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Current Transformer Sizing & Saturation Calculation with Transient Performance Analysis of CT Using ATP Software

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ABSTRACT: The main purpose of a current transformer is to translate the primary current in a high voltage power system to single level that can be handled by delicate electromechanical or electronic device. Current transformers are the very important aspect of the power system protection. So for the correct CT operation the accuracy class of CT sizing&should be Adequate with the system current & related burden and effective transient condition. In this paper, it proposes advance CT sizing concept with K_{TD} and X/R ratio factor with CT performance analysis at different -2 CT Burden and CT saturation analysis at Asymmetrical Current condition with the Alternating Transient Programming (ATP) software.

KEYWORDS: Accuracy Class, Asymmetrical Current, CT Burden, CT Saturation, DC Offset and X/R ratio.

I. INTRODUCTION

Previously, an ANSI/IEEE relay current transformer (CT) sizing criterion was based on traditional symmetrical calculations usually discussed by technical articles and manufacturers' guidelines. In 1996, IEEE Standard C37.110-1996 [1] formalized some of this prior work by introducing (1 + X/R) offset multiplying factor for determine the CT saturation voltage, current asymmetry and current distortion factors; officially changing the CT sizing guideline on the basis for sizing CTs. In C37-1 10.1996 has recognizes primary current asymmetry and CT saturation due to the DC offset current component, it is no longer acceptable to use symmetrical primary current as the basis when performing CT calculations. A critical concern is the performance of fast protective schemes (instantaneous or differential elements) during severe saturation of low ratio CTs. Will the instantaneous element operate before the upstream breaker relay trips?

At the previously in CTsizing has using network maximum fault current& burden of the CT but in advance sizing has considered K_D and (1+X/R)factor for correct operation in transient conditionand reduced the impact of DC off set current. In advance protection scheme has using many electronics device in system as like invertors, chopper, and other Facts device SSSC, UPFS, excitation panel etc that’s why system has incising DC offset current inasymmetrical and symmetrical fault duration and CT will saturate due to large DC off set current.

In I part of in this paper review modern CT sizing calculations using (1+X/R) to determine the CT saturation voltage if the results are practical and if standard CTs can be used. To augment the 1 +X/R consideration, a waveform approach is introduced. Because modern industrial electrical power systems are typically resistance grounded, ground relaying is considered beyond the present scope of this paper. Although the paper focus on minimum ratio CT sizing and the concept of K_{TD} factor& effect of Asymmetrical and symmetrical current of the system.

The Alternative Transients Program (ATP) version of EMTP is an inexpensive, powerful tool for evaluating CT performance. The II part of in this paper briefly describes ATP software, provides instructions for constructing a CT model using ATP, and presents the CT performance analysis in transient condition. The paper uses the CT and relay models to demonstrate:

- The effects of X/R ratio and & CT class Secondary burden on CT saturation.
- Secondary burden and connection effects of CT.

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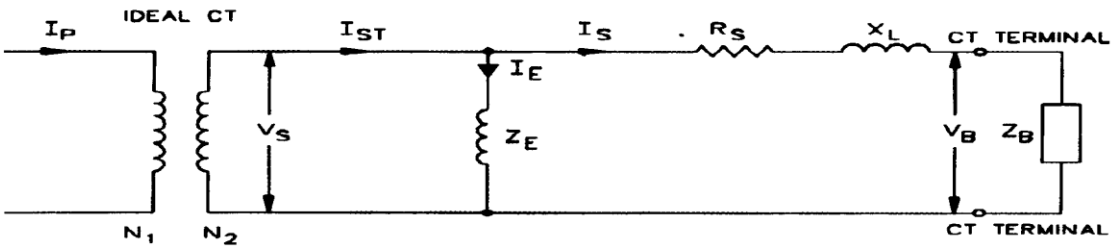
II. THE CONCERNS



