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Single and Multi-Ratio Current Transformer

Are Multi-Ratio CTs Really Necessary for EHV Metering?

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1.0 Introduction

In low- and medium-voltage systems, Current Transformers (CTs) are generally specified with a single primary ratio, such as 1000/1 A. In contrast, Extra High Voltage (EHV) systems are often specified with multi-ratio CTs, sometimes with as many as three primary taps, for example 1500-1000-500/1 A.

However, practical experience accumulated over several decades indicates that, in the overwhelming majority of installations, only one ratio is used throughout the life of the substation. The remaining taps remain unused from commissioning until retirement of the equipment.

This raises an important question: Do multiple CT ratios provide any tangible engineering or commercial benefit, or do they merely increase cost and complexity?

This article examines the selection of CT primary ratios for metering applications and demonstrates that, in most EHV installations, a carefully selected single-ratio CT is entirely adequate. It also discusses the practical relevance of extended accuracy classes (Class 0.2S and 0.5S) and presents recommendations based on operating experience.

2.0 Standard Primary Current Ratings

The preferred standard values of primary current of CT in Amps are given in Table 1, as per are Cl 4.1.1 of [1]. Ratings above 4000 A are generally encountered in large generating units (100 MW to 1000 MW), on the LV side of Generator Transformers (GTs), and on the secondary side of Arc Furnace transformers.

10	12.5	15	20	25	30	40	50	60	75
100	125	150	200	250	300	400	500	600	750
1000	1250	1500	2000	2500	3000	4000	5000	6000	7500
10000	12500	15000	20000	25000	30000	40000	50000	60000	75000

Table 1

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3.0 Selection of CT Primary Ratio for Metering Cores

Refer Table 2 for permissible limits of ratio error as per Tables 11 and 12 of [1].

I_{PRI} (%)	% Error				
	Cl 0.2S	**Cl 0.2**	**Cl 0.5S**	**Cl 0.5**	**Cl 1.0**
120	0.2	0.2	0.5	0.5	1.0
100	0.2	0.2	0.5	0.5	1.0
20	0.2	0.35	0.5	0.75	1.5
5	0.35	0.75	0.75	1.5	3.0
1	0.75	-	1.5	-	-

Table 2

The following examples illustrate the selection of appropriate CT ratios for various EHV applications.

Example 1: 220 kV Transmission Line

Consider a 220 kV transmission line with an expected maximum loading of 225 MVA per circuit, corresponding to 590 A. Allowing a 10% design margin, the required CT primary current is approximately 650 A. The nearest standard ratio is therefore 750/1 A. The corresponding apparent power at rated current is approximately 285 MVA.

For a Class 0.2 CT, the guaranteed accuracy extends from 5% to 120% of rated current. For a 750/1 A CT, this corresponds to an operating range of approximately 14 MVA to 343 MVA, which comfortably covers the expected loading.

The 80/20 Rule

The above selection is based on the well-established 80/20 rule adopted for 'wholesale revenue metering' in grids [2]. According to this principle, the operating current should remain within the guaranteed accuracy range for at least 80% of the operating period.

Although current may occasionally fall below 5% of rated current, the resulting energy measurement error is usually insignificant because:

- The current magnitude itself is very small, and
- it exists only for a limited duration.

Consequently, the cumulative energy error over an extended period remains negligible.

To appreciate this, consider a typical loading profile where the current exceeds 5% of rated current for 80% of the operating time. Refer Fig 1A. Area under the curve (A1 & A2) represents the energy.

Area A1 = ½ [80 x 95] + 80 x 5 = 4200

Area A2 = 20 x 5 = 100

Energy Ratio = (4200/4300) **:** (100/4300) = 98**:**2

Thus, although the current-time relationship is 80:20, the corresponding energy distribution becomes approximately 98:2.

