



IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes

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IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes

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Introduction

This introduction is not part of IEEE Std C37.110-2023, IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes.

This guide was prepared by the Working Group I-15 on Application of Current Transformers for Relaying of the Relay Practices Subcommittee of the IEEE Power System Relaying and Control Committee. The guide is intended to assist relay engineers in understanding the operation of current transformers (CTs) and their selection and application to specific relay protection schemes. The guide was revised to include more comprehensive examples and treatment of the use of modern microprocessor-type relays to aid the relay engineer in the selection and application of CTs.

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1. Overview

1.1 Scope

This guide describes the characteristics and classification of current transformers (CTs) used for protective relaying. It also describes the conditions that cause the CT output to be distorted and the effects on relaying systems of this distortion. The selection and application of CTs for the more common protection schemes are also addressed.

1.2 Purpose

The purpose of this guide is to present a comprehensive treatment of the theory and application of CTs to assist the relay application engineer in the correct selection and application of CTs for protective relaying purposes.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{6,7}

⁶The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std C57.13™ - [2016](#) ~~1993~~, IEEE Standard Requirements for Instrument Transformers.^{8,9 2,3}

3. Definitions

For the purposes of this [document](#) ~~guide~~, the following terms and definitions apply. The ~~Authoritative~~ IEEE Standards Dictionary [Online of Terms \[B16\]](#)⁴ should be [consulted](#) ~~referenced~~ for terms not defined in this clause.¹⁰

~~3.1—accuracy: The extent to which the current in the secondary circuit reproduces the current in the primary circuit in the proportion stated by the marked ratio and represents the phase relationship of the primary current.~~

⁸ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<https://standards.ieee.org/> ~~<http://standards.ieee.org/>~~).

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¹⁰ IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

⁴ The numbers in brackets correspond to those of the bibliography in Annex E.

accuracy classes for relaying (instrument current transformer): Limits in terms of percent ratio error that have been established.

accuracy ratings for relaying: The relay accuracy class is described by a letter denoting whether the accuracy can be obtained by calculation or must be obtained by test, followed by the minimum secondary terminal voltage that the transformer will produce at 20 times rated secondary current with one of the standard burdens without exceeding the relay accuracy class limit. (This [ratio error at 20 times rated secondary current is typically considered](#) ~~usually taken~~ as $\pm 10\%$.)

burden (of a relay): Load impedance imposed by a relay on an input circuit expressed in ohms and phase angle at specified conditions.

NOTE—If burden is expressed in other terms such as voltamperes, additional parameters such as voltage, current, and phase angle must be specified.^{11 5}

burden on an instrument transformer: That property of the circuit connected to the secondary winding that determines the active and reactive power at the secondary terminals. The burden is expressed either as total ohms impedance together with the effective resistance and reactance components or as the total voltamperes and power factor at the specified values of frequency and current.

bushing-type current transformer: A current transformer (CT) that has an annular core with a secondary winding insulated from and permanently assembled on the core but has no primary winding or insulation for a primary winding. This type of CT is for use with a fully insulated conductor as a primary winding. A bushing-type CT is usually used in equipment where the primary conductor is a component part of other apparatus.

continuous thermal current rating factor (RF): The [number](#) ~~factor~~ by which the rated primary current of a current transformer is ~~can be~~ multiplied to obtain the maximum primary current that can be carried continuously without exceeding the limiting temperature rise from 30 °C ambient air temperature. [The RF of tapped-secondary or multiratio current transformers applies to the highest ratio, unless otherwise stated.](#)

^{11 5}Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

NOTE—When [current transformers](#) ~~CTs~~ are incorporated internally as parts of larger transformers or power circuit breakers, the equipment standards usually require that the [current transformers](#) ~~CTs~~ meet allowable average winding and hot-spot [temperature limits](#) ~~temperatures~~ under the specific conditions and requirements of the [larger apparatus](#) ~~specific equipment standard~~.

current transformer (CT): An instrument transformer that is intended to have its primary winding connected in series with the conductor carrying the current to be measured or controlled.-

NOTE— In window-type CTs, the primary winding is provided by the line conductor and is not an integral part of the transformer.

geomagnetic-induced currents (GICs): Spurious, quasi-direct currents flowing in grounded [systems](#) ~~system~~ due to a difference in the earth surface potential caused by geomagnetic storms resulting from the particle emission of solar flares erupting from the surface of the sun.

instrument transformer: A transformer that is intended to reproduce in its secondary circuit, in a definite and known proportion, the current or voltage of its primary circuit with the phase relations and waveforms substantially preserved.

knee-point voltage: (A) The point on the excitation curve where the tangent is at 45° to the abscissa. ~~This definition is for non-gapped CTs - when the excitation curve is shall be plotted on log-log paper with square decades. the CT has a gapped core, the knee point voltage is the point where the tangent to the curve makes an angle of 30° with the abscissa.~~ (B) That sinusoidal voltage of rated frequency applied to the secondary terminals of the transformer, all other windings being open circuited, which, when increased by 10% causes the exciting current to increase by 50%.

NOTE 1—See BS 3938-1973 [[B6](#) ~~B4~~].

NOTE 2—Other definitions of knee-point voltage are [also](#) used [in industry](#). Throughout this guide, definition ~~3.11~~ (A) is used, [except where otherwise noted](#).

NOTE 3—Knee-point voltage is not the same as saturation voltage. See also: [saturation voltage](#).

marked ratio: The ratio of the rated primary value to the rated secondary value as stated on the nameplate.

multi-ratio current transformer: One from which more than one ratio can be obtained by the use of taps on the secondary winding.

multiple-secondary current transformer: One that has two or more secondary coils each on a separate magnetic circuit with all magnetic circuits excited by the same primary winding.

polarity: The designation of the relative instantaneous directions of the currents entering the primary terminals and leaving the secondary terminals during most of each half cycle. Primary and secondary terminals are said to have the same polarity when, at a given instant during most of each half cycle, the current enters the identified, similarly marked primary lead and leaves the identified, similarly marked secondary terminal in the same direction, as though the two terminals formed a continuous circuit.

rated primary current: Current selected for the basis of performance specification.

rated secondary current: The rated current divided by the marked ratio.

remanence: The magnetic flux density that remains in a magnetic circuit after the removal of an applied magnetomotive force. *See also:* **residual flux density**.

NOTE—Remanence ~~is should~~ not ~~to~~ be confused with residual flux density. If the magnetic circuit has an air gap, the remanence will be less than the residual flux density.

residual flux density: The magnetic flux density at which the magnetizing force is zero when the material is in a symmetrically, cyclically, magnetized condition. *See also:* **remanence**.

~~3.20—saturation factor (K_s): The ratio of the saturation voltage of a current transformer to the excitation voltage. Saturation factor is an index of how close to saturation a current transformer is in a given application.~~

saturation voltage (V_s): The symmetrical voltage across the secondary winding of the current transformer for which the peak induction just exceeds the saturation flux density. It is found graphically by locating the intersection of the straight portions of the excitation curve on log-log axes.

NOTE—Saturation voltage is not the same as knee-point voltage, which is the point on the curve where the tangent to the curve makes an angle of 45° to the abscissa.

time-to-saturation: The time during which the secondary current is a faithful replica of the primary current.

NOTE—The core does not saturate suddenly. Beyond the saturation flux level, the exciting current increases more rapidly than the secondary current, causing distortion in the secondary waveform.

transactor: A magnetic device with an air-gapped core having an input winding that is energized with an alternating current and having an output winding that produces a voltage that is a function of the input current.