V_S	is the secondary exciting voltage
V_B	is the ct terminal voltage across external burden
I_P	is the primary current
Z_E	is the exciting impedance
I_{ST}	is the total secondary current
R_S	is the secondary resistance
I_S	is the secondary load current
X_L	is the leakage reactance (negligible in Class C cts)
I_E	is the exciting current
$N_2:N_1$	is the ct turns ratio
Z_B	is the burden impedance (includes secondary devices and leads)

Fig. 1 Equivalent circuit diagram Current Transformer

In Fig. 1 has show the equivalent circuit of a current transformer with load impedance and details of parameter in CT. Basic working principle of the CT is same as the traditional transformer so no more difference in CT equivalent circuit as compare to traditional transformer. As show in fig 1 the CT secondary voltage V_S not should be saturate and exciting current should be low for better protection & measurement. When the voltage developed across the ct burden is low, the exciting current is low. The waveform of the secondary current 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.

III. CALCIFICATION OF CT ACCORDING TO PROTECTION SYSTEM

1. **PS Class CT** – This type of ct is use for where the current balance is precisely required to be maintained. In the Overall differential protection, Transformer, Generator protection needs PS class CT. The developed voltage in ct core is less than the knee voltage of the CTs.
2. **PROTECTION CLASS CT –** They are used for over current & instantaneous & IDMT Relay. As like 5P10, 5P20 are the protection class ct. It means the 5 is the significant the % limit of composite error 20 & 10 is the ALF it means the fault current of ct is in range of 10 & 20 time of the rated primary current of CT with ±5 % of defined % of composite error.
3. **METERING CLASS CT -**The core of ct should be low cross section area low saturation means with stand at high current or fault current condition. According to the accuracy the CT will be selected as like 0.5, 0.2 ,0.2s & 1.

   Note-
   - 0.2 & 0.2S class ct are used for the voltage above the 33 KV level.
   - 0.5 &0.5S class ct are used up to 33 KV level.

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IV. TRADITIONAL CT CALCULATION SIZING APPROACH

Protective relaying has always combined art and applied physics, with the goal of issuing tripping commands during abnormal electrical system conditions. Protective relaying systems are typically straight forward with current transformers, wiring and relays.Traditionally, manufacturers' literature and industry standards provided calculation analysis guidance to ensure CTs were adequately sized for both ratio and accuracy class.
One author's professional development of performing CT saturation calculations began with (1) to determine the minimum CT Accuracy class. The CT's are using for different -2 purposes in power system network.

1. PS class CT calculation

$Vs = I_{FSC} \text{ x } (R_{CT} + R_L + nR_R)$ (1)
V_S= Knee voltage
I_{FSC}= Fault current of secondary side CT
R_{CT} =Resistance of CT secondary
R_L =Lead resistance
R_N = Relay resistance
When the offset waveform concept was introduced, (2) was used.
$Vs = 2 \text{ x } I_{FSC} \text{ x } (R_{CT} + R_L + nR_R)$ (2)
Introduction of waveform peak resulted in (3) calculation.
$Vs = 2\sqrt{2} \text{ x } I_{FSC} \text{ x } (R_{CT} + R_L + nR_R)$ (3)
$Vs = (1+ X/R) \text{ x } I_{FSC} \text{ x } (R_{CT} + R_L + nR_R)$ (4)
$Vs = 2 \text{ X } K_{TD} \text{ x } I_{FSC} \text{ x } (R_{CT} + R_L + nR_R)$ (5)
K_{TD} is using in PS class CT for the Switch Yard (more than 66 KV) because due to the transient condition PS class CT core is affected in High voltage condition.
According to the IEEE standard the formula is drive by the CT sizing.The ANSI C37.110-1996 addition of (1 + X/R) for CT saturation calculation resulted in (4).But in the Advance sizing K_{TD} factor is using for better result and minimum ratio CT Accuracy class.

