NRC·CNRC
From Discovery to Innovation...

Voltage Dependency of HV CT Ratio Errors

E. So,
Electrical Power Measurements
Measurement Science and Standards Portfolio
National Research Council Canada

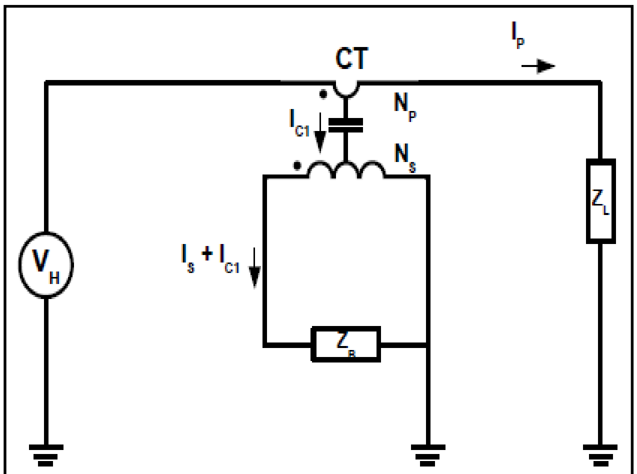
IEEE PES Transformers Committee Meeting
23 October, 2013

National Research Council Canada | Conseil national de recherches Canada | Canada

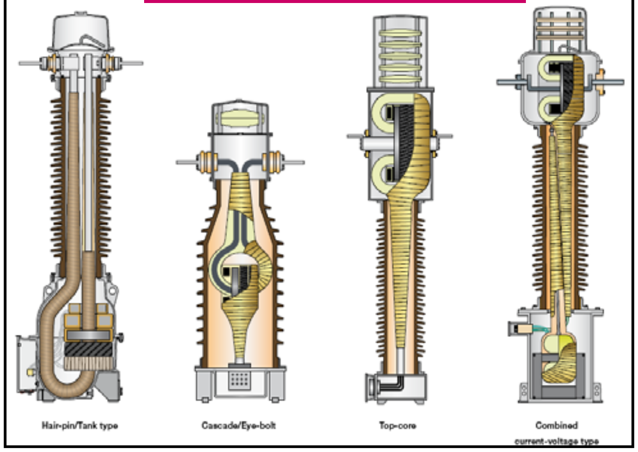
Problem

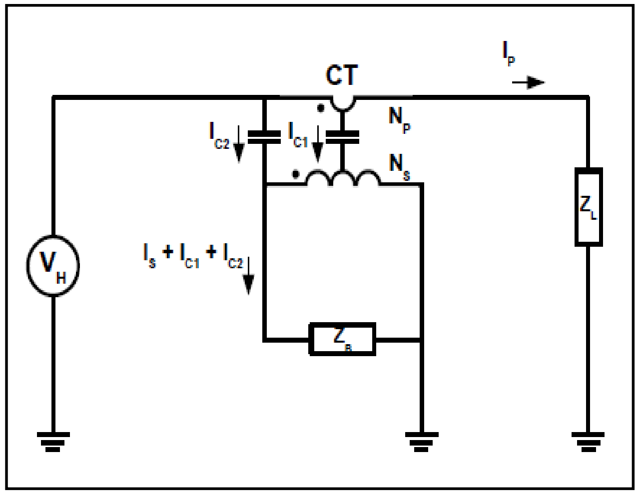
- IEEE/IEC Standards defined Ratio Errors with ratio windings at ground potential.
- HV CTs are calibrated with primary and secondary windings at ground potentials.
- In actual use, the HV CT is operated with one, or the other, or both of these windings at a voltage which is substantially different from the test conditions at ground potential.

- Capacitive currents, which were not present or were negligible during calibrations, will then flow when the CT is in its intended operating conditions and connected to high voltage.
- Operating at high voltage may result in a significant variation of the CT error measured during calibration, especially at low operating currents.
- Ratio Errors of HV CTs are voltage dependent.
- Voltage dependency of Ratio Errors not recognized by IEEE/IEC standards, C57.13/60044-1 .



