IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

# International Journal of Advanced Research

## in Electrical, Electronics and Instrumentation Engineering

Volume 9, Issue 9, September 2020

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.122

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

|| Volume 9, Issue 9, September 2020 ||

# Differences & Similarities in IEC and IEEE Standards for Current Transformers (Part-I)

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**ABSTRACT**:It is generally desirable that current replica on the secondary sides of the current transformers stays within acceptable tolerances for the metering and protective devices connected to CT secondary function as per the design intent. The IEC and IEEE standards for instrument Transformers developed independently, therefore we find many similarities and differences in both the standards. The metering devices and protection relays used internationally are the same; however the current transformers are specified differently according to the standards prevailing in the region or country. The intention of this paper is to bring out these differences and similarities in Current Transformers that will provide more clarity to design engineers, particularly engineers responsible for dimensioning CT for any application. This paper is the first part of the two part series and discusses mainly on similarities and differences in specifying Current transformers to IEC – 61869 and IEEE C57.13. The second part of the series will have CT dimensioning with sample calculation for typical application and discussion on the same.

**KEYWORDS:**Current Transformer, Accuracy class, Protection Devices, Instrument Transformer, knee point voltage, CT Dimensioning.

## I.INTRODUCTION

The IEEE and IEC standards developed independently and therefore the resulting standards are quite different. However the fundamental physics underlying current transformer remains the same. The objective of this paper is to discuss on similarities and differences between IEEE and IEC standards to bring in more clarity to the design engineers responsible for dimensioning and specifying current transformer for different application complying with specified standards.

The primary purpose of CT as we know is to translate the primary current in a high voltage power circuit to a lower signal level that can easily be handled by protective and indicative instruments and devices. In addition it provides isolation between the secondary circuit and the primary circuit. The application, characteristics of measuring & protective devices connected in the secondary circuit is so varied that proper CT selection and specification is very critical in power systems. While this paper makes an attempt to present the basics to understand the behaviour and application of CT, the paper also highlights the differences and similarities in IEEE and IEC standards.

## II.CURRENT TRANSFORMER BASIC CHARACTERISTICS & DIFFERENCES IN BOTH IEC & IEEE DEFINITIONs

The current Transformer function like ears & eyes for protection, monitoring & control systems, they listen to all that is happening in the electrical systems, transfer the signals to the controlling devices/relays & the relay which is the brain that processes the signals & issue decisions to the interrupters. Therefore the quality of relaying decision depends on the faithful production on secondary side of the CT.

A CT is an electromagnetic device, has a laminated magnetic core, a secondary winding around the core (number of turns depending on CT ratio, current scaling) and insulating material, in wound primary CT, a primary winding also exist.

The CT is connected/placed in such a way that primary winding of the CT is wired in series with the power circuit, the current of which is to be measured. The CT primary impedance has negligible effect on the circuit current, Therefore it can be considered as a current source.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

|| Volume 9, Issue 9, September 2020 ||

The equivalent circuit is shown in Fig:01.

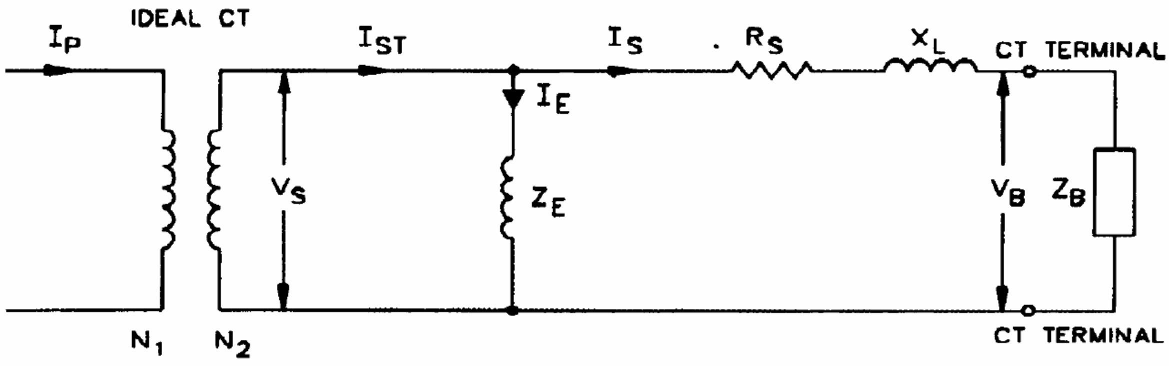


Fig:01

Where,

$I_P$ = Primary Current
$I_S$ = Secondary Load Current
$I_E$ = Excitation Current
$I_{ST}$ = Total Secondary current
$N_1$ = Primary Turn
$N_2$ = Secondary Turn
$R_S$ = Secondary Resistance
$X_L$ = Leakage Reactance
$Z_E$ = Exciting Impedance
$Z_B$ = Burden Impedance
$V_S$ = Exciting Voltage, Secondary
$V_B$ = CT Terminal Voltage (Burden)

The excitation current IE flows in the primary winding only, and is the reasons for error. Therefore designer look at using high grade core material that can produce the required magnetic flux with lower mmf, thereby lower excitation current.

