Africa Journal of Technical & Vocational Education and Training

Analysis and Evaluation of CT Transformation Error for Non Self Contained Smart Meters Installed in Smart Cities

Charles Ndung'u
Institute of Energy Studies and Research – Kenya Power, Nairobi, Kenya

Abstract

Current transformers, commonly abbreviated as CTs, are electrical instruments that are designed to produce an alternate current at secondary windings which is proportional to the current at the primary winding. CTs are mainly used in energy metering and for system protection. In the former, CTs play two key roles, namely; to offer an electrical isolation between measuring devices and high voltage conductors, and as current sensor for a transformer operated (non self-contained) energy meter. Upcoming smart cities are characterized by large power consumers. To be able to accurately measure the energy consumed, non self-contained energy meters are installed at large power consumers. It is important to determine the current transformation errors at various customers' loadings (primary current) and connected CTs' burden; connected loads of CTs, that is, energy meters and respective wire effective resistance. This paper presents the CT errors at different primary current and burdens. In simple terms, this paper describes how CT's error correlates with primary current and burden. The research was conducted using CPC 100, a universal primary injection set, where different current transformer turn ratios (100/5 A, 200/5 A, .. 2000/5 A) were used. It also consisted copper wire of various lengths (16 m, 12 m…4 m) and cross sectional areas (2.5 mm2 and 6.0 mm2) to vary the CT connected load. From the research study, the take away points were that provided the CT is not saturated or near saturation, the turns ratio errors are almost equal on all the CTs under study. Further, high burden results noted to be negative transformation errors. From this study, it is recommended that for accurate energy measurement in smart cities where non-self-contained energy meters are installed, the key factors to consider are the saturation point of CT and the connected burden..

Key words: ***Current transformer, smart cities, burden, non-self-contained***

Copyright © 2022 for AfriTVET Journal held by RVTTI, Rift Valley Technical Training Institute
ISSN 2518-2722

Introduction

In recent times, smart cities have become common occurrences. These are cities that embrace the internet of things (IoT), smart grids, e-health, augmented reality and other advanced technologies to improve and revolutionize cities. Furthermore, smart cities are characterized by high quality and socially integrated urban environments (Puzovic, Koprivica, Milovanovic, & Djekic, 2014). . To realize these key features of a smart city, power supplies play a critical role. To ensure power distribution utility measure accurately power consumed by end users, energy meters are installed at point of common coupling of power end users. It can be pointed out that energy meter is one of the major devices in power system. In addition, it is also used to determine energy generated by electricity generators and what has been delivered to the load center via transmission and distribution networks. The extent to which the smart cities grow fully depends on the sustainability and reliability of power supplying industries and residential houses. It is worth noting that a typical smart city requires smart grid that is expandable and can be integrated with other intermittent power sources such solar, wind, hydrocarbons, power storage, and biomas as shown in https://internetofthingsagenda.techtarget.com/definition/smart-city; a typical structure of smart city (Electrical Engineering Information, 2017).Modern smart cities are characterized by large power consumers that are metered by none self-contained meters depicted in Figure 1.

Figure 2: Non-self-contained energy meter and associated three current transformers

© 2022 RVTTI, *AfriTVET*, **7** (1), 208-217

From Figure 1, the energy meters measure energies by transforming secondary values of the current transformer (CT) to primary values by use of transformation factor. That is, if for instant the CT transformation turn ratio is 100/5 A, the transformation factor config- ured (set) in the meter is 20. A systematic diagram shown in Fig. 2 present single line diagram of a three phase non-self-contained energy meter.