Typical ABB designs of HV CTs





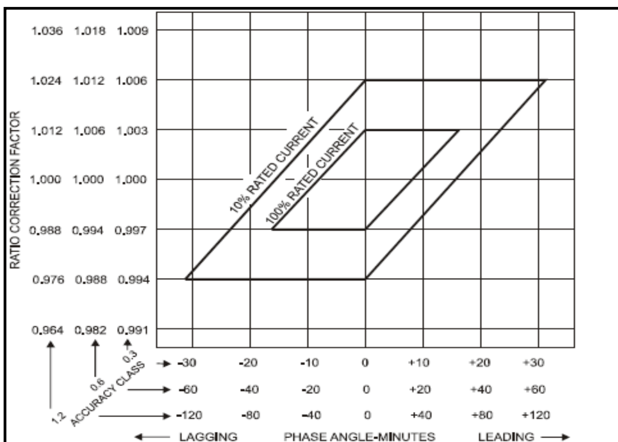
The transformer ratio errors are defined by the following equation:

$$\alpha + j\beta = ((I_S - I_P/n) / (I_P/n)) \times 10^6$$

or $\quad RCF = 1 - (\alpha/10^6) = 1 - A$

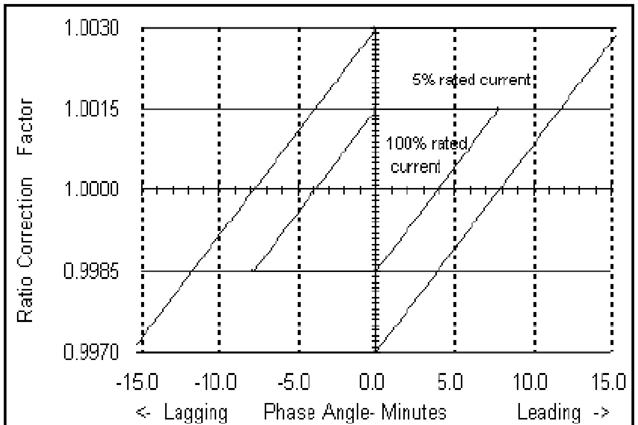
$\quad PA = \beta/291 = B$

where: α and β are the in-phase (magnitude) and quadrature (phase) errors, I_P and I_S are the primary and secondary currents, and n is the nominal ratio.