Some of the differences in the definition covered in the two standards are brought under.

The first one is about selection of CT secondary current. Traditionally IEEE standard is based on 5 A secondary. However the standard values of rated secondary current in IEC 61869-2 is 1A and 5A. Technically CT designed with 1A secondary offer advantage when lead resistance (burden) tends to dominate over the relay burden. The lower ampere tends to use thinner lead, smaller CT core and the transient performance improves. That is why IEC 61869-2 also has standardized 1 A secondary for TPX, TPY & TPZ class of CT. The advantage of 5A secondary is obviously lower cost& size due to lower turn ratio.

The second aspect of differences is about the burden. IEEE defines standard burden with resistance and inductance for metering at 0.9 power factor (0.1/0.2/0.5/0.9/1.8 ohms impedances) and for protection burdens with resistance and inductances with power factor of 0.5 (1.0/2.0/4.0/8.0 ohms impedances). While IEC-61869-2 defines standard rated output for metering CT and "P" class CT in terms of VA (2.5/5/10/15/30 VA) while for TPX, TPY & TPZ rated resistive burden is standardized (0.5/1/2/5 ohms).
The burden expressed in VA can be converted to ohms (impendence) by dividing the VA by Current Square.

The third aspect of differences is about the definition of knee point voltage. The knee point voltage as defined in IEEE is for non-gapped core CTs, the point on excitation curve where the tangent is at 45 degree to the abscissa. For gapped core it is 30 degree to the abscissa, whereas IEC-61869-2 defines knee point voltage as "rms voltage at rated frequency applied at the secondary terminal of the transformer while all other terminal open circuited, increase in 10% voltage cause excitation current increase to 50%". The IEEE definition of knee point voltage is very conservative; it is about 20 to 25% lower voltage than that is defined in IEC.

## III.SPECIFYING METERING CLASS CTs & DIFFERENCES IN BOTH IEC & IEEE

The metering Current Transformer is designed to have linear response generally from 5% to 125% of rated current. The accuracy class of the CT is expressed as the percentage error for a known burden, current & power factor.

IEEE C57.13 defines the standard burden of CT with 5 Amp secondary. The standard percent accuracies are 0.3, 0.6 and 1.2 and the standard metering burdens are 0.1, 0.2, 0.5, 0.9, 1.8 ohms at 60 Hz 0.9 pf lagging. For Tariff metering, IEEE also classifies accuracy class 0.15 & 0.15S in a supplement of IEEE C57.13, the range of current for which the accuracy is specified are 5% and 100% of rated current at a specified burden.
In IEC 61869-2, the accuracy class for metering CT is defined as 0.1, 0.2, 0.5 and 1.0. The standard has defined maximum allowable error for current from 5% to 120% and burden 25% 100% of rated output at pf of 0.8. Additionally IEC also has specified two accurate class tariff metering CT class 0.2S and 0.5S for which maximum allowable error is defined from 1% to 120% of rated current with burden within 25% to 100% of the rated output. For class 3 & 5 the ratio error limit is specified in the standard for 50% & 100% load current.

Well it can be seen that IEC provides a higher range of accuracy class compared to IEEE. The major difference that can be noticed is for instrument security factor specified in IEC. Instrument Security Factor is the ratio of rated instrument limit current to the rated primary current. This is primarily to prevent any damage to the indicating instruments that has limited over current withstand. It must be noted that instrument security factor is affected by the burden on the CT, when the burden is lower, CT secondary current would be larger. Therefore safety of the instrument is highest for lower instrument security factor. Whereas IEEE does not specific any limiting instrument security factor, For a 5A CT, 100Amp will flow in the secondary circuit at rated burden and the instrument connected must be selected to withstand the over current. Therefore should there be any instrument with lower current withstand, the design engineer has to use an auxiliary CT and size in such a way that the auxiliary CT gets saturated when the primary current exceed the instrument limit.

