

There are different materials used as magnetic core, such as M4, M5, Mu-Metal, Super mu-metal and Nano-crystal [2]. Each material has its own B-H characteristic curves. Fig. 1 shows a sample magnetic core B-H characteristic curve.

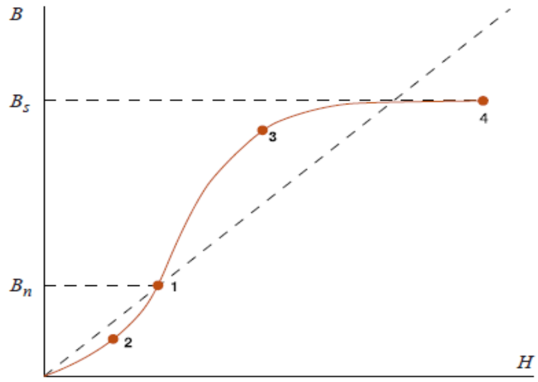

Fig. 1. B-H curve of a magnetic core

In Fig. 1 the point indicated by 3 is the point where magnetic core begins to saturate and the point indicated by 1 is the point where the magnetic core has entered the linear region. The secondary core will provide the desired current ratio between these two working points.

Table 1 and Fig. 2 show the working points (linear region) of the magnetic cores made from different materials, and the linear spacing in accordance with these points.

Table 1. Saturation Points of Core Materials

M4 & M5		Mu-metal		Super Mu-metal		Nano-crystal		MOH	
B	H	B	H	B	H	B	H	B	H
0,1	0,03	0,04	0,005	0,04	0,004	0,013	0,003	0,1	0,03
1,4	0,30	0,33	0,020	0,33	0,020	0,470	0,050	1,6	0,30

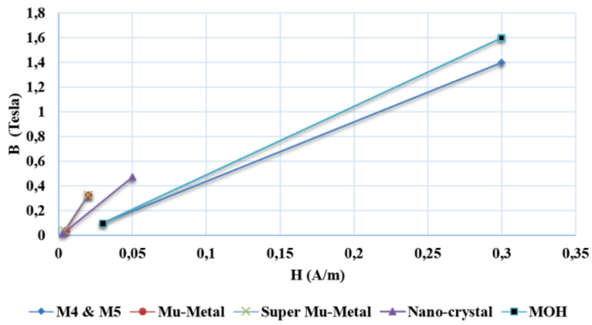

Fig. 2. B-H characteristics of core materials

As can be seen in the Fig. 2, the magnetic cores with the greatest linear ranges are the cores made of M5 & M4 and MOH. For this reason, these materials must be used in protection secondary [3]. The M4 & M5 core feature will be used for the calculation of core cross-section.

3. CORE CROSS-SECTION CALCULATION

The voltage to be induced between the ends of a conductor wound on the magnetic core is calculated by the following equations[4].

$$\phi = \int Bx\partial S \qquad (1)$$

$$\phi = BxA_C x\cos wt \; , w = 2\pi f \qquad (2)$$

$$E = -Nx\frac{\partial \phi}{\partial t} \qquad (3)$$

$$E = 2\pi fxNxBxA_C x\sin wt \qquad (4)$$

$$E_{\max} = 2\pi fxNxBxA_C \qquad (5)$$

$$E_{rms} = 4{,}44\, fxNxBxA_C \qquad (6)$$

$$A_C = \frac{E_{rms}}{4{,}44\, fxNxB} \qquad (7)$$

The core cross-section to be used in the secondary of the current transformer can be calculated using the equation (7). With this formula, the core cross section calculation can be explained more clearly through an example.

- Highest system voltage : 36 kV
- Frequency : 50 hZ
- Rated burdens and accuracy classes of secondaries: 0.5FS5 - 15VA , 5P10 - 30 VA
- Standard : IEC 61869-1/2
- Current ratio : 300 / 1-1 A
- Short circuit current and duration : 25 kA / 1s

All the technical specifications are given above in order to design the current transformer. The core cross-section can be calculated from this example.

3.1. Core Cross-Section Calculation for Protection Secondary

The load value of the example is 30VA and the protection secondary class is 5P10. Class 5P10 means that the current transforming ratio up to a minimum of 10 times the rated primary current (300 A) is achieved when an excessive current flows from the primary at any fault of the transformer [1], [5]. When a current of 10 times or more of the primary current passes, the magnetic core must saturate. This prevents high currents from passing through the secondary windings.