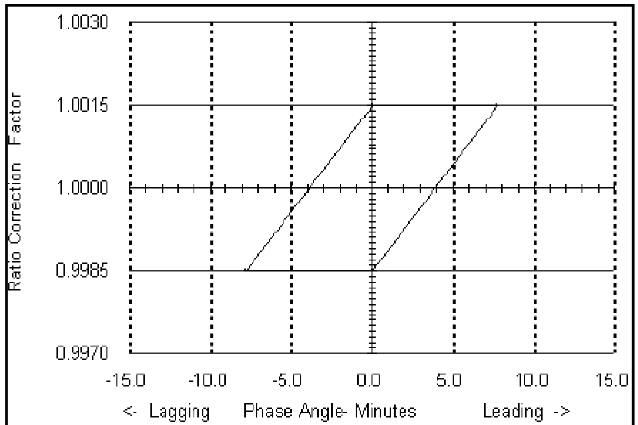
IEEE Std. C57.13

Limits of accuracy classes for current transformers for metering



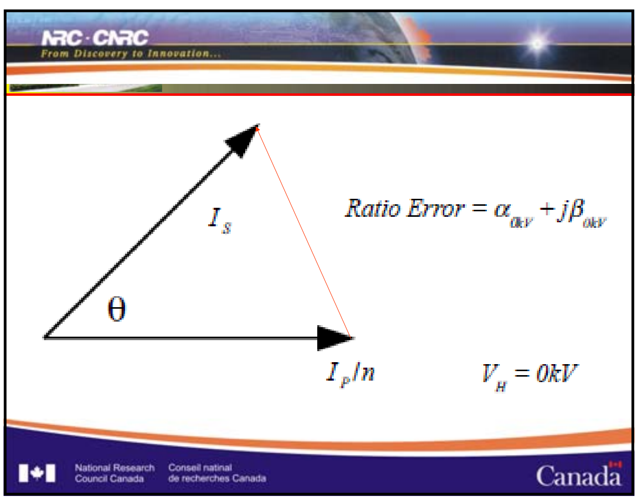
IEEE Std. C57.13.6

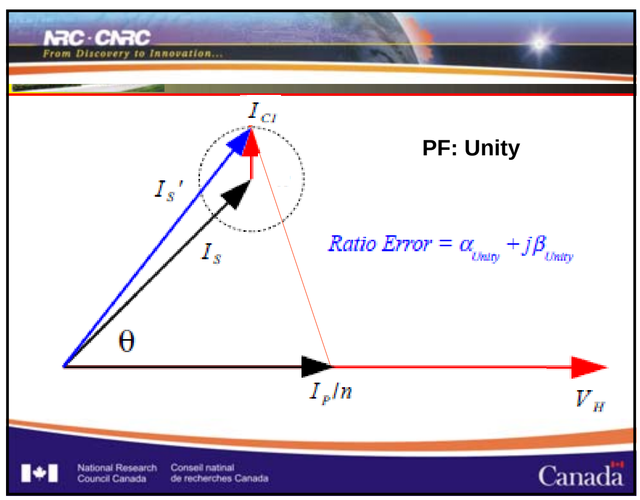
Limits for 0.15 accuracy class for current transformers for metering