2. Protection Class CT sizing.

$E_{MAX\ CALCULATED} = ALF \text{ X } (R_{CT} \text{ X } I_{Sec} + \text{VA Burden Selected} / I_{Sec})$
$E_{MAX\ REQUIRED} = K_{TD} \text{ X } (I_{FSC}/CT_{\ RATIO}) \text{ X } (R_{CT} + R_L + nR_R)$
K_{ALF} = Accuracy Limit Factor
K_{TDF} = Transient Dimension Factor

Note - $E_{MAX\ CALCULATED}$ is always grater then $E_{MAX\ REQUIRED}$ for the safer side of CT sizing according to IEC 60044-6.
Required Accuracy Limit Factor = $K_{TDF} \text{ X } (I_F/I_P)$
Calculated Accuracy Limit Factor = $K_{ALF} \text{ X } \dfrac{(\text{Selected burden} + I_{SEC} \text{ X } R_{CT})}{(\text{Required burden} + I_{SEC} \text{ X } R_{CT})}$
Note – For correct CT sizing Calculated ALF is greater than Required ALF.

3. For Metering class Ct sizing.

Required Burden = (Connected meter Burden + total Burden)
Factor of Safety = $FS \text{ X } \dfrac{(\text{Selected Burden} + R_{CT} \text{ X } I_{SEC})}{(\text{Required Burden} + R_{CT} \text{ X } I_{SEC})}$

Note = In metering class CT Required Burden is always is less then Selected Burden for correct CT sizing.
According to IEEE standard the Selected Burden in the range of 25% of Selected Burden ≤ Required Burden ≤ 100 % Selected Burden for the Metering class CT.

To show the impact of introducing the (1+X/R) and K_{TD} factor in term, two industrial examples are selected. Using through the CT calculation results, the significant change introduced by (4) & (5) is shown- Examples 1 and 2 use a system X/R=14; this is less than the ANSI switchgear interrupting X/R rating (X/R=17). Modern industrial electrical power systems, particularly systems with generators or large synchronous motors, may have X/R magnitudes

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significantly greater than 14. Some large industrial system generators have X/R greater than 100, and large industrial transformers may have X/R of 30 to 40.

Example 1 - Typical Industrial 13.8kV Switchgear Feeder with high-ratio CT's. 3000/1 CT with 5P20 Accuracy Class 30 kA secondary fault current (As per system study fault current is 23 KV future we have taken 30 KV for safer side) RMS Short-Circuit Magnitude System X/R = 14.
R_{CT}= 12.00 ohms
Selected Burden =15 VA
No. Of Relay =2
Relay Burden =0.20 VA
R_R (Relay resistance) = 0.20 ohm (VA/I^2)
Cable Size = 4mm (As per cable catalogue)
Cable Resistance = 4.61 0hm/km (Resistance at 20®c)
Cable Resistance at Ambient temperature= 5.61 ohm / km at 75®c temp.
Lead Length = 100 meter
R_{WIRE} =R_R= 5.61 X 100 X 2 = 1.12 ohm
P_{TOTAL}= (0.20 X 2 + 1.12 X 1) = 1.52
Introduction of waveform peak resulted in (3) calculation.
$V_S = 2\sqrt{2}$ X (30000 X (1/3000)) X (13.32) = 376.74 (6)
Finally, the ANSI C37.110-1996 addition of (1+X/R) for CT saturation calculation resulted in (4)
V_S = (1+14) X (30000 X (1/3000)) X (13.32)= 1998 volt (7)
Now the K_{TD} factor is using for CT saturation calculation resulted in (5)
V_S = 2 X 2.49 X (30000 X (1/3000)) X (13.32) = 663.34 volt (8)
Now if we are sizing the CT according to eq. (2) the CT are saturate in transient condition. Then CT sizing is inadequate according to the ANSI C37.110-1996 IEEE clause and equation (7) & (8). So for the special purpose protection condition CT must have sizing according to eq. (7) & (8).
In eq. 7 & 8 has the different -2 Knee voltage value of CT according to the K_{TD} factor the CT has minimum ratio CT Accuracy. The CT's are actual using in TEESTA URJA site according to eq. (8).