In normal operation;

$$|S| = |Z| x |I_S|^2 \quad (8)$$

$$30 = |Z| x |1^2| \quad (9)$$

$$|Z| = 30\Omega \quad (10)$$

When 10 times rated current flows from the primary, this current will also be reflected in the secondary section, so the secondary current will also increase from 1 A to 10 A. In this case;

$$|S| = |Z| x |I_S|^2 \quad (11)$$

$$|S| = 30x10^2| \quad (12)$$

$$|S| = 3000VA \quad (13)$$

The voltage at the moment of saturation of magnetic core is calculated by the following equation.

$$|E| = \frac{|S|}{|I_S|} \quad (14)$$

$$|E| = \frac{3000}{10} \quad (15)$$

$$|E| = 300V| \quad (16)$$

From equation 7;

$$A_C = \frac{E_{rms}}{4{,}44\, fxNxB} \quad (17)$$

$$A_C = \frac{300}{4{,}44x50x300x1{,}4} \quad (18)$$

$$A_C = 32{,}1cm^2 \quad (19)$$

B_{sat} is 1,4 Tesla for material M4 & M5 according to Fig. 2 and Table.

Saturation curve of a M4 & M5 magnetic core with 300 secondary turns and 32.1 cm^2 cross-section is given in Fig. 3. It can be seen that the magnetic core is saturated when the voltage rises above 300 V.

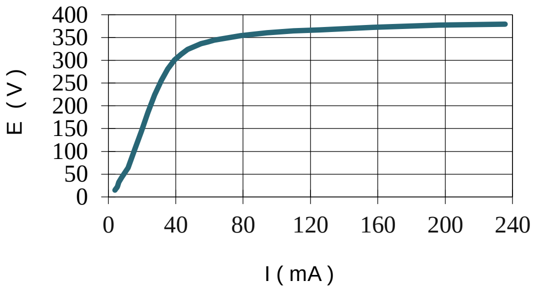

Fig. 3. Saturation curve of M4&M5 core with 300 turns

For the same example, if the design is made with 600 secondary turns;

$$A_C = \frac{300}{4{,}44x50x600x1{,}4} \quad (20)$$

$$A_C = 16cm^2 \quad (21)$$

Saturation curve of a M4&M5 magnetic core with 600 secondary turn and 16 cm^2 cross-section is given in Fig. 4. It can be seen that the magnetic core is saturated when the voltage rises above 300 V.

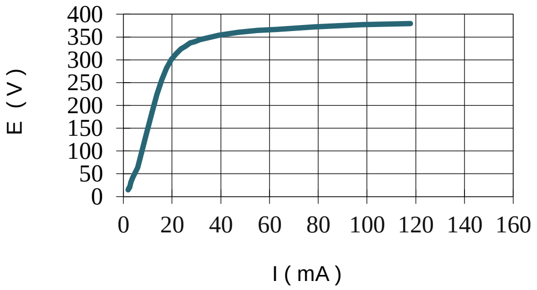

Fig. 4. Saturation curve of M4&M5 core with 600 turns

It can be seen that the same class (5P10) can be achieved by using a smaller core cross-section when the number of secondary turns is increased. In both cases, the magnetic core is saturated at 300 V. On the other hand, the leakage current flowing through the core with 300 turns is 40 mA but the leakage current flowing through the core with 600 turns is 20 mA. Here, when the number of secondary turns is increased, it can be deduced that the leakage currents flowing through the core can be reduced. Thus, the correctness of the values received from the secondary part will be more precise.

3.2. Core Cross-Section Calculation for Metering Secondary

The load value given in the example is 15 VA and the metering secondary class is 0.5FS5. The class 0.5FS5 means that the current conversion ratio (300/1) of the transformer is provided up to a maximum of 5 times of the rated primary current (300A) [1], [5]. In this case, the secondary core must be saturated before 5 times of the rated primer current is reached.

According to above equations (8)-(16), the voltage of the secondary at the point that 5 times of primary current can be found.

$$|E| = 15\Omega \qquad (22)$$

From equations (17)-(22) with 600 turns at secondary core;

$$A_C = 4cm^2 \quad \text{M4 \& M5} \qquad (23)$$

This value for the metering secondary is the maximum core cross-section value. This is because the metering class 0.5FS5 requires that the secondary magnetic core must saturate before 5 times of the rated primary current [1], [5]. Therefore, it is appropriate to use a value below this core cross-section calculated in the metering secondary. When a magnetic core of 3 cm^2 is used for this example, core saturation is observed at 60V under 75V saturation voltage calculated for secondary as seen at Fig. 5.

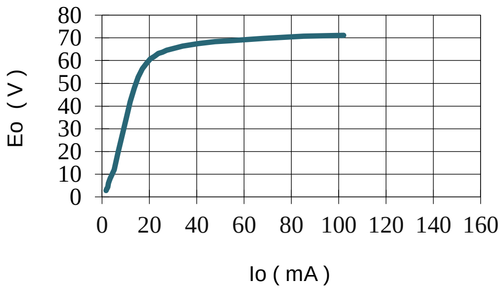

Fig. 5. Saturation curve of metering core

4. ACCURACY CLASS CURVES

Another important point for metering secondary is whether the computed core cross-section can provide the requested 0,5 class or not. The core cross-sections calculated in the above section are the core cross-sections calculated according to M4&M5 core and 600 secondary turns. When these values are entered into a core class calculation program, the following Fig. 6 is obtained.