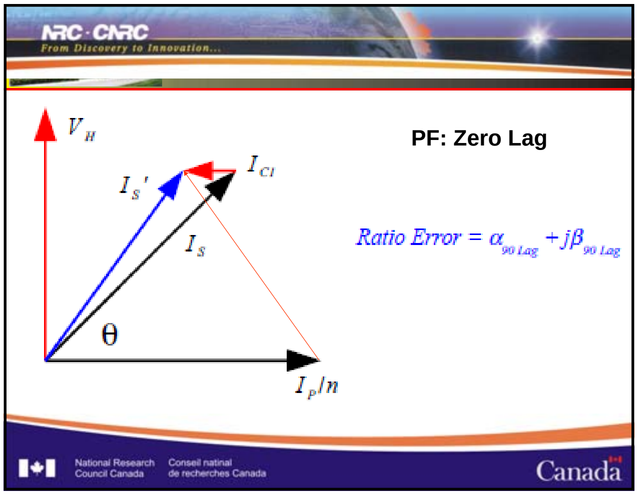


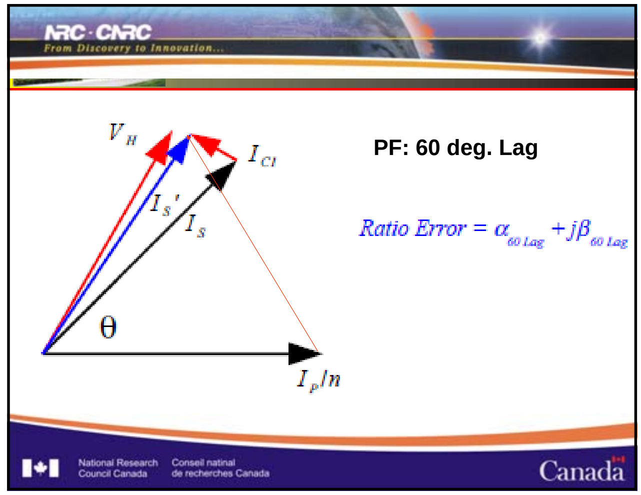
IEEE Std. C57.13.6

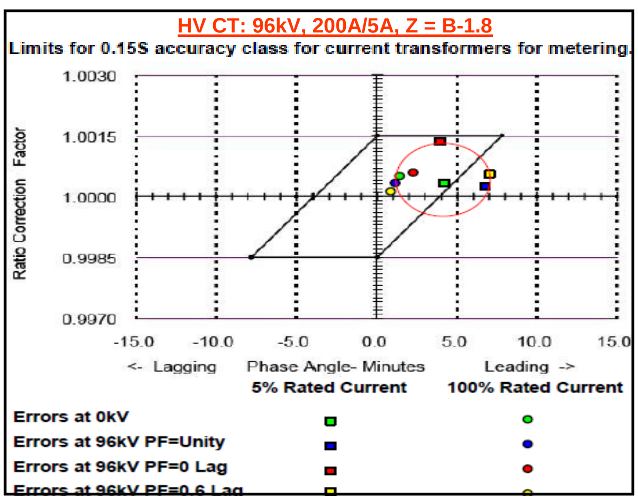
Limits for 0.15S accuracy class for current transformers for metering

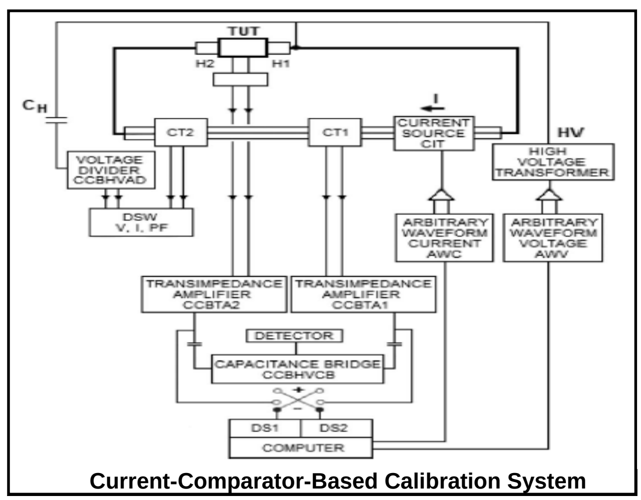


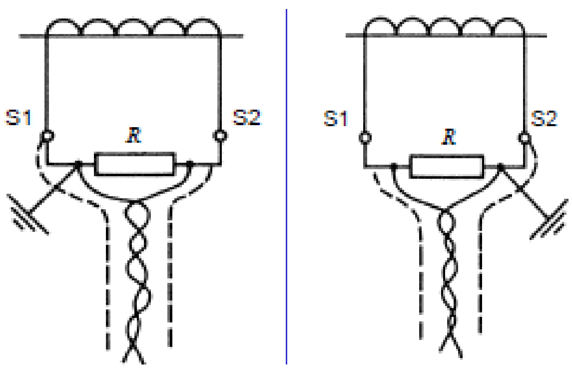



NRC · CNRC
From Discovery to Innovation...
V_H
I_S'
I_{CI}
I_S
θ
I_P/n
PF: Zero Lag
$Ratio\ Error = \alpha_{90\ Lag} + j\beta_{90\ Lag}$
National Research Council Canada
Conseil national de recherches Canada
Canada


NRC · CNRC
From Discovery to Innovation...
V_H
I_{CI}
I_S'
I_S
θ
I_P/n
PF: 60 deg. Lag
$Ratio\ Error = \alpha_{60\ Lag} + j\beta_{60\ Lag}$
National Research Council Canada
Conseil national de recherches Canada
Canada


HV CT: 96kV, 200A/5A, Z = B-1.8
Limits for 0.15S accuracy class for current transformers for metering.
Ratio Correction Factor
1.0030
1.0015
1.0000
0.9985
0.9970
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0
<- Lagging
Phase Angle- Minutes
Leading ->
5% Rated Current
100% Rated Current
Errors at 0kV
Errors at 96kV PF=Unity
Errors at 96kV PF=0 Lag
Errors at 96kV PF=0.6 Lag