For Protection class CT
$E_{MAX\ CALCULATED}$ = 20 X (12 X 1+ (15/1))
$E_{MAX\ CALCULATED}$ = 540
$K_{TD} = 1+W*T_P*\{1-\exp(-5/T_P)\}$
Grid Time Constant (T_P) = (X/R)/W
T_P = 44.58
K_{TD} = 2.49 sec.
$E_{MAX\ REQUIRED=}$ 2.49 X (30000 X (1/3000)) X (13.32) = 331.66 volt
Required Accuracy Limit Factor (K_{OALF}) =(K_{TD}*I_F)/I_P
K_{OALF} = 24.90
Calculated Accuracy Limit Factor (K_{OALF}) = K_{NALF} X ((P_N+R_{CT} X I_{SEC}) / (P_{TOTAL}+R_{CT} X I_{SEC}))
K_{OALF} = 39.9
The Required E_{MAX} is within the Calculated Range it should be ($E_{MAX\ REQUIRED} \leq E_{MAX\ CALCULATED}$)
The Required burden is within the Selected Range it should be ($BURDEN_{REQUIRED} \leq BURDEN_{SELECTED}$)
The Required Accuracy Limit Factor is within the Calculated Range.
Hence selection is Adequate for Protection Class CT.

IEEE Std. C57.13-1993 (R2003) [11], Section 6.4.1 defines relaying accuracy ratings as a designation by a classification and a terminal voltage rating. "These effectively describe the steady-state performance." "The secondary voltage rating is the voltage the current transformer can deliver to a standard burden at 20 times rated secondary current without exceeding 10% ratio correction factor [11]
With a known CT internal resistance and CT saturation curve, the CT maximum terminal voltage can be estimated. Obviously, the CT accuracy rating must be greater than the required CT voltage. In Example 1, with 30kA primary fault current and 3000/1 ratio, the CT secondary current is 10A. This is 10 times the CT 1A nominal secondary current rating (10A/1A = 10 x 1A CT rating). This is not exceeds the 20 times CT secondary rating requirement.

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Hence,predictable CT performance with more than 10% ratio correction is guaranteed because CT performance may become linear. The results of PS Class indicated the selected 3000/1 CT is Adequate.

Example 1 shows the results with high-ratio CTs on feeder circuits. At this point the application question could be asked, what is required for typical 13.8kV switchgear feeders with low-ratio CTs?

Example 2 - Typical industrial 13.8kV feeder with low ratio CTs. 450/1 CT with 5P20 Accuracy Class 18 KA(As per system study fault current is 16 KV future we have taken 18 KV for safer side) RMS Short Circuit Magnitude System X/R = 14
R_{CT} = 12.00 ohms
Selected Burden =15 VA
No. Of Relay =2
Relay Burden =.20 VA
R_R (Relay resistance) = 0.20 ohm $(VA/I^{2)}$
Cable size = 4mm (Resistance at 20®c)
Cable Resistance = 4.61 0hm/km
Cable resistance at ambient temp. = 5.61 ohm / km (at 70®c)
Lead Length = 100 meter
Lead Resistance = (Cable Resistance X Cable lead length X2) =1.12ohm
P_{TOTAL}= (Total relay burden + lead resistance X I_{SEC}) = 1.52

For Protection class CT
$E_{MAX\ CALCULATED}$ = 20 X (12X1+ (15/1)) = 540
K_{TD} = 1+W X T_P X {1-exp (-5/T_P)}
Grid Time Constant (T_P)= (X/R)/W
T_P = (14 / (2 X 3.14 X 50)) X 1000 = 44.58
K_{TD} =2.49 sec.
$E_{MAX\ REQUIRED=}$ 2.49 X (18000 X (1/450)) X (13.32) = 1326.6 volt
Required accuracy Limit Factor (K_{OALF}) =(K_{TD} X I_F/I_P) =99.6
Calculated accuracy Limit Factor (K_{OALF}) = K_{NALF} X ((P_N+R_{CT} X I_{SEC}) / (P_{TOTAL}+R_{CT} X I_{SEC})) = 39.9