## IV.SPECIFYING PROTECTION CLASS CTs & DIFFERENCES IN BOTH IEC & IEEE

The characteristics of protection class CT is that it maintains magnetizing impedance in the range of fault current it is designed for, it is designed to have linear response up to 20 times rated primary current at rated burden. Its performance has to be accurate (within the specified range) in normal rated current as well as fault current.

IEEE C57.13 defines two fundamental relaying classes, “C” classes: indicates the transformer performance can be calculated, standard exciting curve can be used. It’s because the effect of leakage flux, the leakage reactance are negligible. This happens due to the construction where the primary is either bar primary, window type while the secondary winding is fully distributed.

“T” classes: indicates the transformer performance must be determined by tests, standardized performance curves cannot be used. It’s because due to its construction, it is associated with high leakage flux that affects the accuracy, the construction generally wound type CTs having multiple primary turn, generally becomes a requirement for low turns ratio CT.

“K” class CT also is classified in IEEE C57.13, it is same as class “C” but the knee point voltage must be at least 70% of the secondary terminal voltage, resulting in comparatively large cross section. This is designed for circulating current differential protection, particularly high impendence type.

The most common of the three above is class “C”. The designation “C” is followed by a number, which is the secondary terminal voltage that the CT will support while within the maximum allowable error limit of 10% at 20 times rated primary current, the secondary terminal voltage classes have a direct link to the allowable secondary circuit burden. IEEE C57.13 relaying accuracy class and burden data is as furnished under in the Table:01.

Table:01

| Secondary Terminal Voltage | Burden | Resistance (Ohms) | Inductance (Ohms) | Impendence (Ohms) | Total Power (VA @5A) |
|---|---|---|---|---|---|
| 10 | B-0.1 | 0.09 | 0.116 | 0.1 | 2.5 |
| 20 | B-0.2 | 0.18 | 0.232 | 0.2 | 5.0 |
| 50 | B-0.5 | 0.45 | 0.580 | 0.5 | 12.5 |
| 100 | B-1.0 | 0.50 | 2.30 | 1.0 | 25.0 |
| 200 | B-2.0 | 1.00 | 4.60 | 2.0 | 50.0 |
| 400 | B-4.0 | 2.00 | 9.20 | 4.0 | 100.0 |
| 800 | B-8.0 | 4.00 | 18.40 | 8.0 | 200.0 |

The relaying accuracy of “C” class CT is determined from the CT excitation curve.

Here is an example of CT accuracy verification. Consider a CT with ratio of 1200:5 A. For 20 times rated current, that is 100A secondary current, the upper limit of excitation current is 10%x5Ax20=10Amp. From the specified excitation curve of IEEE C57.13, at 10A excitation current, the secondary voltage is approx. 340V ($V_S$). Secondary CT resistance voltage drop at 100A secondary current = 100Ax0.418 ohm= 41.8 V. Therefore 340 V-41.8 V= 298V, should be the voltage across burden ($V_B$), that is accuracy class C200. It may be noted here that, the user can benefit for using more precise class, for example C280 over discrete number C200 as specified in the standard.

Let us now talk about how the accuracy class protection class CT as defined in IEC 61869-2.
For general over current protection applications, “P” class CTs are used extensively. These are high remanence types, with no limit for remnant flux.
The IEC 61869-2 “P” class CT resembles to “C” class of IEEE C57.13.
IEC defines “P” class CT such that the current, phase and composite error do not exceed the prescribed value, refer Table: 02 under.

Table: 02

| Accuracy Class | Ratio Error (rated Current) | Phase displacement (rated current) | Composite error |
|---|---|---|---|
| 5P | +/-1% | +/-60 min | 5% |
| 10P | +/-3% | - | 10% |

For high impedance circulating current protection class PX CTs are used, these are high remanence like “P” class but with low leakage reactance. For Dimensioning PX class CT, knowledge of excitation characteristic (knee point voltage & excitation current) and CT Secondary resistance are the key parameter.

Protection class CT with low remanence flux, are termed as class PR where the remanent flux not to exceed 10% of the saturation flux.

For better transient performance TPX class CT is used, TPX class are high remanence & low secondary reactance type, typically used for high impedance circulating current protection.

TPY class CTs are with low remanence & TPZ with no remanence. TPX are generally used for line differential, TPY for line protection with auto reclose function, TPZ for differential protection of large generators.

Now let’s apply the above concepts into IEEE accuracy class;

- The rated output is equivalent to specifying the secondary burden. The output power is the square of the rated current times the burden in ohms, or for rated current of 5A, 25 times the burden.
- IEEE C57.13, the allowable error “C” class CT is always 10%. However in IEEE, the secondary burden has a 60 degree impendence angle, whereas in IEC, the secondary burden is purely resistive. As a consequence an IEEE CT with a limiting error of 10% will have a limiting error close to 5% with purely resistive burden. Therefore in IEC terms, the accuracy is a 5P class rather than 10P.
- For an IEEE C57.13, the Accuracy Limit Factor is always 20.