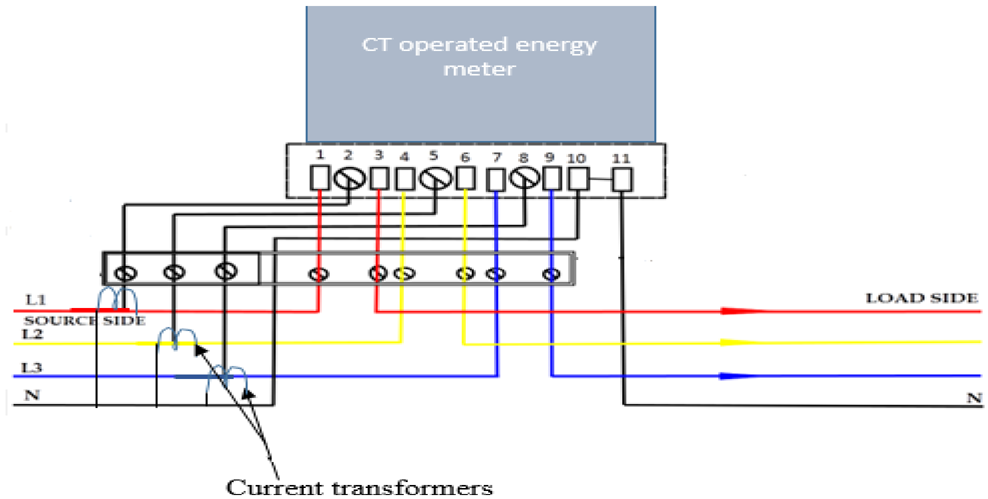

Figure 2: Non self-contained three phase energy meters using current transformer to step down primary current to small current sufficient to be connected to a meter.

This paper presents the factors that affect the CT transformation errors to enable the power distribution utility do correct energy measurement where non self-contained three phase energy meters are installed.

Literature Review

The Principle Operation of CT

A CT consists of two sets of wire windings wound around an iron core as depicted in Figure 3. It operates in principle of electromagnetic induction. This implies that primary current produces magnetic field, H that generates magnetic flux, ϕm. Magnetic flux determines the amount of magnetic density, B in a material core. Induced magnetic flux at secondary windings generates voltage Vs and also secondary current Is (when a burden is connected to the secondary leads of the CT, example an energy meter). The induced magnetic flux at secondary windings, which has opposite polarity, neutralize the magnetic flux generat- ed by primary current, Ip hence resulting to a zero net flux in CT core. The relationship between Is and Ip depends on turn ratio (N) and exciting current IE (Hargrave, Thomp- son, & Heilman, 2018).

A simplified equivalent CT electrical circuit is shown in Figure 3.

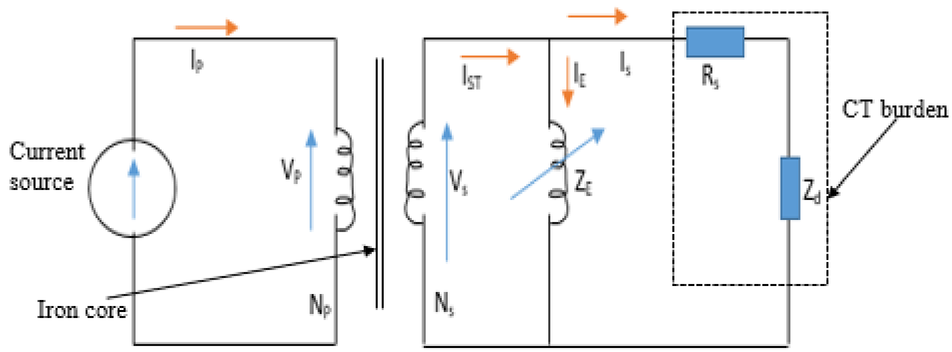

Figure 3: Simplified equivalent CT circuit (Hargrave, Thompson, & Heilman, 2018).

Where; I_{ST} is the transformation current, I_E is the Exciting current.

From Figure 3, it can be seen that excitation current, I_E has direct relationship with primary current (I_p). A current phasor diagram, also known as vector diagram of the above CT circuit, is shown in Figure 4 (Theraja, 1994).