Hence
The Required E_{MAX} is NOT within the Calculated Range it should be ($E_{MAX\ REQUIRED} \leq E_{MAX\ CALCULATED}$)
The Required burden is NOT within the Selected Range it should be ($BURDEN_{REQUIRED} \leq BURDEN_{SELECTED}$).
The Required Accuracy Limit Factor is within the Calculated Range.
Hence selection is **Inadequate**.

Obviously, the low-ratio CT is underrated for an 18kA fault magnitude with a system X/R of 14. This ct is not suitable for the Protection purpose in the power system network because they saturated if the transient condition occurring in the network. This is the commonly unrecognized dilemma - using underrated low-ratio CTs with protection relays. Industrial systems with large supply transformers, large motors or local generators could have a short-circuit X/R ratio in excess of 50 value, making the DC offset condition more severe.Finally it is calculated if we are reducing the ct ratio than the ct resistance should be low and the burden should be incising.

V. CONSTRUCTING A CT MODEL USING ATP

The ATP version of EMTP is the basic software tool for electric system transient modelling. ATP Draw is a graphical, mouse-driven pre-processor to ATP on the MS Windows platform and uses a standard Windows layout. The Alternative Transients Program (ATP) version of EMTP is an inexpensive, powerful tool for evaluating CT performance. Fig no. 2 is the excitation test circuit has using 1200/5 CT ratio with1 phase saturation transformer form ATP library and connected suitable load with voltage source and set the parameter of saturated transformer required and test the model by recreating the CT excitation curve using ATP Draw circuit in Fig.2.

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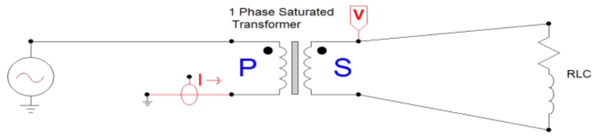

Fig. 2 CT Excitation Test Circuit with Load

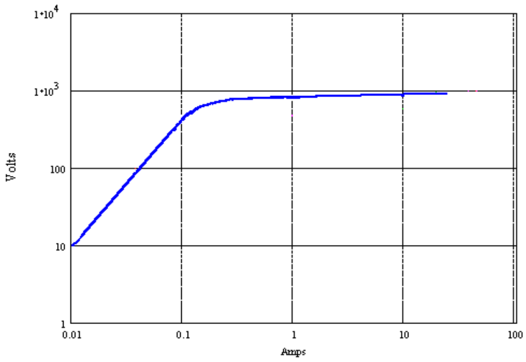

Fig. 3 CT Excitation Curve

Fig.3 shows the results of excitation curve tests of the model saturation. The RMS secondary excitation current from ATP plotted along with the current voltage from the CT characteristic curve. So according to the Fig. 3 the 1200/5 ratio CT will be saturated up to 1000 volt.

VI. THE EFFECTS OF X/R, CT CLASS, AND BURDEN ON CT SATURATION

The criterion to avoid CT saturation X/R ratio, Burden and Class are playing important role now draw a model for CT X/R ratio & burden analysis using ATP. As an example, consider a transmission line with an impedance angle of 85.24° (X/R = 14) and a 3000/1, 5P20 CT. The maximum fault current is 10 times the rated CT current. The criterion is satisfied when Z_b is less than or equal to 0.38 per unit of the standard 8 Ohm burden, or 3.08 Ohms.Use the circuit shown in Figure 4 to model this example and find out the CT secondary burden voltage, secondary burden current.