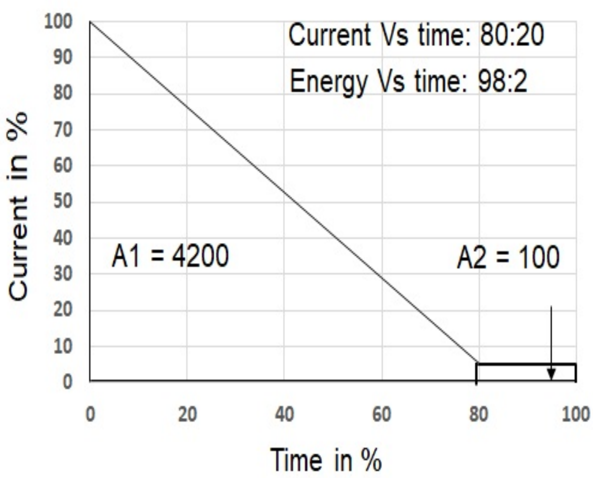

Figure 1A

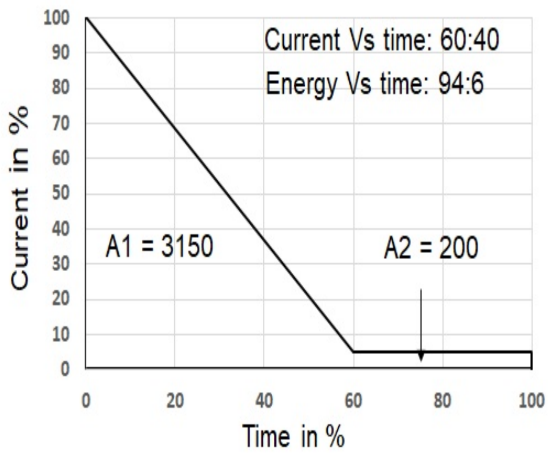

Figure 1B

Consider a more conservative loading profile where current exceeds the 5% threshold for only 60% of the time. Refer Fig 1B.,

Area A1 = ½ [60 x 95] + 60 x 5 = 3150

Area A2 = 40 x 5 = 200

Energy Ratio = (3150/3350) **:** (200/3350) = 94**:**6

Even in this case, though current ratio is 60**:**40, energy ratio is 94**:**6.

Therefore, the 80/20 criterion is itself highly conservative. If the current profile satisfies this requirement, the overall inaccuracy in energy measurement becomes practically insignificant.

Is a Dual-Ratio CT Necessary?

Many times, dual ratio primary is specified. With the availability of Cl 0.2 CTs, which guarantees error from 5% to 120%, the need for dual primary ratio is usually not there. If the user still insists on procuring dual ratio CT, the next *lower* standard ratio of 600/1 can be considered. The lower rating is chosen considering that 220kV line loading will not exceed 275MVA (√3x220x1.2x600) except under very abnormal system conditions. In this case the CT rating will be <u>750</u>-600/1 (as per convention,

operating tap is shown with underline). However, this additional tap merely increases manufacturing cost *without providing any meaningful operational benefit*.
Also, by default percentage error is guaranteed only at the highest tap. Field experience shows that, in most installations, the CT ratio selected during commissioning has never been changed throughout the service life of the installation.

Example 2*: *220 kV Cable

For 1200mm^2 Cu, 220kV Cable, the average maximum loading expected per circuit is 300MVA corresponding to 787A. With 10% margin, the approximate rating is 866A. The nearest standard rating of 800A/1 can be chosen. The guaranteed accuracy class shall be applicable for this ratio. For Cl 0.2, percentage error is guaranteed from 5% to 120% corresponding to 15MVA (40A) to 366MVA (960A). This comfortably satisfies the 80/20 criterion.

The charging current of a typical 220 kV cable is about 8 A/km. Consequently, even an unloaded 5 km cable carries approximately 40 A, which already falls within the guaranteed accuracy range.
For this reason, specifying Class 0.2S, which extends accuracy down to 1% of rated current (8 A), offers little practical benefit. Even the no load (charging) current of a 1 km cable reaches this value.

Example 3*: *400 kV Transmission Line

Consider a 400 kV transmission line with an expected loading of 600 MVA, corresponding to approximately 860 A. Including a 10% design margin, the required CT primary current becomes approximately 953 A. The nearest standard CT ratio is therefore 1000/1 A.
For Cl 0.2, guaranteed measurement accuracy extends from 50 A (5%) to 1200 A (120%). This corresponds to approximately 35 MVA to 831 MVA. This will generally fall within 80/20 criterion.
The charging current of a typical 400 kV overhead line is approximately 0.8 A/km. Thus, even an unloaded 62 km transmission line carries about 50 A, which already lies within the guaranteed accuracy range of a standard Class 0.2 CT.
Similarly, the extended Class 0.2S accuracy begins at 10 A, corresponding to the no load (charging) current of only about 12 km of line. Consequently, the additional benefit of the extended accuracy class is minimal for this application.

