Computation of Accurate Energy from the Recorded Past Data for High Valued Consumers in NEA

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Abstract: In the present day context of conservation of energy and collection of revenue, the role of energy meter and metering is vital for any Electricity utilities. Accuracy and proper functioning of energy meters and metering equipment are of utmost importance, otherwise there may be heavy loss to the utilities. The Nepal Electricity Authority (NEA), a utility involved in generation, transmission & distribution of electricity has faced many difficulties in computation of actual energy occurring due to some peculiar error connection of meter & metering units. The analysis and computation of actual energy occurring due to common connection errors such as current transformer (CT) and potential transformer (PT) polarity reversal, missing potential/current input and missing multiplying factor are available in many documents and are being practiced in NEA. However, there are two most important cases namely CT secondary of two or more phases wired in series and incorrect association of CT & PT that has been studied and analyzed in this paper. In the paper, the analytical as well as vectorial analysis has been made under each of the aforementioned abnormal conditions and its impact on the actual energy has been assessed. Simultaneously, mathematical solution has been devised to calculate the accurate energy and verified with MATLAB.

Keywords: accurate active energy, accurate reactive energy, CT, PT.

1. Introduction

There are approximately 5,000 consumers where NEA has installed Static Energy Meters for energy measurement purpose. Despite of many amazing features, initially Static Energy Meter was introduced to NEA only for the Time of Day (TOD) facility which was recently being introduced. The Static Energy Meter was introduced to NEA in the year 1999 by Loss Reduction Project as a pilot project to meet the recent tariff structure. As there was increasing deficit of power in the peak hours, it was a necessity to install energy meters which was capable of recording energy in the different periods of time intervals of day. Electricity Tariff Fixation Committee had proposed a tariff structure that recommended a day to be divided into three time slots and different tariffs to be applied to these time slots energy consumption with the target of lowering the peak demand.

The Static Energy Meters records energy as the arithmetic sum of the energy flowing through individual phase which is also the principle of Electro-mechanical energy meters. Beside all other facilities provided by static meters, most significant is it records energy, both active and reactive, on either direction, i.e. it is bi-directional energy meter.

There are various problems identified in the field of installation of meter and metering equipments in NEA which lead ultimately to the incorrect and unusual billing to the consumer resulting legal dispute between consumer and utility when problem gets identified and rectified [1]. Those problems are CT polarity reversal, missing Potential/Current input, missing multiplying factor [2, 3]. Basically, the above mentioned three problems are common to NEA and are being practiced with appropriate assumptions according to its rules and regulations.

Apart from the above mentioned cases, there are two most important cases that need to be studied and analyzed for the accurate billing purpose. Those cases may arise from the wrong wiring by manufacturer or by poor workmanship of the authorized personals. Those cases are CT secondary of two or more phases wired in series with each other and incorrect association of CT & PT[3].

2. Measurement of Power and Energy

The power expression for a single phase ac system is given by

$P = V_{rms}I_{rms}Cos\phi - V_{rms}I_{rms}\cos(2\omega t \pm \phi)$ which is obtained with multiplication of instantaneous voltage and current.

For a 3 phase system, the sinusoidal components are 120 degrees separated from each other and get cancelled. So the electrical power for a three phase system is defined as $P = 3V_{rms}I_{rms}Cos\phi$ [4]. This power when multiplied with time duration yields energy which energy meter records in cumulative form. The multiplication of variables voltage $v = V_{pp}\sin\omega t$ and current $i = I_{pp}\sin(\omega t + \phi)$ never yields term containing $\sin\phi$. So the reactive power measurement by static meter is done by using $\cos(90-\phi)$ [3]. As energy is product of time and power, the cumulative energy can be expressed as

$$E = \sum_{t=1}^{n} P_n * t_n$$

And so is for reactive energy. It insists that any expression for power is equally valid for energy also. In the cases presented in the following sections assumptions made are

2.1 Balanced Load

Assuming balance load, the sinusoidal components with double the fundamental frequency would cancel each other, leaving a constant DC component of power.

2.2 Harmonics Free

The system under consideration is considered to be free from either type of harmonics, generated by source or by load or by the transformers installed.

3. Results and Discussion

The mathematical formulations derived for all identified cases presented are simulated with MATLAB. All simulations are done with load of 1KVA at different power factors.

3.1 Incorrect Association of CT and PT

To calculate the actual power, the measuring device must have inputs with correct sequence. This means that R section of the energy meter should get inputs from R phase PT and R phase CT, similarly for Y and B terminals. But due to incorrect installation this may not be the scenario in the actual field. Incorrect association of CT and PT can have 3 different configurations. For the sake of simplicity it is assumed correct PT sequence and varying CT sequence.

3.1.1 Correct PT sequence, CT sequence rotated 120 degrees clockwise

Assume a connection scenario in which A, B, C terminals of meter are connected with correct sequence A, B, C of potentials but with sequence of Current as C, A, B i.e. current sequence reflects 120 degrees clockwise rotation with respect to potential. The meter always records energy in reverse direction.