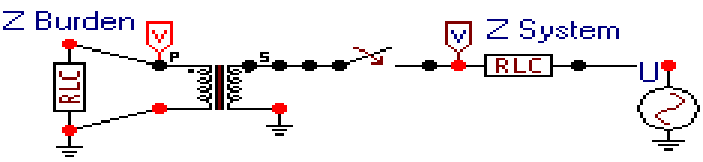

Fig. 4 Test Circuit in ATP Draw

Now in the Fig. 5 shows the voltage developed across the 3000/1 ratio CT secondary during the simulation and the load current of CT. According to the curve at starting time the secondaryvoltage is incising gradually due to DC offset current and after 2 & 3 cycle the voltage decay due to the X/R ratio factor or time constant parameter. If the X/R ratio value is high then the voltage decay time is also high.

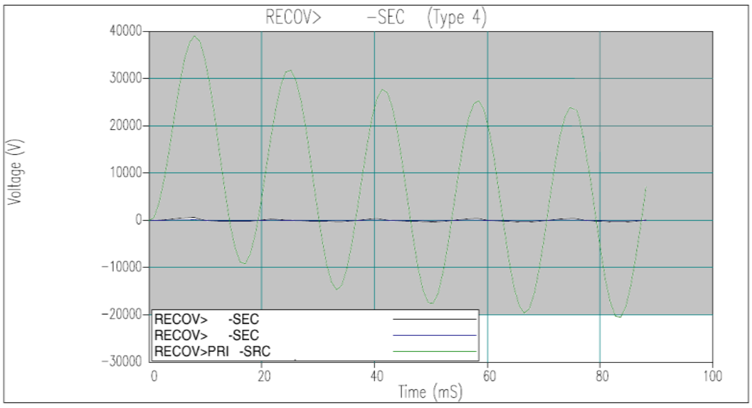

Fig. 5 CTSecondary Voltage & Load Current

In Fig.5 has notice that the secondary current quantities appear very small because of the plot vertical scale. But at the Asymmetrical and symmetrical fault current condition should be not saturate and the X/R ratio and K_{TD}Transient Dimension factor is playing important role to increase the time of voltage decay and protect the CT for the saturation condition.

VII. SUMMARY

Modern IEEE Standard C37.110-1996 CT saturation calculations include a (1+X/R) multiplier that significantly increases the required CT accuracy class during fault conditions in medium-voltage industrial power feeder circuit applications, particularly when low-ratio CT's are implemented so the secondary voltage of the current transformer. The K_{TD} factor are using according to IEC standard and minimum ratio CT sizing. In general ct ratios are selected to match the maximum load current requirements, i.e., the maximum design load currentshould not exceed the ct rated primary current. The highest ct ratio permissible should usually be used to minimize wiring burden and to obtain the highest CT capability and performance in transient condition. As ATP model analysis we can summarised the role of the KTD factor and the performance analysis of CT

VIII. CONCLUSIONS

When IEEE Standard C37.110-1996 formally introduced the (1+X/R) multiplier for CT saturation calculations, CT accuracy class requirements significantly increased for heavy industrial applications with low-ratio CTs on typical medium voltage feeder applications because the X/R ratio is 'high" (14 or greater). The DC offset voltage value is more in DC component where the inductance value is more. As like in near to excitation system of transformer and minimum in Transmission line because there are low DC component. This did not appreciably affect utility transmission applications because the utility industry X/R range is "low" (4 to 8). Because the (1+X/R) multiplier may require significant CT accuracy requirements, a modem method is needed to confirm the CT ratio and accuracy class and relay response during fault conditions. Multiplying (1+X/R) ratio is better & more safe in transient condition but sizing voltage is incising much more & cost also but the K_{TD} factor has approx. minimum voltage CT sizing.

ATP, ATP Draw, TOP, and MathCAD are effective, inexpensive tools for power system transient analysis and relay simulation. ATP is very effective for modeling particular power systems and equipment configurations. Using ATP derive an accurate relay model from public information such as conference papers and instruction manuals. Use the model to understand relay transient performance in your system to improve applications and settings

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