NOTE—The term “transactor” is a contraction of the words “transformer” and “reactor.”

turns ratio of a current transformer: The ratio of the secondary winding turns to the primary winding turns.

window-type current transformer: One that has a secondary winding insulated from and permanently assembled on the core, but has no primary winding as an integral part of the structure. Primary insulation is provided for a primary winding in the window through which one turn of the line conductor can be passed to provide the primary winding.

wound-type current transformer: A current transformer that has a primary winding consisting of one or more turns mechanically encircling the core or cores. The primary and secondary windings are insulated from each other and from the core(s) and are assembled as an integral structure.

4. Current transformer characteristics and classification

Faults on power systems cause transients in the system currents, which modify the steady-state behavior of CTs. Both steady-state and transient conditions, therefore, ~~need to~~ **must** be considered when examining the characteristics of CTs.

4.1 Current transformer equivalent circuit and phasor diagrams

4.1.1 Current transformer equivalent circuit

Figure 1 and Table 1 show a simplified equivalent circuit of a CT and its connected burden. The primary leakage impedance and the reactive part of the secondary leads do not substantially affect calculations and are, therefore, neglected.

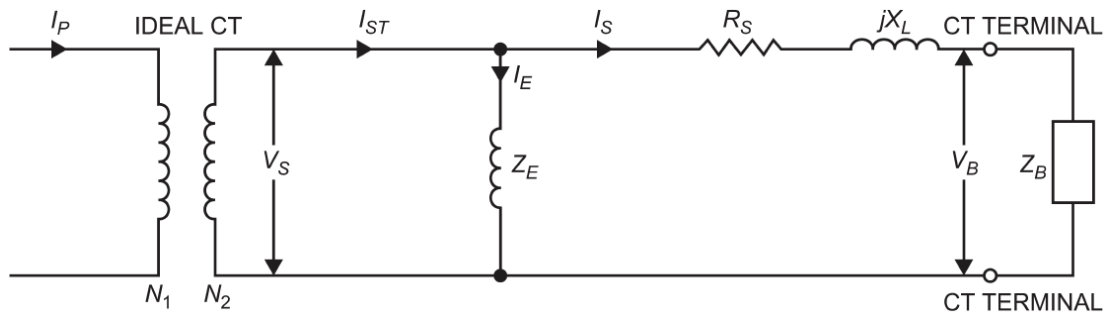


Figure 1—Simplified equivalent circuit of a CT and its connected burden

Table 1—Equivalent circuit of a CT

Symbols used in Figure 1			
V_S	Secondary exciting voltage	V_B	CT terminal voltage across external burden
I_P	Primary current	Z_E	Exciting impedance
I_{ST}	Total secondary current	R_S	Secondary resistance
I_S	Secondary load current	X_L	Leakage reactance (negligible in Class C CTs)
I_E	Excitation current		
N_2/N_1	CT turns ratio (equivalent to CTR)	Z_B	Burden impedance (includes secondary devices and leads)

(New)

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I_E	Excitation current		
N_2/N_1	CT turns ratio	Z_B	Burden impedance (includes secondary devices and leads)

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4.1.2 Phasor diagram of a current transformer with burden

To construct the phasor diagram for a CT, the procedure is as follows:

- Start with the secondary load current, I_S .
- Draw the secondary volt drops: $I_S \times R_S$ and $I_S \times jX_L$.

- c) Add V_B to the resultant voltage in order to obtain the internal secondary exciting voltage, V_s .
- d) ~~When V_s has been obtained,~~ Draw the flux phasor lagging V_s by 90° .
- e) The exciting current, I_E , is composed of the magnetizing current, I_M , which is needed to generate the flux in the CT core, and the loss current, I_{LOSS} , which is mainly due to the hysteresis and eddy current losses.
- f) Draw the magnetizing current, I_M , in quadrature with the voltage and the resistive loss current, I_{LOSS} , in phase with the secondary exciting voltage [see Equation (1) and Equation (2)].

$$I_M + I_{LOSS} = I_E \quad (1)$$

$$I_{ST} = I_S + I_E \quad (2)$$

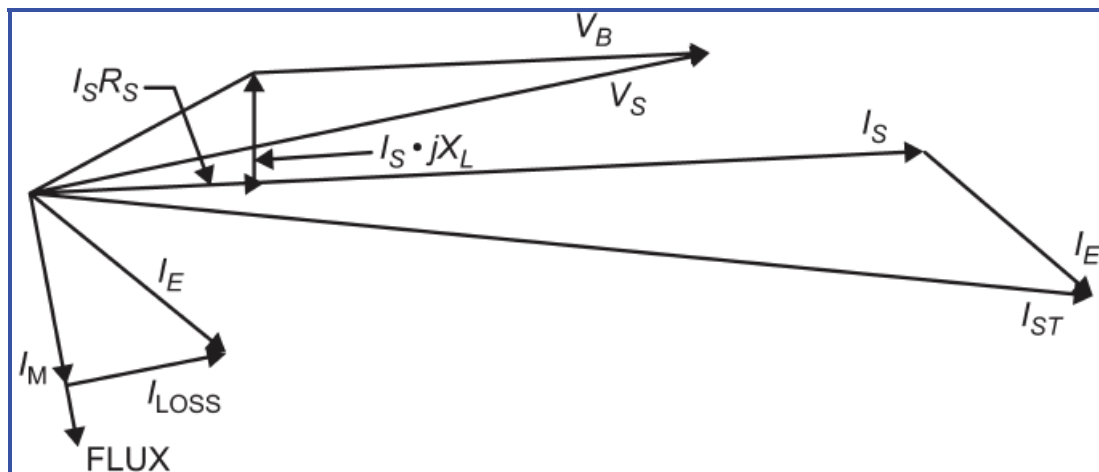
As shown in the following Equation (3), the primary current is then:

$$I_P = \left(\frac{N_2}{N_1} \right) (I_S + I_E) \quad (3)$$

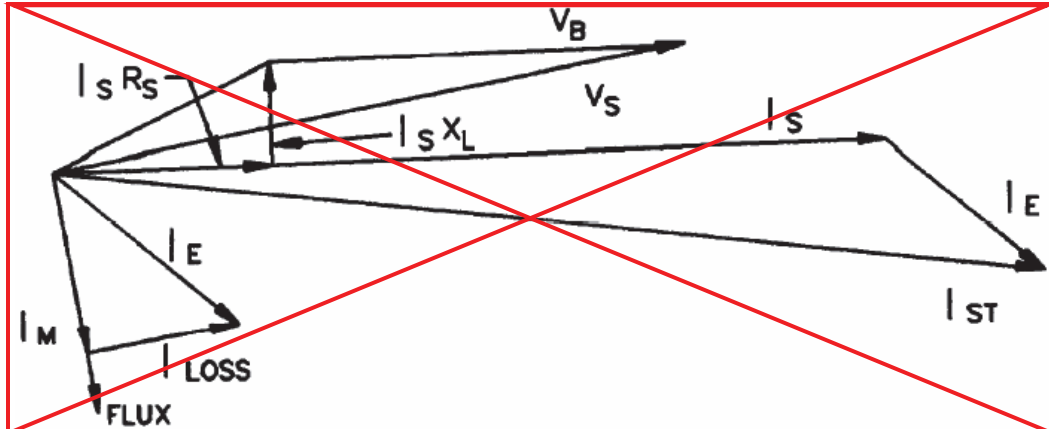
where

$\frac{N_2}{N_1}$ ~~N_2/N_1~~ is the CT turns ratio

Figure 2 and Figure 3 show the phasor diagrams for a resistive burden (power factor of 1.0) and a standard burden (power factor of 0.5), respectively.