Now let us draw an equivalent IEC “P” class accuracies corresponding to IEEE “C” class accuracy classes for a 5A CT. please refer Table: 03.

Table: 03

| Secondary Terminal Voltage | Secondary Burden Designation | Impendence (Ohms) | IEEE Relay Accuracy | Equivalent IEC Protective Accuracy |
|---|---|---|---|---|
| 10 | B-0.1 | 0.1 | C10 | 2.5 VA-5P20 |
| 20 | B-0.2 | 0.2 | C20 | 5 VA – 5P20 |
| 50 | B-0.5 | 0.5 | C50 | 12.5 VA – 5P20 |
| 100 | B-1.0 | 1.0 | C100 | 25 VA – 5P20 |
| 200 | B-2.0 | 2.0 | C200 | 50 VA – 5P20 |
| 400 | B-4.0 | 4.0 | C400 | 100 VA – 5P20 |
| 800 | B-8.0 | 8.0 | C800 | 200 VA – 5P20 |

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

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The IEEE "C" class standard voltage rating required will be lower than an IEC knee point voltage, that is because IEEE voltage rating is at terminal of CT while Knee point voltage across the internal secondary winding. The IEC knee point is typically 20% higher thatof IEEE knee point. So a relation can be drawn as under;

$$Vk = 1.20C + Kssc \times I \times Rct = 1.20C + 100 \times Rct \quad [1]$$

Table: 4 depict the knee point voltage Vk calculated according to equation [1] for the comparison.

Table: 04

| CT Ratio | Rct | Vk – C50 | Vk – C100 | Vk – C200 | Vk – C400 | Vk – C800 |
|---|---|---|---|---|---|---|
| 100/5 | 0.04 | 64 | 124 | 244 | 484 | 964 |
| 200/5 | 0.08 | 68 | 128 | 248 | 488 | 968 |
| 800/5 | 0.32 | 92 | 152 | 272 | 512 | 992 |
| 2000/5 | 0.80 | 140 | 200 | 320 | 560 | 1040 |
| 3000/5 | 1.20 | 180 | 240 | 360 | 600 | 1080 |

The main concern for protection CT selection is on correct response to short circuit transients. When the CT gets saturated, the magnetizing impendence falls down. The CT behaves more like an air core device with negligible coupling between primary and secondary winding, thereby the CT secondary cannot replicate the primary current. It is necessary to over dimension the CTs to avoid saturation. During fault the CT's will be forced to develop a flux necessary to feed fault current to the secondary with the exponential DC offset asymmetrical component and the AC symmetrical component. The resultant voltage generated must be right to feed the load connected in secondary without distortion caused by saturation.

Now to draw differences in specifying protection class CT with respect to IEC and IEEE standard,

- The composite error limits of IEC is 5% or 10% at given ALF, The ALF as per IEC can be up to 30 times. Whereas IEEE assures only 10% error limit at accuracy limit factor of 20. But the important difference in the definition is IEC burden is resistive burden while IEEE assumes impendence angle of 60 degree. Therefore 10% error defined in IEEE is almost same as 5% with resistive burden.
- The Accuracy limit factor defined in IEC is 5, 10, 15, 20 and 30 while IEEE standardized with 20.
- The IEC range of accuracy class for selecting for appropriate application ranges is wider in comparison to IEEE, (P, PR, PX, PXR, TPX, TPY or TPZ), while in IEEE only three classes have been defined "C", "T"&"K". IEC therefore offers more optimized selection of CT for specific application over IEEE.

## V. REQUIREMENTS FOR CTs FOR OVER CURRENT PROTECTION APPLICATION

In The objective of this section is to highlight similarities and differences in Current Transformer dimensioning for specific overcurrent protection application complying to the IEC standard and IEEE standard. Every protection relay manufacturer provide the CT sizing guideline for the respective Relay application, however the basics remain same. The second part of this article will cover CT dimensioning criteria with sample calculation highlighting the differences in specifying the CT to IEC and IEEE standard. This part of the article only gives a brief on CT sizing criteria for Feeder Over-current protection, both time delayed IDMT overcurrent and instantaneous overcurrent protection, the second part of the article covers more detail with sample calculation.

### TIME DELAYED OC PROTECTION (51):

The fault current could be as high as 20 to 30 times the relay set current. The transient saturation is not critical for IDMT over current but symmetrical AC saturation is of concern and CT saturation voltage has to be checked against the voltage generated during maximum fault condition.