Example 4: 765 kV Transmission Line

Consider a 765 kV transmission line with an expected maximum loading of 2000 MVA per circuit, corresponding to 1509 A. Allowing a 10% design margin, the required CT primary current becomes approximately 1660 A. The nearest standard CT ratio is therefore 2000/1 A.

For a Class 0.2 CT, guaranteed measurement accuracy extends from 100 A (5%) to 2400 A (120%), corresponding to an operating range of approximately 132 MVA to 3180 MVA. This operating range comfortably satisfies the 80/20 criterion.

The charging current of a typical 765 kV transmission line is about 1.8 A/km. Hence, even an unloaded 56 km line carries approximately 100 A, which already lies within the guaranteed accuracy range of a standard Class 0.2 CT.

The extended Class 0.2S accuracy begins at 20 A, corresponding to the no load (charging) current of only about 11 km of line. Consequently, the additional benefit of specifying Class 0.2S for this application is negligible.

Example 5: 220/33 kV, 125 MVA Power Transformer

The rated HV current of a 220/33 kV, 125 MVA transformer is 328 A. Allowing 10% overload, the maximum expected current becomes 360 A. The nearest standard CT ratio is therefore 400/1 A, corresponding to 153 MVA.

For Cl 0.2, guaranteed measurement accuracy is available from 8 MVA (5%) to 183 MVA (120%). This will fall within 80/20 criterion.

Immediately after transformer energization, the loading may remain below 5% of rated current for a short duration. The resulting measurement error is acceptable because the magnitude of the measured energy during this period is very small.

It may also be noted that the no-load current of modern transformers is typically less than 0.5% of rated current and is predominantly reactive. Accurate measurement of no-load losses under site conditions is neither practical nor necessary.

On the 33 kV side, the rated current is 2187 A. Allowing 10% overload, the expected maximum current becomes 2406 A. The nearest standard CT ratio is 2500/1 A, corresponding to 143 MVA.

For a Class 0.2 CT, guaranteed measurement accuracy extends from approximately 8 MVA (5%) to 171 MVA (120%).

Accordingly, the recommended metering CT ratios are:

- HV Side: 400/1 A, Class 0.2
- LV Side: 2500/1 A, Class 0.2

Example 6: Auto-Transformers

Example 6.1 – 400/220 kV, 600 MVA Auto-Transformer

The rated current on the 400 kV side is 866 A. Allowing 10% overload, the maximum expected current becomes 953 A. The nearest standard CT ratio is 1000/1 A, corresponding to 694 MVA.

For a Class 0.2 CT, guaranteed measurement accuracy extends from approximately 35 MVA (5%) to 833 MVA (120%). The recommended HV-side metering CT is therefore, 1000/1 A, Class 0.2.

The rated current on the 220 kV side is 1575 A. With 10% overload, the expected maximum current becomes 1732 A. The nearest standard CT ratio is 2000/1 A, corresponding to 763 MVA.

This provides guaranteed measurement accuracy from approximately 38 MVA (5%) to 916 MVA (120%). Accordingly, the recommended LV-side metering CT is 2000/1 A, Class 0.2

Example 6.2: 765/400 kV, 1000 MVA Auto-Transformer

The rated current on the 765 kV side is 755 A. With 10% overload, the expected maximum current becomes 830 A. The nearest standard CT ratio is 1000/1 A, corresponding to 1327 MVA.

For a Class 0.2 CT, guaranteed measurement accuracy extends from approximately 66 MVA (5%) to 1591 MVA (120%). The recommended HV-side metering CT is therefore, 1000/1 A, Class 0.2.

For the same transformer, the rated current on LV side is 1443A. With 10% overloading maximum current expected is 1588A. Choose the nearest standard rating of 1500/1, corresponding to 1040 MVA.

For this ratio, guaranteed measurement accuracy extends from approximately 52 MVA (5%) to 1248 MVA (120%). The recommended LV-side CT is therefore 1500/1 A, Class 0.2

A Practical Observation

The philosophy adopted for selecting CT ratios has an interesting parallel with the tap range specified for On-Load Tap Changers (OLTCs).

As a general practice, power transformers are specified with a tap range of ±10%. However, operational experience indicates that many transformers either remain on their initial tap throughout their service life or utilize only a very small portion of the available tap range.