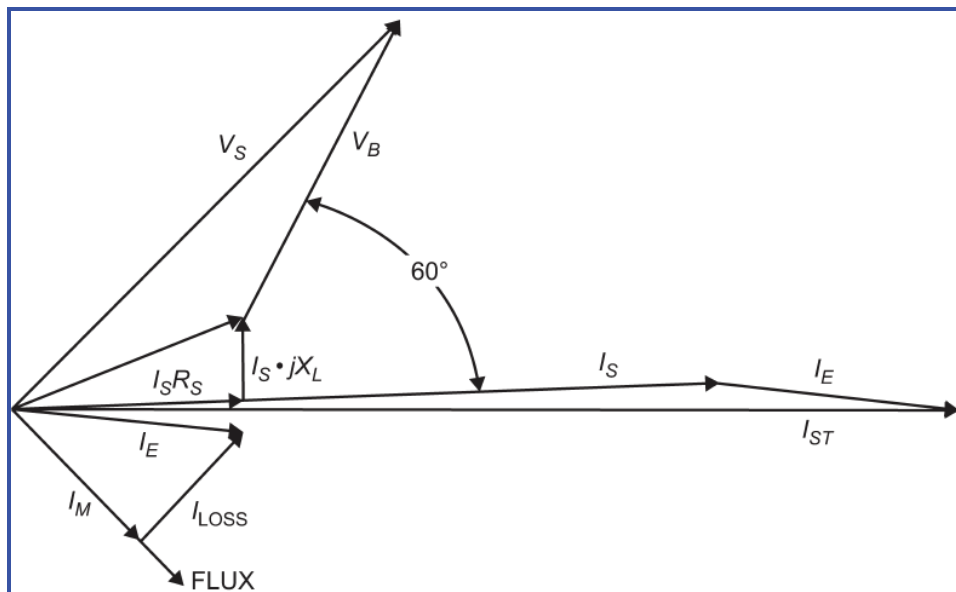


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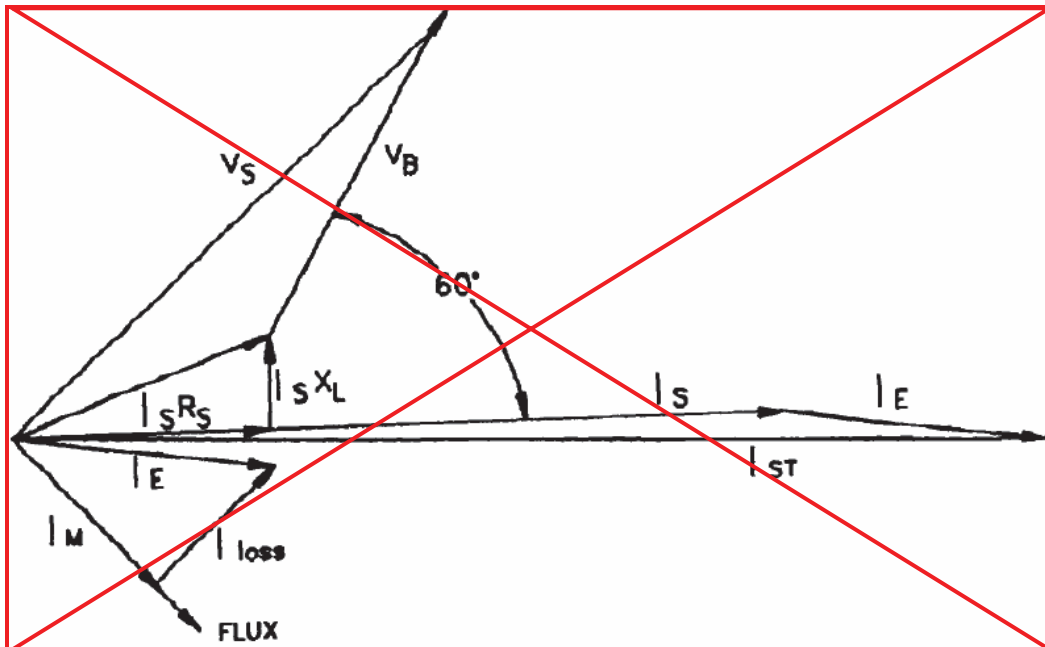


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Figure 2—Phasor diagram of a CT with a standard burden
(1.0 power factor)



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**Figure 3—Phasor diagram of a CT with a standard burden
(0.5 power factor)**

4.2 Current transformer secondary excitation characteristics

When the voltage developed across the CT burden is low, the exciting current is low. The ~~of the~~ secondary current waveform will contain no appreciable distortion. As the voltage across the CT secondary winding increases because either the current or the burden is increased, the flux in the CT core will also increase. Eventually the CT will operate in the region where there is a disproportionate increase in exciting current. The CT core is entering the magnetically saturated region; operation beyond this point will result in an increasing ratio error and a distorted secondary current waveform.

CT operation is illustrated by using excitation curves. These curves show the relationship of secondary exciting voltage (V_s) to the excitation current (I_E). A typical set of excitation curves for a C class CT is shown in Figure 4. Note that the curves are plotted on log-log [scale charts](#) ~~paper~~ and are developed from test data in the field and generated through calculations ~~by at~~ the [manufacturer](#) ~~factory~~. The primary winding must be open circuited for this test. Curve tolerances are stated in Figure 4. More specific information concerning construction of excitation curves is found in 6.10 and [8.2](#) ~~8.3~~ of IEEE Std C57.13-[2016](#) ~~1993~~.^{12 6}