TUT
H2
H1
C_H
CT2
CT1
CURRENT SOURCE CIT
HV
VOLTAGE DIVIDER CCBHVAD
HIGH VOLTAGE TRANSFORMER
DSW V, I, PF
ARBITRARY WAVEFORM CURRENT AWC
ARBITRARY WAVEFORM VOLTAGE AWV
TRANSIMPEDANCE AMPLIFIER CCBTA2
TRANSIMPEDANCE AMPLIFIER CCBTA1
DETECTOR
CAPACITANCE BRIDGE CCBHVCB
DS1
DS2
COMPUTER
Current-Comparator-Based Calibration System



IEC 60044-3_Part 3

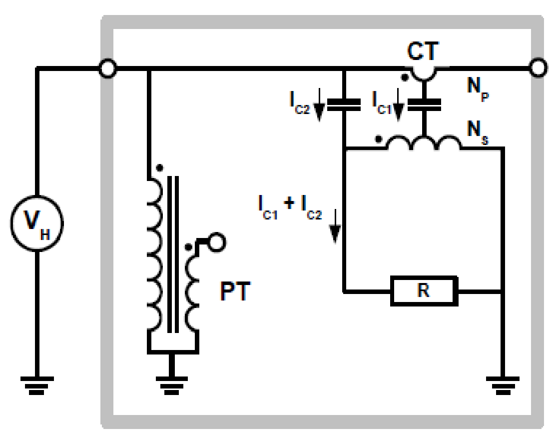
Combined Transformers

Influence of the voltage transformer on the current transformer

In the case of combined instrument transformers, the influence of the voltage transformer on the current transformer has to be tested as follows.

With an unexcited voltage transformer, the current error ε_i and the phase displacement δ_i of the current transformers are determined according to 11.4 and 12.4 of IEC 60044-1 (measurement 1).

A voltage equal to 120 % of the rated voltage and the rated voltage multiplied by the rated voltage factor shall then be applied to the terminal of the voltage transformer which is directly connected to a terminal of the current transformer, the latter not being excited. A capacitive current is generated in the current transformer by the voltage and this is measured as the voltage drop U_i across a resistor R connected to the secondary terminals of the current transformer. The burden of the secondary windings of the voltage transformer does not affect the results. They may therefore be open-circuited.



It generally suffices to determine the influence of voltage at 5 % of the rated current.

The variation of the current error is then

$$\pm\Delta\varepsilon_{\mathrm{i}} = \frac{U_{\mathrm{i}}}{R \times 0{,}05\ I_{\mathrm{sN}}} \times 100\ [\%] \text{ at 5 \% of the rated current.}$$

where

R is expressed in ohms;

U_{i} is expressed in volts;

I_{sN} is the rated secondary current in amperes.

The variation of the phase displacement is then

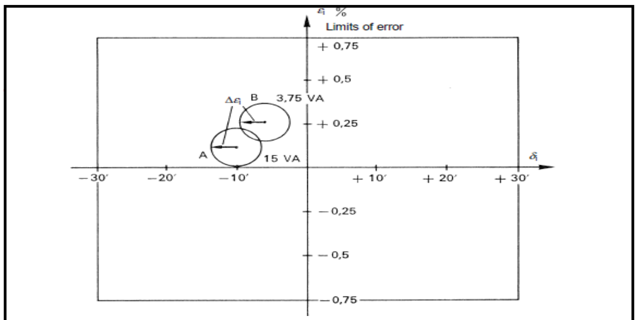
$\pm\Delta\delta_{\mathrm{i}} = \Delta\varepsilon_{\mathrm{i}} \times 34.4$, in minutes, or

$\pm\Delta\delta_{\mathrm{i}} = \Delta\varepsilon_{\mathrm{i}}$, in centiradians;