It is therefore prudent to avoid specifying features that are unlikely to be used. In fact, for several EHV auto-transformers, particularly 765/400 kV and 400/220 kV units, tap changers have *even been eliminated* without any adverse operational consequences.

The same philosophy applies to multi-ratio CTs**:** features that are seldom, if ever, used only increase equipment cost without delivering commensurate engineering benefits.

Example 7: 660 MW Generator

Consider a 660 MW, 21 kV, 0.9 pf generator. The rated current is 20,162 A. Allowing 10% overload, the expected maximum current becomes 22,178 A. The nearest standard CT ratio is 25,000/5 A, corresponding to 910 MVA.

For generator Cl 0.2S accuracy is chosen. This extended accuracy class provides guaranteed measurement accuracy from approximately 9 MVA (1%) to 1092 MVA (120%), comfortably satisfying the 80/20 criterion.

Of course, continuous operation below 60MW is not practical, even with oil firing, in steam units due to flame instability.

Secondary resistance R_{CT} for generator CTs will be about 5Ω. Since the rated secondary current I_S is 5A, the burden {proportional to $I_S^2 \times R_R$) will be in the range of 150 to 200VA. Thus, the typical specification for metering core will be 25000/5, Cl 0.2S, 200VA.

Generator metering core is also used for Reverse Power and Low Forward Power relays, which require very sensitive settings. The extended accuracy class is advantageous for these applications.

A similar recommendation applies to hydro generators.

For diesel generator sets and gas turbine generators, however, Class 0.2 is generally adequate, and the extended accuracy class is not mandatory.

Example 8: HT and LT Motor Feeders

Electrical measurements in motor feeders are primarily used for performance monitoring and trend analysis rather than revenue metering. In such applications, measured values are compared over time to identify gradual changes in operating conditions. Since the CTs and measuring instruments remain unchanged, small absolute errors have little practical significance. Consequently, an accuracy better than Class 1 is generally unnecessary.

For illustration consider a large motor, say 9MW, 6.6kV, 920A. This is the typical size of a BFP (Boiler Feed Pump) motor in power plants. Choose the nearest standard rating of 1000/1. For Cl 1, guaranteed measurement accuracy is available from 120% to 5%. i.e., 1200A to 50A. No load current of induction motor is above 30%, i.e., about 275A. Hence the guaranteed measurement accuracy is obtained under *all operating conditions*. Specifying an extended accuracy class for HT motor feeders offers no meaningful benefit.

Let us compare error magnitudes considering extreme cases Cl 1 and Cl 0,.2S. Assume the motor is generally loaded up to 60%. In case of Cl 1, the error will be about 1.25% and for Cl 0.2S the error will be 0.2% (interpolated from Table 2). The maximum differential error will be 1.45% assuming one error is positive and the other is negative. Let ΔI be the difference in current measurement. For 600A primary current, this corresponds to about 9A (600 x 0.0145). Let ΔP be the change in process parameters like flow, pressure, temperature, etc., for given ΔI . If ΔP is almost non-measurably small for a given ΔI, as in actual practice, there is no value addition in measuring the current with extraordinary precision. It is difficult to believe that the trend obtained with Cl 0.2S CTs can only reveal significant changes in process parameters that may not be revealed using Cl 1.0 CTs.

Accurate measurement per se does not necessarily result in process improvement. Using an atomic clock to measure the speed of passenger train gives only a false sense of accuracy without delivering any tangible operational benefit.

Summary of Recommended Metering CT Ratios

Table 3 summarizes the recommended CT ratios and accuracy classes for typical EHV applications. A noteworthy conclusion emerges from these examples.

For the overwhelming majority of transmission lines, cables and transformers, a carefully selected single-ratio CT with Class 0.2 accuracy fully satisfies metering requirements.

The extended accuracy class 0.2S is justified only in a limited number of specialized applications, while Class 1 is entirely adequate for motor feeders.