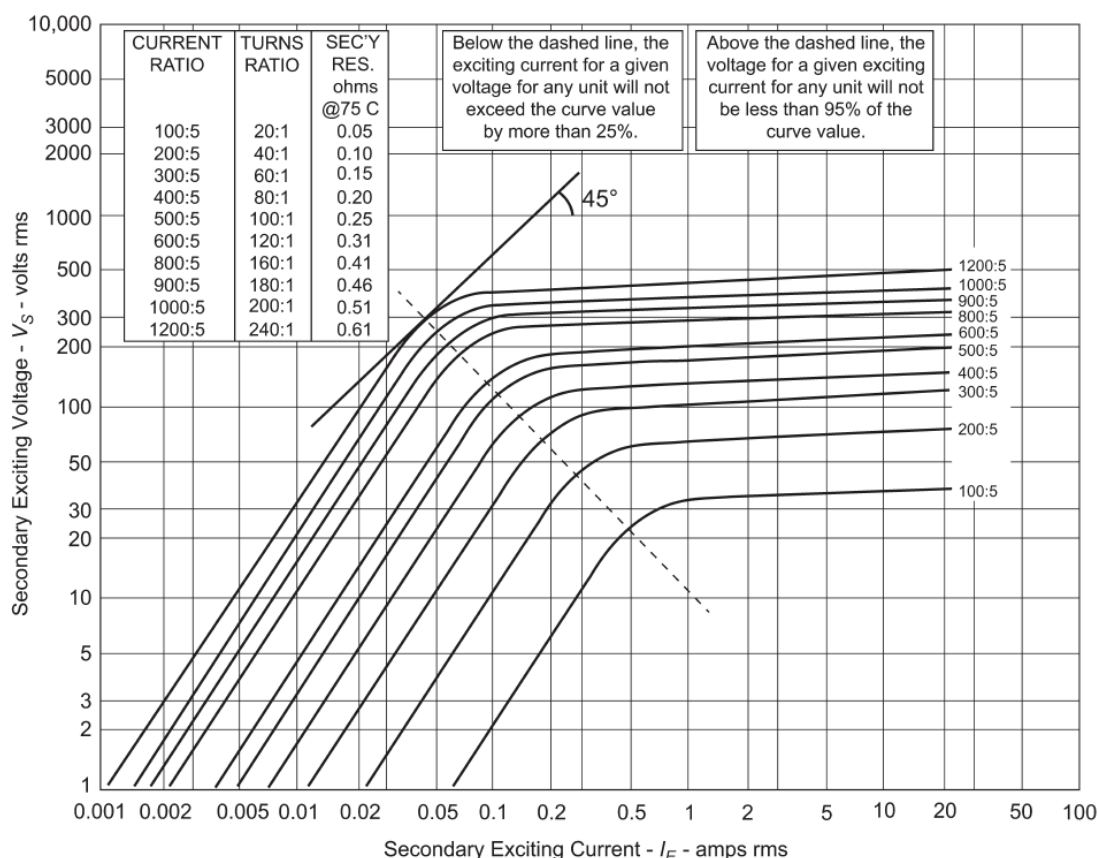


Figure 4—Typical excitation curves for multi-ratio C class CTs

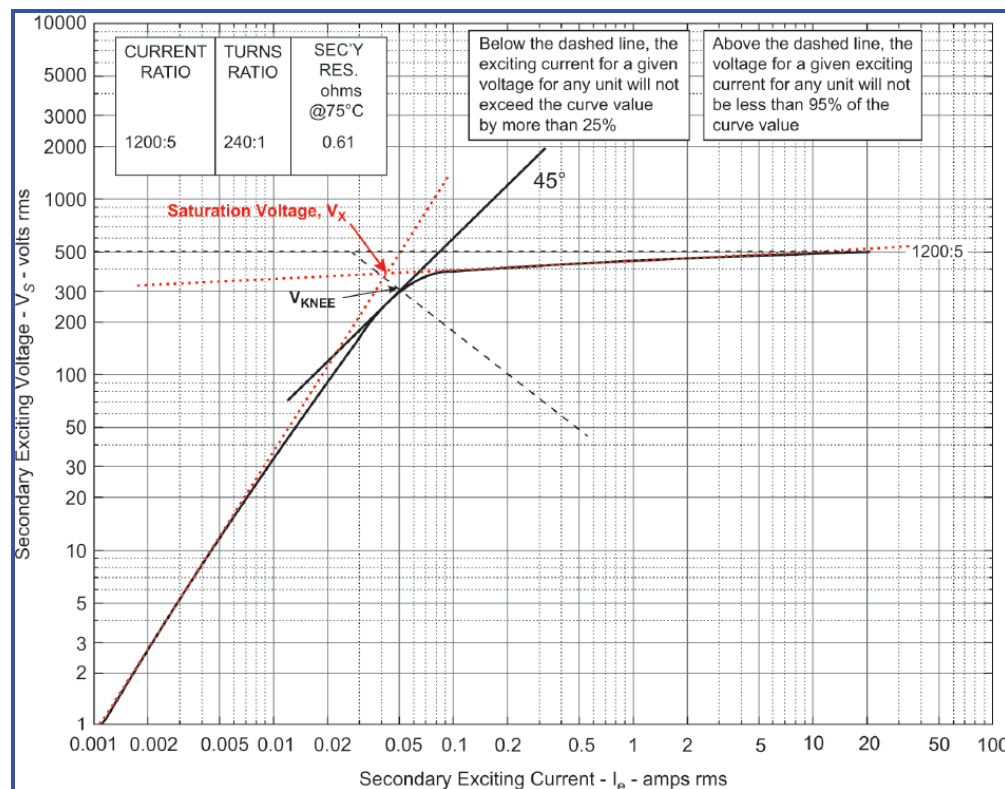
Note that in [the plot of](#) Figure 4, the vertical [and horizontal scales are adjusted](#) ~~scale should be increased~~ so that the log-log decades are square as defined in [the definition for knee-point voltage in Clause 3](#) ~~3.11~~.

^{12 6}Information on references can be found in Clause 2.

4.3 Knee-point voltage and saturation voltage

4.3.1 Saturation voltage

The saturation voltage (V_x) is ~~the that~~ symmetrical voltage across the secondary winding of the CT for which the peak induction just exceeds the saturation flux density (Blackburn [[B5 B3](#)]). It can be determined graphically by locating the intersection of the straight portions of the excitation curve on log-log axes.



(New)

Figure 5—Typical excitation curve for C class CT

4.3.2 Knee-point voltage

The knee-point voltage of a CT with a non-gapped core is the point of maximum permeability on the excitation curve, plotted on log-log axes with square decades, where the tangent to the curve makes a 45° angle with the abscissa. This is shown in Figure 5 4 and gives a knee-point for the 1200 : 5 A winding of about 300 V. ~~When the CT has a gapped core, the knee point voltage is the point where the tangent to the curve makes an angle of 30° with the abscissa.~~

Clause 3 of this guide lists two different definitions ~~3.11(A) and 3.11(B)~~, for the knee-point voltage. Definition ~~3.11~~ (A) is for Class C transformers and is the definition described in IEEE Std C57.13 - ~~1993~~. Definition ~~3.11~~ (B) is derived from BS 3938-1973 [~~B6~~ ~~B4~~] and is given also as an IEC definition for knee-point voltage. Both of these definitions appear in the IEEE *Standards Authoritative Dictionary of IEEE Standards Terms*. These two definitions do not give the same value for knee-point voltage.

The knee-point voltage per definition 3.11 (B) ~~defined~~ in Clause 3 is the ~~located at a~~ point on the curve where an increase in the secondary voltage of 10% causes an increase in current of 50%. On a square log-log plot, a tangent straight line through this point will have a slope as given by Equation (4):

The tangent rises 1 vertical decade for 4.25 horizontal decades making an angle of 13° with the abscissa. The voltage at this point is about 20% to 25% higher than the knee-point voltage per definition (A) in Clause 3 ~~3.11~~ .

Throughout this guide, definition (A) is used unless otherwise specified. Other definitions of the knee-point voltage are sometimes used in the industry and other publications. One relay manufacturer specifies it as the rms excitation voltage that produces a peak flux density of 1.5 T. Another manufacturer identifies it as the voltage that produces an excitation current equal to the secondary rated current. Be sure to understand what is meant by the knee-point voltage when reviewing other publications and selecting CTs for a particular design.

4.4 Current transformer accuracy

The ANSI CT relaying accuracy class is determined by a letter designation and a secondary terminal voltage rating. These effectively describe the steady-state performance (see 6.4.1 of IEEE Std C57.13-[2016](#) ~~1993~~). The secondary terminal voltage rating is the CT secondary voltage that the CT will deliver when it is connected to a standard secondary burden, at 20 times rated secondary current, without exceeding a 10% ratio error. Furthermore, the ratio correction must be limited to 10% at any current from 1 to 20 times rated secondary current at the standard burden or any lower standard burden. The given voltage rating applies to the full winding ratio only. However, if a tap is utilized on a multi-ratio CT, the voltage capability is directly proportional to the ratio between the tap value being used and the full winding capability provided the windings are fully distributed around the core. As an example, a C800 2000:5 CT tapped at 1000:5 has an effective accuracy class of C400 which may impact the possibility of CT saturation ~~This is usually the case with CTs made after 1978, but not necessarily with CTs made before that date.~~

For example, CT relaying accuracy class C100 means that the ratio error will not exceed 10% at any current from 1 to 20 times rated secondary current with a standard $1.0\ \Omega$ burden ($1.0\ \Omega \times 20 \times$ rated secondary current = 100 V). Almost all of the CTs used for protective relay applications are covered by the C or K classification. This includes bushing CTs with uniformly distributed windings and other CTs with minimal core leakage flux.