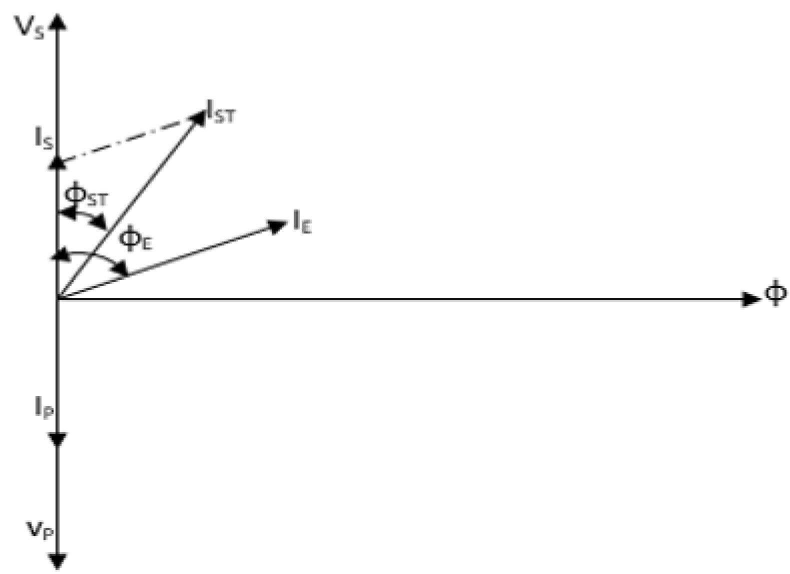

Figure 4: A vector diagram for current transformer

From Figure 4, it can be seen that IST is a vector sum of excitation current (I_E) and load current (I_S). It is worth to mention that high primary current result to high excitation current which is limited by core getting saturated (Theraja, 1994). Excitation current consists of eddy and leakage currents. The former current is responsible of hysteresis losses and no-load losses of current transformer.

CT Transformation Error

It is well known that the value of transformation ratio (actual ratio) is not equal to the turn ratio (N). The error, g in percentage, mainly depends on magnetizing current and loss components of the CT, burden and burden power factor (inductive/ capacitive) (IEC,

2012). CT error is expressed as equation (1).

$$g = \left(\frac{NI_{s-}I_p}{I_p}\right) *100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where terms in (1) are defined as follows;

g is the CT error in %, N is turn ratio, I_p is the primary current, and I_s is the burden current

Methodology

Setup to determine CT Error Vs Primary Current A set of CT turn ratios *(100/5 A, 200/5 A, 300/5 A, 500/5 A, 1000/5 A, 1500/5 A,* and *2000/5 A*) were investigated in laboratory experiment. The investigation was done using a current generator, CPC 100, a universal primary injection test set, of class 0.02S shown in Figure 5.

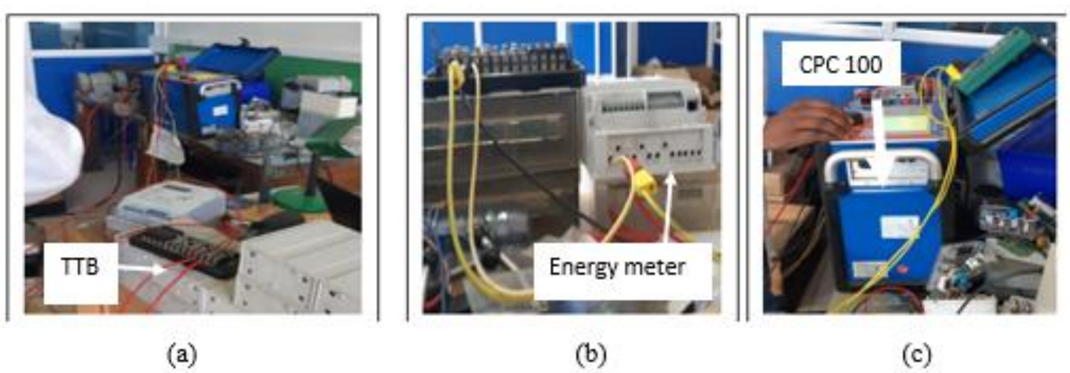

Figure 5: An experiment setup; (a) experiment setup, (b) non-self-contained energy meter, and (c) a CPC 100, a universal primary injection test set with automated testing procedure and test reports

Where; TTB is the test terminal block

Set Up to Determine CT Error Vs Connected Burden

Burden of a CT depends on the connected load (measuring device) and effective resistance of the wire. The effective resistance of the wire is a factor of length and cross-sectional area of the wire. The two factors are related as per equation (2).

$$\text{Wire Burden (Resistance)} = \frac{\rho L}{A} \tag{2}$$

Where; ρ the resistivity constant, L is is the loop length of the wire i.e. to and from the meter, and A is the cross-sectional area of the wire.

A laboratory setup to establish the impact of burden on the performance of CT was done. The experiment involved a non self-contained energy meter, test terminal block (TTB) and wire of different lengths and cross-sectional areas (sizes) to obtain diverse CT burdens as depicted in Figure. 5(a). A systematic diagram of experiment setup is as shown in Figure. 6.