Equipment	CT Ratio	MVA Range for Guaranteed Accuracy		Accuracy Class
		Minimum	Maximum	
220 kV Line	750/1.	14	343	0.2 (0.2S)*
220 kV Cable	800/1.	15	366	0.2 (0.2S)*
400 kV Line	1000/1	35	831	0.2 (0.2S)*
765 kV Line	2000/1	132	3180	0.2 (0.2S)*
220kV/33kV 125MVA Transformer	HV:400/1 LV:2500/1	8 8	183 171	0.2 0.2
400kV/220kV 600 MVA Auto-Transformer	HV:1000/1 LV:2000/1	35 38	833 916	0.2 0.2
765kV/400kV 1000MVA Auto-Transformer	HV:1000/1 LV:1500/1	66 52	1591 1248	0.2 0.2
660MW, 21kV Generator	25,000/5	9	1092	0.2S
Motor Feeders	As per Rating			1.0

Note **-** * **:** Refer Sec 4.0 for applicability of Extended Accuracy Class

Table 3

4.0 Application of Extended Accuracy Class

For most of the lines / cables / equipment, Cl 0.2 accuracy class will be adequate. For motor feeders Cl1 accuracy class is adequate. The percentage error is guaranteed from 5% to 120%. If at all, only in the following cases extended accuracy class of 0.2S, where percentage error is guaranteed from 1% to 120%, is recommended:

i) Generator / UAT / ST (UAT – Unit Auxiliary Transformer Incomer to MV Switchgear, ST – Station Transformer incomer to MV Switchgear) – used usually for estimating Unit Auxiliary Consumption and Heat Rate for submission to statutory authorities.
ii) Power evacuation lines from generating Plants
iii) Inter-state & Inter-regional ties only if it involves commercial settlement mechanism
iv) Feeders at consumer plant premises receiving supply directly from utility

For most other applications, the additional cost associated with the extended accuracy class is difficult to justify.

Why Higher Accuracy Does Not Always Produce Better Measurements

There is a common perception that specifying Class 0.2S automatically results in highly accurate energy measurements. In practice, the overall measurement accuracy depends on several factors, many of which introduce uncertainties far greater than the improvement offered by the extended accuracy class.

Some of the important factors are discussed below.

1. Multi-Ratio CTs

   Manufacturers generally guarantee the specified accuracy only for the highest primary tap. If any lower tap is used, the actual ratio error can differ from the guaranteed value. Consequently, the perceived benefit of specifying an extended accuracy class may not be realized in service.

2. Actual Burden at Site

   CT accuracy is guaranteed for the specified burden. In practice, the burden connected to the CT often differs substantially from the design value because of variations in CT secondary resistance, cable lengths, meter burden, etc. Such deviations can alter the actual measurement error.

3. Summation of CT Currents

   Certain EHV substation configurations, particularly the 1½-breaker scheme, require currents from more than one CT to be electrically summed before being supplied to the metering device. This additional processing introduces another source of uncertainty that is independent of the CT accuracy class.

4. Voltage Transformer Errors

   Energy measurement is based on both current and voltage. Even if the CT were perfectly accurate, the measured energy would still be influenced by the errors introduced by the associated Voltage Transformer (PT/CVT).

5. Cumulative Effect of Multiple Errors

   An energy measurement chain consists of several components—CTs, PTs, meters, wiring and associated signal processing. Each component contributes its own error, which may be either positive or negative. The combined error therefore depends on the cumulative effect of all these elements rather than on the CT alone.

A Practical Perspective

Considering all these factors, it is unrealistic to assume that the energy recorded at site using a Class 0.2S CT represents the 'exact energy' flowing in the primary circuit. The improvement obtained by extending the guaranteed accuracy from 5% to 1% of rated current is often overshadowed by uncertainties introduced elsewhere in the measurement chain. When the loading profile satisfies the 80/20 criterion, a Class 0.2 CT provides more than adequate accuracy for monthly energy accounting in almost all transmission and substation applications.

Similarly, Class 1 CTs are entirely adequate for motor feeders, where the objective is operational monitoring rather than revenue metering.

The selection of CT accuracy class should therefore be guided by engineering necessity rather than perceived precision. Specifying an unnecessarily high accuracy class increases equipment cost without delivering any measurable improvement in system performance or commercial accounting.

5.0 CT requirement for ABT meters

At the MV level (typically 11 kV and 33 kV), CTs used for Availability Based Tariff (ABT) metering are often specified with Class 0.2S accuracy as a mandatory requirement. While this requirement appears attractive from the standpoint of measurement accuracy, its practical value deserves closer examination.

The primary objective of the ABT mechanism is to forecast system demand and prepare a day-ahead generation schedule. The forecast forms the basis for scheduling power under the Power Purchase Agreement (PPA). If the actual demand exceeds the scheduled requirement, the additional power must normally be procured through the Power Exchange.