NOTE—IEEE standard C values and standard burdens are listed in Annex B.

The letter class codes are as follows:

C Indicates that the leakage flux is negligible and the excitation characteristic can be used directly to determine performance. The CT ratio error can thus be calculated. It is assumed that the burden and excitation currents are in phase and that the secondary winding is distributed uniformly. (See [9.1.12](#) ~~8.1.10~~ of IEEE Std C57.13- [2016](#) ~~1993~~ for further detail.)

T Indicates that ratio error must be determined by test. The T class CT has an appreciable core flux leakage effect and contributes to appreciable ratio error.

X User defined for a specific condition in which the minimum secondary excitation requirements are defined in IEEE Std C57.13-2016. Class X is generally a “catch all” class to allow designation of special ratings for specific applications in which the other classes of C and T are not specifically applicable.

K This is an old IEEE Std C57.13-1993 classification that is not currently listed. This class is the same as the C class, but the knee-point voltage must be at least 70% of the secondary terminal voltage rating. K classification requirements result in larger core cross sections than corresponding C class requirements.

H, L These classes are old ANSI classifications. There were two accuracy classes recognized: 2.5% and 10%. CTs were specified in the following manner: 10 L 200, 2.5 H 400, etc. The first number indicated the accuracy class and the last number indicated the secondary voltage class. L class CTs were rated at the specified burden and at 20 times normal current. H class CTs were rated at any combination of burden from 5 times to 20 times the normal current. These classes are applicable only to old CTs mostly manufactured before 1954.

4.4.1 Determination of the C or K classification using the excitation curve

Figure 1 shows the CT secondary winding, the secondary winding resistance (R_s) and a connected burden, (Z_B). I_E is the excitation current, and I_s is the secondary load current through the burden.

Set $I_E/I_s = 0.1$ to define a 10% error (I_E and I_s are assumed to be in phase). For the 1200:5 CT in Figure 4,

$$I_s = 100 \text{ A} \quad (20 \text{ times rated secondary current})$$

$$I_E = 10 \text{ A}$$

The secondary exciting voltage (V_s) for the full-ratio winding, corresponding to $I_E = 10 \text{ A}$ is obtained from the excitation curve. Figure 4 shows that with $I_E = 10 \text{ A}$, $V_s = 490 \text{ V}$. Although the standard burdens involve power factor, a quick arithmetic (worst ~~worse~~ case) calculation of the secondary terminal voltage (V_B) may determine the classification since the standard voltage values for 5 A secondary are 10 V, 20 V, 50 V, 100 V, 200 V, 400 V, or 800 V (see Annex B):

From Figure 1, see Equation (5) as follows:

$$V_B = V_S - (I_S \times R_S) \quad (5)$$

where

X_L is negligible

V_S is = 490 V

R_S is 0.61 Ω (from Figure 4)

$I_S \times R_S$ is = 100 A $\times$ 0.61 Ω = 61 V

V_B is = 490 – 61

V_B is = 429 V

By selecting the next lowest classification voltage, this CT is determined as having a C400 classification.

If the arithmetic calculation of V_B is marginal with respect to a standard classification voltage, a more exact check ~~may should~~ be done with a standard burden (Z_B) at 0.5 pf. For the CT shown in Figure 4 at a standard 4 Ω burden, see Equation (6) as follows:

~~$R_S = 0.61 \Omega$ (from Figure 4)~~

$$V_S = I_S \times (R_S + Z_B) \text{ (refer to Figure 1)} = 100 \times (0.61 + 2.0 + j3.464) = 261 + j346.4 = 434 \text{ V} \angle 53^\circ \quad (6)$$

Referring to Figure 4 for $V_S = 434$ V, I_E is approximately 2.0 A. The error (I_E/I_S) is about 2%, so the CT has a classification of C400 because at this secondary terminal voltage ($V_B = I_S \times Z_B = 400$ V) the error is <10%.

4.4.2 Examples of using the accuracy classification to assess steady-state current transformer performance

Example 1

A 1200 : 5, C400 CT with excitation curves (as shown on Figure 4) is connected to a 2.0 Ω burden (burden includes the connecting leads). Based on the accuracy classification, what is the maximum symmetrical fault current that may be applied to this CT without exceeding a 10% ratio error?

Answer

Based on the criteria that the CT can deliver 20 times rated secondary current without exceeding a 10% ratio error, the maximum primary fault current should not exceed ~~will be~~ 24 000 A when ~~However, the 2.0 Ω burden will produce a voltage below the knee point of the CT is applied and as a practical matter, will be within 10% accuracy~~ at the full tap ratio 1200:5 at rated burden. However, given that the rated burden for a C400 is 4.0 Ω and the example burden is only 2.0 Ω , there are values of secondary ~~higher~~ currents above 100 A for which the error is still less than 10%. This can only be accurately determined from excitation curves or ratio correction curves and not from the accuracy classification. For ~~CT with~~ the curve characteristics shown in Figure 4, a secondary current of 200 A (48 000 A primary) would result in a terminal voltage of 400 V and an exciting voltage of 522 V. The exciting current at 522 V is approximately 20 A, or a ~~will produce between 180 V to 240 V without exceeding the~~ 10% ~~ratio~~ error for ~~depending on the power factor of~~ the 200 A secondary current. Confirm that the excessive current is within the CT's rated short-time mechanical withstand capability as well as its rated short-time thermal capability.

Example 2

A 1200 : $\frac{1}{5}$, C400 CT is connected on the 1000 : $\frac{1}{5}$ tap. What is the maximum secondary burden that can be used and still maintain rated accuracy at 20 times rated symmetrical secondary current?

Answer

Because ~~Since~~ the secondary voltage capability is directly proportional to the connected tap, the CT will support a voltage of $(1000/1200) \times 400$ V or 333 V. Twenty times rated secondary current is 100 A. Therefore, the maximum burden is 333 V/100 A or 3.33 Ω .

4.4.3 Determination of percent error and ANSI voltage classification for T class current transformers using overcurrent ratio curves

For T class CTs, the secondary leakage reactance is not negligible. For this reason, IEEE Std C57.13-2016 ~~1993~~ requires manufacturers to provide overcurrent ratio curves for these CTs on rectangular coordinate paper plotted in terms of primary versus secondary current from 1 to 22 times rated primary current for all standard burdens up to the burden that causes a ratio correction of 50%.

The percent error of a T class CT can easily be computed from an overcurrent ratio curve for any standard burden and a known primary current using the following relationship in Equation (7):

$$\% \text{ error} = \left[\left(\frac{\text{Multiples of Rated Primary Current}}{\text{Multiples of Rated Secondary Current}} \right) - 1 \right] \times 100 \quad (7)$$

Example 1

In Figure 6 5, find the percent error of a T class CT with a 4 Ω standard burden carrying 17 times rated primary amperes. When “times rated primary current” = 17, then “times rated secondary current” = 13 at the intersection of 17 with the 4 Ω curve.