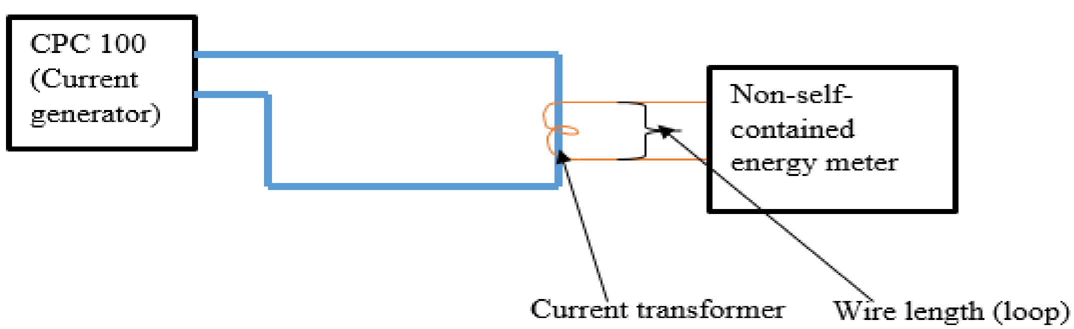

Figure 6: Systematic diagram of setup that involved CPC 100, current transformer and non-self contained meter

The wire sizes used were as shown in Table 1.

Table 1
Length and Cross-Sectional Area of Wires used in Experimental Setup

Wire cross-sectional area	Length of the wire				
2.5mm^2	4m	6m	8m	12m	16m
6.0mm^2	4m	6m	8m	12m	16m

From the Table, it is noted that the wires used for investigation were of different length but same for each wire size, to easily compare the results obtained for two different wires' cross-sectional areas.

In this experiment, CT of turn ratio 100/5 A was used during investigation to;

i). Avoid overheating of the current generator (CPC 100)
ii). Achieve 150% of rated primary current on the wire lengths and sizes samples

Assumption was made, that all the other CT turn ratios (200/5 A, 300/5 A, ...) give similar results when tested under similar condition.

Findings

CT Errors Vs Primary Current Results Obtained

The aim of this study was to establish how CTs error changes at different primary current. Two values of primary current were supplied to each sample of the CTs, that is, 1 A and5 A respectively. This range of current was selected to avoid tripping of current generator. If a higher current, for instant, 20 A was used, this could cause the CPC 100 to trip (stop) due to overheating before all the CTs errors are obtained for the higher CT ratios. Table 2 shows the results for 1 A and 5 A respectively for the sampled CT turn ratios under investigation which was conducted at power frequency of 50 Hz

Table 2

Results Obtained for Current of 1 A and 5 A, Respectively

CT turn ratio	**100/5A**	**200/5A**	**300/5A**	**500/5A**	**1000/5A**	**1500/5A**	**2000/5A**
% of In (1A)	1%	0.50%	0.33%	0.20%	0.10%	0.06%	0.05%
Error	-0.26	-1.27	-0.58	-0.4	-0.6	-0.5	-1.2
% of In (5A)	5%	2.50%	1.67%	1.00%	0.50%	0.33%	0.25%
Error	-1.13	-0.25	-0.03	-0.02	-0.32	-0.08	-0.12

Where; In is the nominal current

From Table 2, it is noted that the lower the primary current, the higher (negative) is the CT transformation error. It is important to point out that the error increases proportionally with decrease of percentage of nominal current of the CT (comparing errors measured for 100/5 A and 2000/5 A when the primary current is 1 A). This result was as expected because small magnitude of CT inputs implies high magnetization current IE and therefore less current burden (I) flows. Furthermore comparative analysis between transformation errors of 200/5 A and 1000/5 A, both at 0.5% of nominal current, (i.e. when 200/5 A primary current is 1 A, and 1000/5 A primary current is 5 A), shows that errors obtained are not comparable. It can be concluded that CT transformation errors are not entirely determined by percentage of the primary current. It is for this reason an experiment was setup to establish the other factor that affect CT transformation ratio errors, that is, the burden. The subsequent section shows the results obtained.

CT Errors at Different Burdens

The purpose of this investigation was to establish how CT errors varies with CT burden. In this experiment, a CT turn ratio of 100/5 A was used and different wire length (4 m, 8 m, 12 m, 16 m) and cross-sectional areas (2.5 mm2 and 6.0 mm2). With a 100/5 A CT turn ratio, the CPC 100 equipment could supplies upto a primary current of 150 A (1.5 times of nominal current of the CT under test) without tripping due to overload. The CT error results obtained were for 1 A and 150 A. The reason for injecting 1 A was to establish the effects of low load on CT transformation errors and on the other hand, 150 A was selected to investigate the effect of CT saturation (assumption made was CT saturate at approx. at 120% of nominal current of the CT, in this case at 120 A). Tables 3 and 4 show the measurement results obtained when primary current was 1 A and 150 A, respectively.