Preparing an accurate day-ahead schedule is a complex exercise that depends on numerous variables, including:

- Historical load pattern
- Ambient temperature
- Humidity
- Cloud cover
- Seasonal variations
- Consumer behaviour
- Data collected from individual ABT meters

Thus, the CT is only one element in a much larger forecasting process.

Availability of Meter Data

ABT meters record energy in 96-time blocks per day, each representing the average demand over a 15-minute interval. These measurements are automatically transferred to the Automatic Meter Reading (AMR) server, which forms the primary database for forecasting and scheduling.

However, in practice, data from some meters may occasionally become unavailable due to Meter hardware failure, Communication failure, AMR server issues, Maintenance activities, etc. Whenever this occurs, the missing data are generally substituted using measurements obtained from the SCADA system, provided the SCADA database is available.

Limitations of SCADA Measurements

Unlike revenue meters, SCADA analog measurements incorporate a dead band, typically around 2%. An updated value is transmitted from the Remote Terminal Unit (RTU) to the SCADA server only when the measured quantity changes by more than this preset threshold. This practice is intentionally adopted to reduce communication traffic between substations and the control centre. Consequently, dead band itself introduces inherent errors in measured data obtained from SCADA.

Further Sources of Forecasting Error

If SCADA data are also unavailable, manually substituted values may be used to replace the missing measurements. Naturally, the uncertainty associated with manually entered data is considerably greater than the normal measurement error of the CT.

Moreover, weather-related parameters—such as temperature, humidity and cloud cover—are themselves subject to forecasting errors, and these uncertainties often have a much greater influence on load prediction than the small differences between CT accuracy classes.

Since the day-ahead schedule is derived by combining information from multiple sources, the contribution of normal CT errors becomes relatively insignificant.

Practical Recommendation

From the foregoing discussion, it follows that specifying an Extended Accuracy Class (0.2S or 0.5S) CT for ABT metering provides little measurable improvement in forecasting accuracy. For the purpose of preparing 15-minute average demand schedules, a Class 0.5 metering CT is generally adequate. The improvement achieved by extending the guaranteed low-current accuracy from 5% to 1% of rated current is negligible when compared with the larger uncertainties introduced elsewhere in the forecasting process.

Accordingly, Class 0.5 CTs are adequate for ABT metering applications, and specifying an extended accuracy class should not be regarded as a mandatory requirement.

6.0 Conclusion

The practice of specifying multi-ratio CTs and extended accuracy classes has evolved over many years and, in many organizations, has become a standard specification rather than a consciously evaluated engineering decision. This paper has attempted to revisit that practice from the standpoint of actual system operation.

The examples presented demonstrate that a single, appropriately selected CT ratio is adequate for most transmission lines, cables and transformers. The unused primary taps provided in multi-ratio CTs rarely contribute any operational advantage throughout the service life of the equipment.

Similarly, the analysis shows that Class 0.2 accuracy is sufficient for the majority of EHV metering applications, while Class 1 is adequate for motor feeders. The Extended Accuracy Class (0.2S) should be reserved only for applications where improved low-current accuracy has genuine commercial or operational significance, such as generator metering, power evacuation lines from generating stations and selected revenue metering installations.

The paper also highlights an important engineering reality: the overall accuracy of an energy measurement system depends not only on the CT, but also on several other factors, including burden variations, voltage transformer errors, current summation, communication systems and data processing. Pursuing ever-higher CT accuracy without considering these factors offers little practical benefit.

The same reasoning applies to ABT metering, where the accuracy of demand forecasting is governed far more by load prediction algorithms, weather forecasts and data quality than by marginal improvements in CT accuracy.

Ultimately, good engineering is not about specifying the highest possible performance for every component. It is about selecting specifications that are fit for purpose, technically justified and economically sound.

Replacing the routine use of multi-ratio CTs with well-chosen single-ratio CTs can reduce cost, simplify design, facilitate testing and maintenance, and improve standardization—without sacrificing the accuracy required for reliable metering and commercial accounting.

7.0 References

[1] IEC 60044-1 -2003: Instrument Transformers – Part 1- Current Transformers

[2] CT loading assessment - The IESO Revenue Metering Standing Committee Final report – 2010, Ontario, Canada