Answer

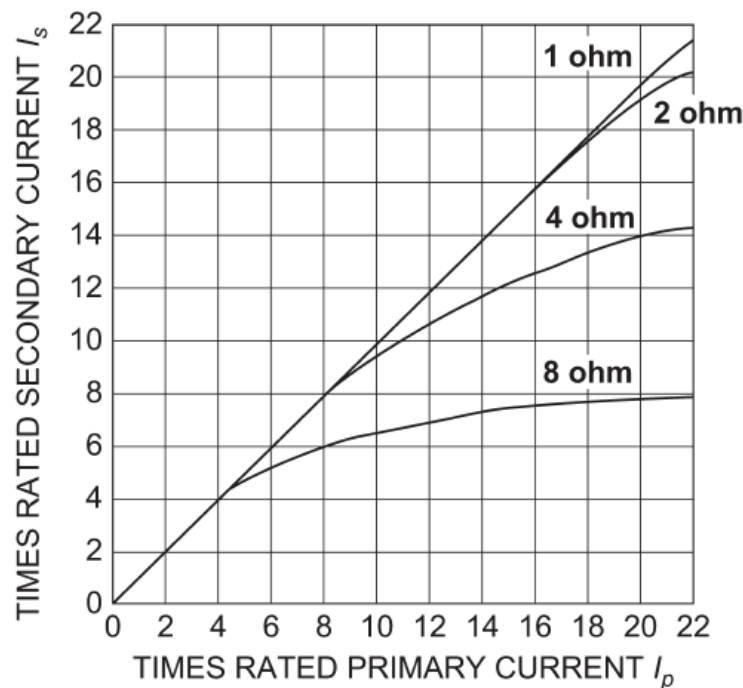
$$\% \text{ error} = \left(\frac{17}{13} - 1 \right) \times 100 = 30.77\%$$

(New)

$$\therefore \% \text{ error} = \left(\frac{17}{13} - 1 \right) \times 100\% = 30.77\%$$

(Deleted)

Figure 6 5 – A typical overcurrent ratio curve for a T class CT



The ANSI voltage accuracy rating can also be determined from a T class overcurrent ratio curve. By trial and error, find the ratio of “times rated primary current” to 20 times rated secondary current starting with the lower standard burden and incrementing to the next higher burden until the percent error calculated exceeds 10%. The burden with the percent error no greater than 10% is the one with which to classify the ANSI accuracy voltage rating.

Example 2

In Figure 6 5, find the ANSI accuracy voltage rating of this 5 A rated T class CT.

Answer

Assume 2 Ω standard burden. When $I_s = 20 \times$ rated secondary current, then $I_p = 22 \times$ rated primary current

$$\% \text{ error} = \left(\frac{22}{20} - 1 \right) \times 100 = 10\%$$

Voltage rating = $20 \times 5 \times 2 = 200$ V.

Therefore, the CT can also be classified as a T200 where the 10% error is implied.

All higher burdens will exceed 10% error. Therefore, the ANSI classification is not applicable in this case for the 4 Ω and 8 Ω burdens.

4.5 Dynamic characteristics

4.5.1 Flux change with asymmetrical primary current

The dc component of an asymmetrical current greatly increases the flux in the CT. When the dc offset is at a maximum, the CT flux can potentially increase to $1 + X/R$ times the flux resulting from the sinusoidal, or non-offset component, where X and R are the primary system reactance and resistance to the point of the fault (IEEE Power Engineering Society [B20 B19]).

The difference between the non-offset and offset flux is illustrated in Figure 7 6 and Figure 8. In Figure 7 6, there is remanent flux but no offset in the primary current. The CT core does not go into the saturated region of operation so the secondary current is undistorted. Figure 8 7 shows the resulting flux and secondary current when the primary current is fully offset. The increase in flux is not instantaneous, indicating that saturation does not occur instantaneously but takes time. This time is called the time-to-saturation.

The secondary current delivered by a CT to a relay circuit is always less than the current available from an ideal CT. The ideal, or ratio current ($I_{ST} = \frac{I_P}{CTR}$ I_P/RCT), is reduced by the excitation current (I_E) to yield the actual current (I_S). This relationship is illustrated in the CT equivalent circuit shown in Figure 2.8.

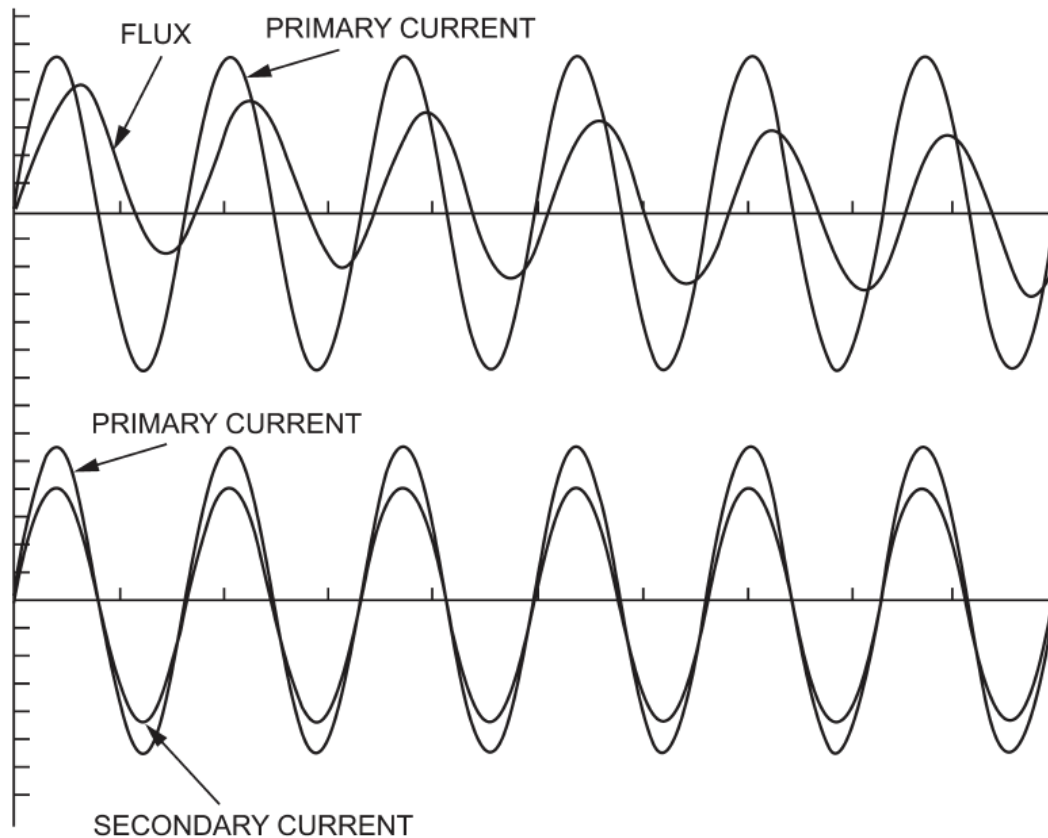


Figure 7.6 — Non-saturated CT: Relationship between primary current and flux and between primary current and secondary current