In IEC application, the primary check is done to ensure the CT (P class) does not get saturated or go to nonlinear zone with maximum symmetrical fault current in primary circuit. Therefore calculation is done to check the operating ALF (accuracy Limiting Factor) is higher than the required ALF.

The actual ALF is the ratio of the rated CT burden to the actual CT burden; refer equation [2] under,

$$ALF_A = ALF_R \times (R_{CT} + R_{BR}) / (R_{CT} + R_{BA}) \quad [2]$$

Where,

$ALF_A$ = Actual Accuracy Limit Factor  $ALF_R$ = Rated Accuracy Limit Factor
$R_{CT}$ = CT secondary resistance  $R_{BR}$ = Rated CT Burden (Lead, protective relayetc)
$R_{BA}$ = Actual CT Burden (Lead resistance with protective relay burden)
$ALF_{REQ}$ = Required Accuracy Limit Factor

The required $ALF_{REQ}$ is calculated as under;

$ALF_{REQ} = I_F/I_P$ (Ratio of Primary prospective maximum short circuit current to CT rated primary current) [3]

The calculation or check is done to ensure $ALF_A$ is higher than $ALF_{REQ}$ thereby the voltage generated across CT secondary winding will remain less than knee point voltage and shall remain in linear range at maximum through fault condition.

Now coming over to IEEE standard for same application, Low current ratio with high symmetrical fault, things are little different. IEEE standard defines the secondary terminal voltage the CT can deliver to a standard burden at 20 times the rated secondary current. There is a mixed message in ANSI standards. According to IEEE C37.20.2, it recommends either special accuracy class CT or use two sets of CTs, a low ratio CT determined by the rated full load current and overload protection requirements, and a much higher ratio CT dictated by short circuit current levels so that the CT secondary current does not exceed 20 times nominal secondary current under maximum symmetrical fault current.

However IEEE- 242 (the BUFF book) has depicted an example with a required accuracy limit factor of 40 (ratio of maximum fault current to nominal full load current), in such case by using lower burden and ensuring the voltage generated across the burden less that the knee point voltage of the CT. That would mean the Buff book suggest "where fault currents of more than 20 times the current transformer nameplate rating are anticipated, a different current transformer with special accuracy, or different current transformer ratio, or less burden may be used.

**HIGH SET INSTANTANEOUS OC PROTECTION (50) :**

Relay operating time for instantaneous phase or ground OC protection is typically 1 to 2 cycles. It is essential to ensure either the relay operates before CT goes into saturation or the CT Knee point voltage or ANSI voltage rating is higher than the maximum fault burden voltage to ensure CT does not get saturated.

Saturation is avoided by selecting ANSI voltage rating larger than the maximum fault burden voltage with suitable allowance for DC asymmetry (1+X/R) factor and remanence applied.

Saturation Voltage Vs according to ANSI standard= (1+X/R)/(1-per unit remanence) x $I_F$ x $R_B$ [4]

The degree of saturation depends on the magnitude of fault current, primary time constant, secondary time constant of the CT and magnitude of the DC component. The time to saturation would depend on various factors that include degree of fault current offset, fault current magnitude, remnant flux in the CT core, saturation voltage etc.

Numerical relays use finite impulse response filter for current acquisition using Fourier or cosine filter to determine average and peak. The root mean square filters respond to the DC component as well as all harmonics.

IEC classification includes specific accuracy class in IEC – 61869 for transient performance TPX, TPY and TPZ. TPY has small gapped core, while TPZ has larger gapped core to have a time constant very low, less than 60 m sec.

IEC classified CTs saturation voltage is calculated as under;

Saturation Voltage $V_S = K_{SSC} \times K_{TF} \times K_{REM} \times I_F \times (R_{CT} + R_B)$ [5]

Where $K_{SSC}$ = Short Circuit Factor  $K_{TF}$ = Transient Factor  $K_{REM}$ = Remanence Factor

The knee point voltage for the CT selected must be higher than the calculated Vs.

## VI. CONCLUSION

Current transformers which are a critical component to the protection systems are specified differently based on the applicable standard to the region for the same protection relays or metering devices used internationally. It is imperative that for accurately sizing and dimensioning the current transformer for specific application, one has to have the best of understanding of the requirements specified in the standards. This paper discussed about the similarities and differences in specifying metering and protection class CTs, The second part of this paper will cover CT dimensioning criteria with sample calculation for specific application highlighting the differences in specifying the CT to IEC and IEEE standard.

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