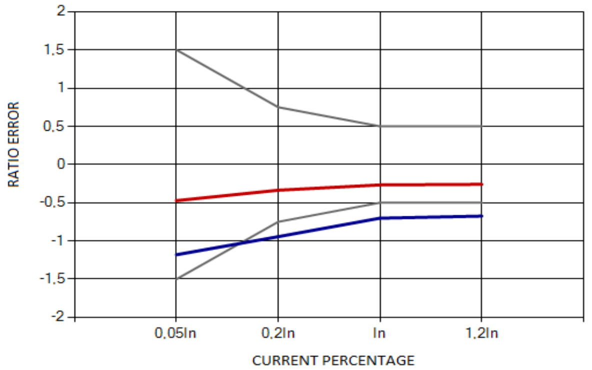

Fig. 6. Accuracy class curves of class 0.5FS5 with M4&M5 core and 600 secondary turns

According to IEC standards, the maximum ratio error for class 0,5 in the current transformer must be within the above gray range when full load and quarter load are connected. With M4 & M5 core, the difference between full load (blue line) and quarter load (red line) is less than 1 but quarter load curve is not exactly within the desired range.

In this case, one of the ways to put it in range is to use a core that works with less magnetic loss. Since the magnetic losses of Mu-metal and Super Mu-metal cores are less than the ones of M4&M5 cores, they can be used as the magnetic cores as replacements. When Mu-metal is used with the same cross-section, corresponding accuracy curves are given in Fig. 7.

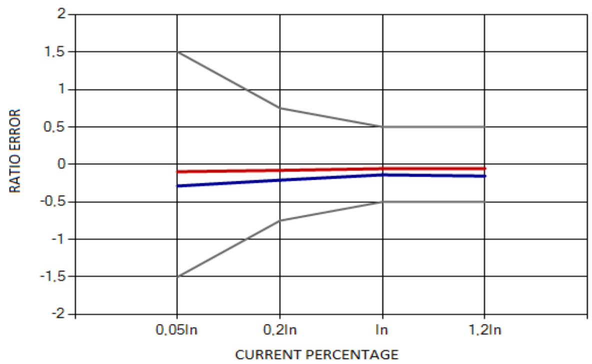

Fig . 7. Accuracy class curves of class 0.5FS5 with Mu-metal core and 600 secondary turns

Another method is to change the number of secondary turns without changing the core type used to put it in desired accuracy class. When 900 turns is wound instead of 600 turns to the secondary, the required core cross-section will be 2.67 mm^2 according to above equations (8)-(19). When a core is used with 900 secondary turns and 2.67 mm^2 cross-section, the accuracy class graph will be as shown in Fig. 8.

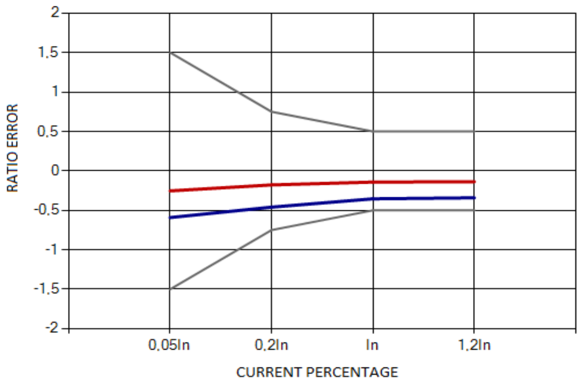

Fig. 8. Accuracy class curves of class 0.5FS5 with M4&M5 core and 900 secondary turns

In this case, the desired class can be provided by using a smaller cross-section core and having more secondary turns.

5. CONCLUSIONS

The minimum and maximum core cross sections to be used for the protection and measurement classes for the current transformer can be calculated by the same core cross-section calculation method. The number of turns in the secondary can be increased to reduce the cross-section of the core to be used. In this case, the cost of the transformer to be designed must be taken into account, without considering that the amount of copper wire to be used will increase.

In addition to that only magnetic core saturation point is important for protection secondary, the required class must also be provided at the metering secondary. If the calculated core does not satisfy the accuracy class, the class can be satisfied by changing the number of the secondary winding or the type of the core material.

Nomenclature

ϕ Magnetic flux (Wb)

B Magnetic flux density (T)

A_C Core cross-section (m^2)

N Number of secondary turns

f Frequency (Hz)

S Burden (VA)

I_S Secondary current (A)

Z Impedance (ohm)

E Secondary voltage (V)

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