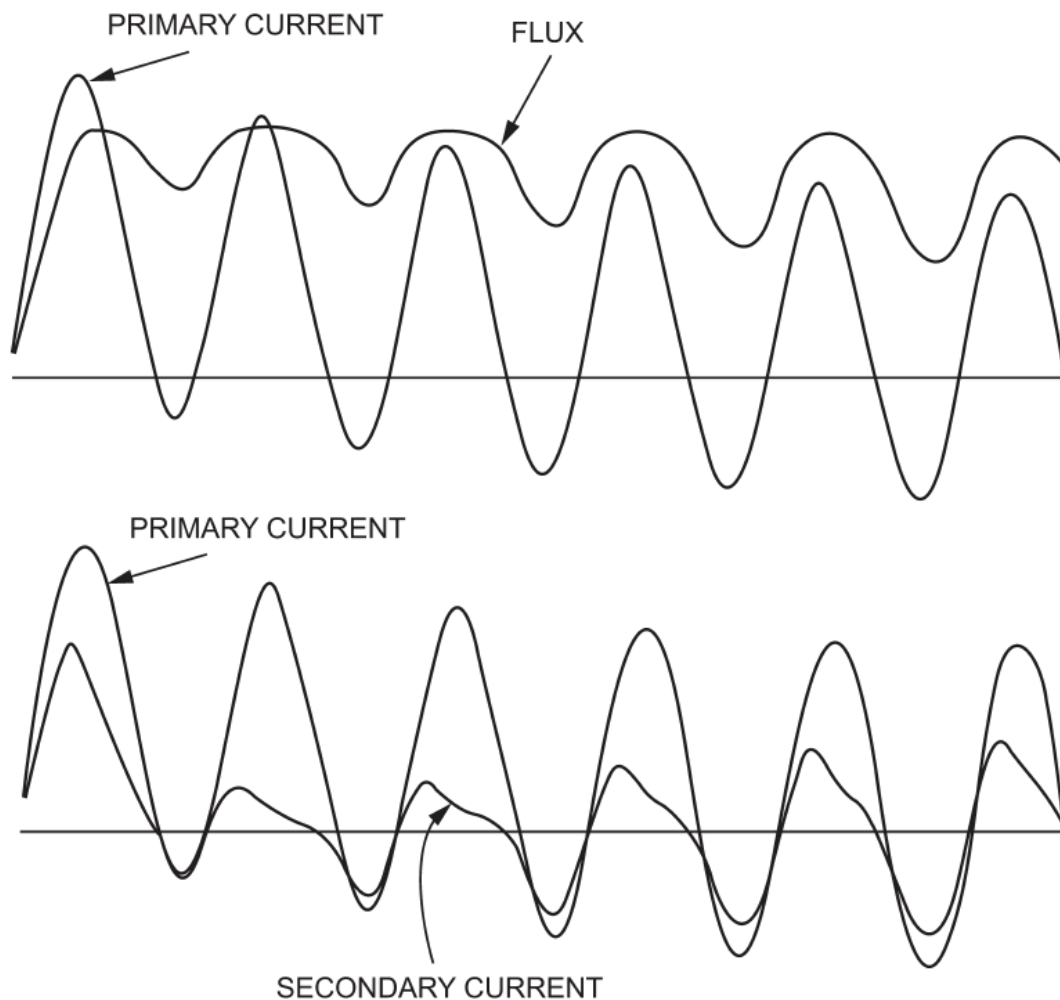
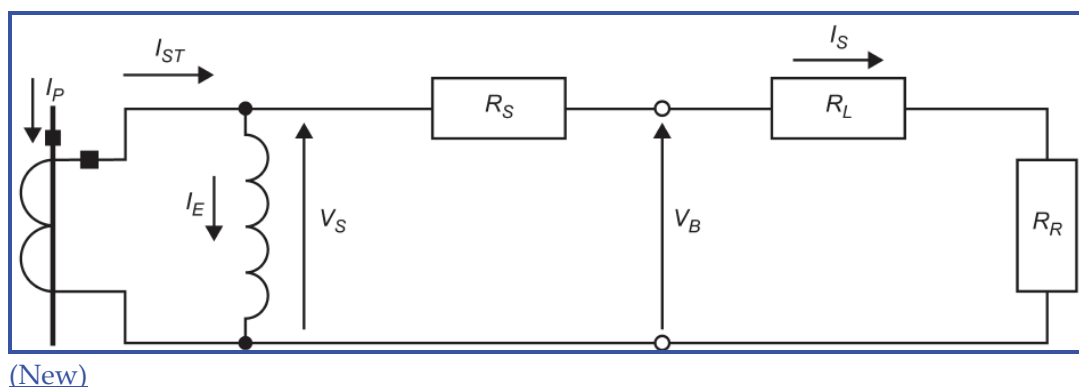
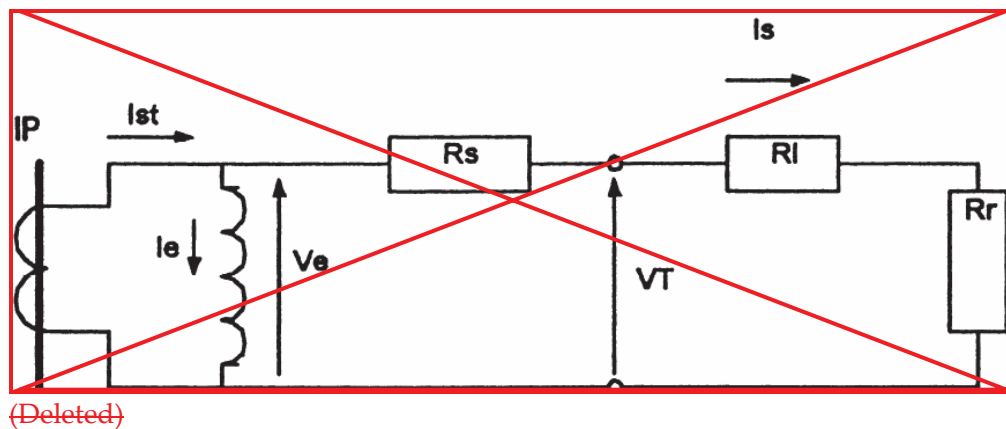


Figure 8.7 — Saturated CT: Relationship between primary current and flux and between primary current and secondary current



(New)



4.5.2.1.1 Saturation ratio ~~factor~~ determined from the ANSI C classification

~~In Figure 9,~~ The CT terminal voltage increases linearly with the secondary current according to ~~along~~ $V = Z_B \times I$ ~~line~~, where Z_B is the total CT burden (leads plus relays for a particular fault and connection). The maximum fault current corresponds ~~a~~ to the maximum terminal voltage, V_T , which, ~~if saturation is to be avoided, needs to be~~ This voltage is lower than the maximum voltage (V_C) that ~~the this C200~~ CT can support. Saturation under steady-state conditions will occur (i.e., ratio error will exceed 10%) for ~~secondary currents in excess of I_F , where the corresponding~~ terminal voltages ~~that exceed~~ degree of saturation with the saturation factor voltage crosses the accuracy class limit, V_C ~~(point C in Figure 9). We can define~~. A measure of the degree of saturation can be defined with the saturation ratio ~~factor~~ as follows in Equation (8):

$$S_R = \frac{V_T}{V_C} \quad (8)$$

(New)

~~$$SF = \frac{I_F}{I_F} \quad (8)$$~~

~~(Deleted)~~

~~By examination of triangles OAB and OCD, the same saturation factor can be expressed as follows in Equation (9):~~