If the variations of the current error $\pm\Delta\varepsilon_{\mathrm{i}}$ and of the phase displacement $\pm\Delta\delta_{\mathrm{i}}$ are added to the absolute values of the measuring results ε_{i} and δ_{i} obtained in Measurement 1 at 5 % of the rated current within the specified range of burden, then the values obtained

$$\pm\varepsilon'_{\mathrm{i}} = |\varepsilon_{\mathrm{i}}| + |\Delta\varepsilon_{\mathrm{i}}| \quad \text{and} \quad \pm\delta'_{\mathrm{i}} = |\delta_{\mathrm{i}}| + |\Delta\delta_{\mathrm{i}}| \quad \text{(see Figure 5)}$$

shall not exceed the limits of error for the current transformer given in 11.2 and 12.3 of IEC 60044-1. It must be ensured, however, that current errors do not exceed the limits of error, even between 5 % and 120 % of the rated current and in the case of extended current rating at the rated continuous thermal current.



$\Delta\varepsilon_{\mathrm{i}}$ is the variation of the error caused by the applied voltage.

According to the angle between the voltage and the current phasors, the end points of $\Delta\varepsilon_{\mathrm{i}}$ lie on circles round the points of current transformer errors without applying voltage.

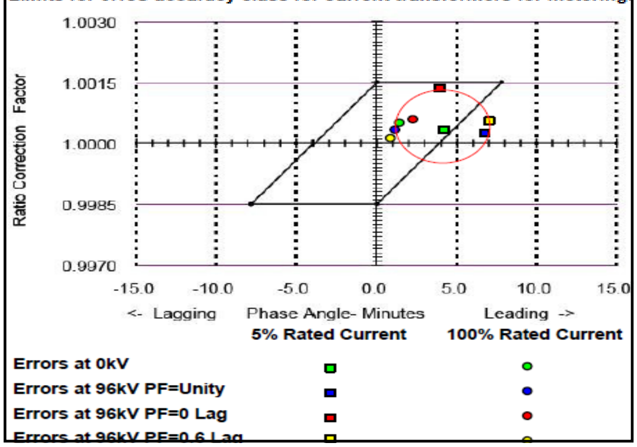
A error of the current transformer at an output of 15 VA.

B error of the current transformer at an output of 3,75 VA.

Figure 5 – Error diagram of a current transformer class 0.2 at 5 % of rated current

HV CT: 96kV, 200A/5A, Z = B-1.8

Limits for 0.15S accuracy class for current transformers for metering.



Reference

A Current-Comparator-Based System For Calibrating High-Voltage Current Transformers Under Actual Operating Conditions

Eddy So, *Fellow, IEEE,* Rejean Arseneau, *Senior Member, IEEE,*
David Bennett and Michelle E. Frigault

IEEE Transaction on Instrumentation and Measurements, Vol. 60-7, July 2011

CONCLUSIONS

- The effect of voltage dependency on the ratio errors of HV CTs is dependent, not only on their operating voltage, but also on the phase of the primary current with respect to the operating voltage (Load Power Factor).
- At low currents the voltage dependency effects could render the CT to be no longer meeting its original accuracy class.
- Problem for Regulating Bodies that do Type Approval Tests and also for utilities/users, manufacturers. Also for IEEE/IEC Standards (?).

CONCLUSIONS (Cont.)

- Further study and evaluation on voltage dependency effects of different types and designs of high accuracy class HV CTs, in particular of class 0.2s, 0.15s, 0.1s, or better, under actual operating conditions of high voltage and not only sinusoidal current waveforms, but also distorted current waveforms.
- Proposal to the Instr. Trafo SC to consider CT voltage dependency characteristics to be mentioned in the next update of C57.13 and/or C57.13.6 “High-Accuracy Instr. Transformers”.

Questions?

Email: eddy.so@nrc.ca