Table 3

Burden Vs CT Error when Primary Current is 1 A

Wire X-area	**Wire length**	**16m**	**12m**	**8m**	**6m**	**4m**
6.0mm2	Burden (VA)	2.69	2.7	2.76	2.77	2.85
	Error	0.51	0.08	0.55	0.53	0.4
2.5mm2	Burden (VA)	3.34	3.41	3.3	3.47	3.37
	Error	0.16	-0.2	0.46	0.51	0.08
% burden changes		**24.16**	**26.30**	**19.57**	**25.27**	**18.25**

Table 4

Burden Vs CT Error when Primary Current is 150 A

Wire X-area	**Wire length**	**16m**	**12m**	**8m**	**6m**	**4m**
6.0mm2	Burden (VA)	3.69	3.63	3.51	3.61	3.89
	Error	-0.23	-0.2	0.12	0.04	0.14
2.5mm2	Burden (VA)	3.83	4.0	3.65	4.18	4.27
	Error	0.25	0.19	0.38	0.07	-0.1
% burden changes		**3.79**	**10.19**	**3.99**	**15.79**	**9.77**

From above Tables 3 and 4, the followings are deduced;

i). The burden of the CT is higher for 2.5 mm2 wire when compared to 6.0 mm2 wire. This could be due to high effective resistance associated with 2.5 mm2 wire.

ii). The CT errors are negative error when the burden increases as can be seen in Table 3. This could be due to the fact that less current flow through the burden due to wire high resistance as can be seen from equation (2).

iii). When the CT is assumed is saturated (i.e. In >120% of In), the burden difference between the two cross-sectional areas wire, i.e. 2.5 mm2 and 6.0 mm2, reduces as noted in Table 4. This is presumed to be due to high excitation current hence less current flows to the load (energy meter).

Conclusion and Recommendation

From this study, for accurate metering of the energy supplying large consumers in smart cities,it has been shown that primary current plays a major role on CT transformation errors. Low primary current results to high negative CT transformation errors. This implies that large power consumers operating on low load, the energy consumption is usually less than when operating at higher loads. Both 6.0 mm2 and 2.5 mm2 cross-sec- tional areas of copper wire were found to give satisfactory CT transformation errors and burdens that were well within CT rated burden (i.e.15 VA). However, for a low primary current and high burden (long wire loop), a bigger size of cross sectional area wire is recommended. Further, where a precious primary to secondary current transformation is paramount, that is, small current transformation error may results to high energy (kWh) measurement deviation such as at bulk energy measurement, (at power generation stations) and at bulk power consumers for instant cement manufacturers and steel mills industries.

References

CPC 100. (2007). *A universal primary injection test set reference manual*. OMICRON electronics GmbH. Retrieved from https://www.omicronenergy.com/ en/products/cpc-100/.

Electrical Engineering Information. (2017). *Errors, characteristics and methods to reduce errors in current transformer*. https://www.electricalengineeringinfo.com/ 2017/04/errors-characteristics

Hargrave, A., Thompson, M. J., & Heilman, B. (2018, March). Beyond the knee point: A practical guide to CT saturation. *In 2018 71st Annual Conference for Protective Relay Engineers (CPRE)* (pp. 1-23). IEEE.

IEC. (2012). IEC61869-2: *Instantaneous transformers part 2 additional requirements for current transformers*.

KPLC. (2016). KP1/10A.2B/3/4-02: *Specifications for low voltage ring type measuring current transformers*. https://kplc.co.ke/img/full/UpMzgA14Ll2TSCANNEDSPECS-%20RING%20TYPE%20CTs.pdf

Puzovic, S., Koprivica, B. M., Milovanovic, A., & Djekic, M. (2014). Analysis of measurement error in direct and transformer-operated measurement systems for electric energy and maximum power measurement. *Facta Universitatis, Series: Electronics and Energetics*, 27(3), 389-398.

Theraja, B. L. (1994). *A text Book of Electrical Technology*. (21st ed.). New Delhi: S. Chand Publishing. Retrieved from https://www.pinterest.com/pin/681099143627970487/

© 2022 RVTTI, *AfriTVET*, **7** (1), 208-217