~~$$SF = \frac{V_T}{V_C} \quad (9)$$~~

~~(Deleted)~~

where

V_T is the secondary terminal voltage

V_C is the maximum terminal voltage the CT can support based on the ANSI C classification ~~(e.g., for C200 CT, V_C is 200 V) with an excitation current of 10 A and secondary current of 100 A~~

This first determination of the saturation ratio relates the CT terminal voltage to the accuracy class of the CT (effective class in case of multi-ratio CTs). It is easy to calculate and practical since it requires only readily available data. ~~An application is considered reasonably secure when $SF < 0.5$.~~

4.5.2.1.2 Saturation ratio ~~factor~~ determined from the CT excitation curve

Instead of comparing the terminal voltage to the CT classification voltage, the saturation ratio (SR') can be determined using ~~factor given in~~ Equation (9) This method compares ~~is the most conservative because it assumes~~ the ~~worst-case ratio error. It corresponds to an~~ excitation voltage to the voltage on a curve passing through point R Q in Figure 10 9 at which the excitation current is 10 A (the maximum error allowed by the accuracy class definition). ~~The $R_s \times 100$ term represents the voltage drop across the CT internal resistance. A new saturation factor can be determined on the excitation curve, as follows in Equation (10):~~

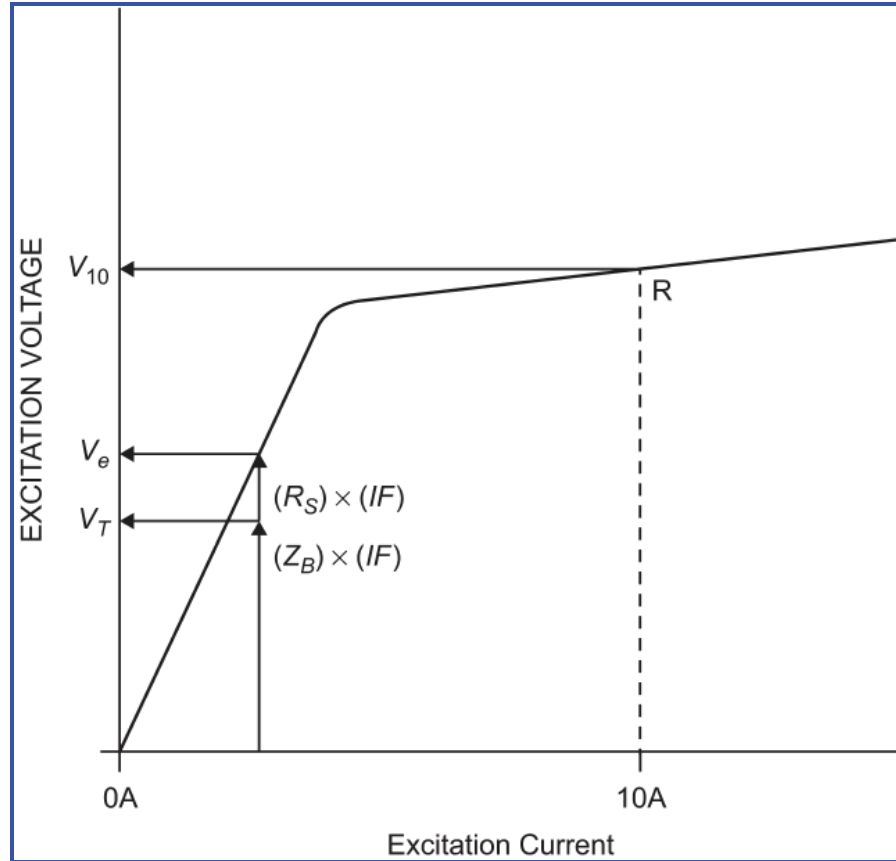
$$SR' = \frac{V_E}{V_{10}} \quad (9)$$

(New)

$$SF' = \frac{V_e}{V_{10}} \quad (10)$$

~~(Deleted)~~

Where V_E is the internal excitation voltage ($V_T + R_s \times I_F$) at the maximum fault current I_F and V_{10} is the voltage of the curve passing through point R Q where the exciting current is 10 A the (maximum error allowed by the accuracy class definition) ~~This voltage is practically close to the knee voltage, $V_{K'}$, which would yield nearly the same (slightly more conservative) result.~~



(New)

Figure 10 9 – CT performance graphical representation

4.5.2.2 Knee-point method

~~Since in all likelihood the excitation voltage capability of the CT will be higher (passing through point R in Figure 9 for instance) the saturation factor defined on the excitation curve appears to be lower, i.e., more favorable. A detailed analysis can be performed to compare the two factor definitions.~~

Saturation factor definitions compared

~~Using the equivalent circuit in Figure 8 and the ANSI accuracy class definition that the CT must be able to source 20 times nominal current into a standard burden Z_e , we now develop a comparative analysis between the two definitions, as follows in Equation (11) through Equation (14):~~

$$SF = \frac{VT}{VC} \quad (11)$$

$$SF' = \frac{V_e}{V_{10'}} \quad (12)$$

$$SF = \frac{Z_B \times I_F}{100 \times Z_c} \quad (13)$$

$$SF' = \frac{I_F \times (Z_B + R_s)}{100 \times (Z_c + R_s)} \quad (14)$$

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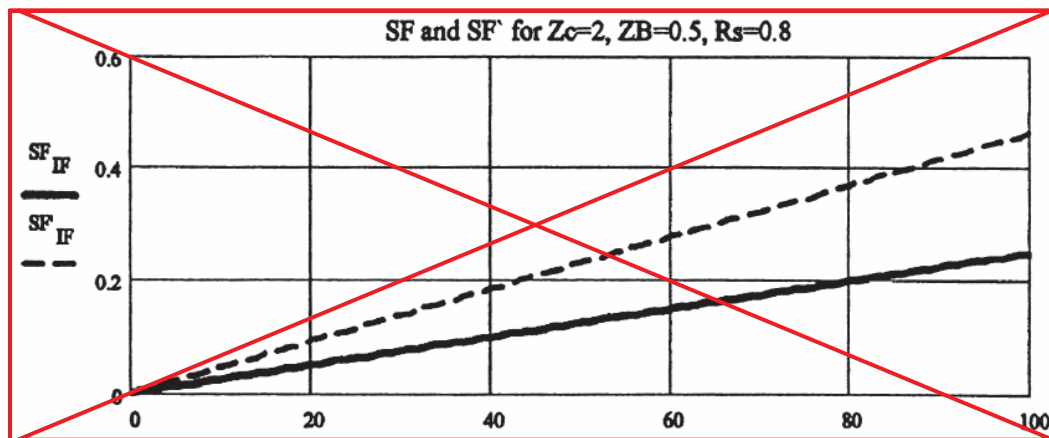
To compare the two expressions, we take the ratio SF'/SF , which follows in Equation (15):

$$\frac{SF'}{SF} = \frac{Z_c}{Z_B} \times \frac{(Z_B + R_s)}{Z_c + R_s} \quad (15)$$

(Deleted)

This expression varies with the ratio of the actual relay circuit burden, Z_B , to the accuracy class burden, Z_c , and the CT internal resistance, R_s .

The absolute values of SF and SF' are compared in Figure 10 for the particular case, where $Z_c = 2$, $Z_B = 0.5$, and $R_s = 0.8$ when I_F varies from 0 A to 100 A.



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Figure 10 SF and SF' for $Z_c = 2$, $Z_B = 0.5$, and $R_s = 0.8 \Omega$

The graph in Figure 11 illustrates how a lower R_s value reduces the difference between SF and SF' .