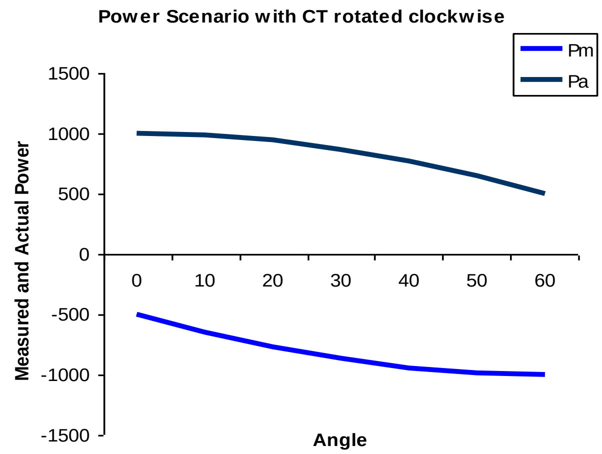

Figure 3.1: Actual power/energy vs measured power/energy

Such case can be presented with the vector diagram as shown below:

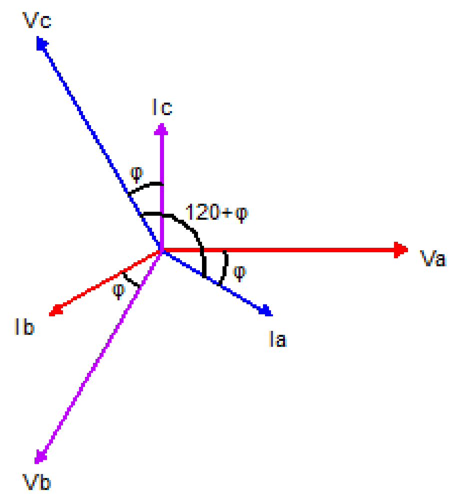

Figure 3.2: 3-phase system with CT rotated 120 degrees clockwise

The accurate power for presented case may be expressed as

$$P_a = -\frac{\left(P_m - \sqrt{3}Q_m\right)}{2}$$ where 'a' stands for accurate value and 'm' stands for measured value.

This relation can be expressed in terms of Total Cumulative energy as:

Active Energy actual = - (Active Energy measured - √3 Reactive Energy measured)/2

The expression above, for balanced condition, also holds for unbalanced condition. Assuming balanced voltage as it generally is, we can get the following relation for individual phases where capital sub-script stands for phase.

$$P_{Aa} = -\frac{\left(P_{Cm} - \sqrt{3}Q_{Cm}\right)}{2}, \quad P_{Ba} = -\frac{\left(P_{Am} - \sqrt{3}Q_{Am}\right)}{2}$$

$$P_{Ca} = -\frac{\left(P_{Bm} - \sqrt{3}Q_{Bm}\right)}{2}$$

The relations indicate that the actual power and hence energy for phase A is to be calculated from the recorded parameters of phase C and so for other remaining phases. It is obvious from the vector diagram also. As we are interested in the total cumulative energy, by adding these three equations we get the same equation presented earlier.

3.1.2 Correct PT sequence, CT sequence rotated 120 degrees anti clockwise

Another scenario is correct potential sequence but current sequence as B, C, A i.e. current sequence reflects 120 degrees anti-clockwise rotation with respect to potential. The meter records very small positive or negative value of energy for the practical power factor but goes positive with degrading power factor.

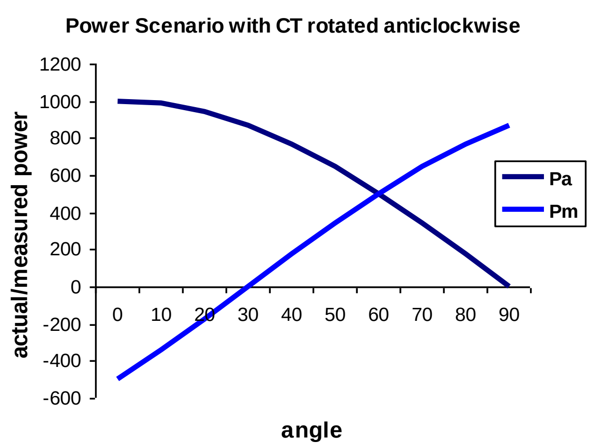

Figure 3.3: Actual power/energy VS measured power/energy

Such case can be presented with the vector diagram as shown below:

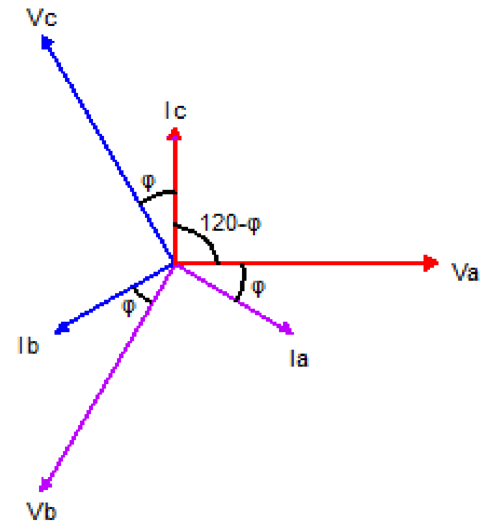

Figure 3.4: 3 phase system with CT rotated 120 degrees anticlockwise

The accurate power, for balanced load, for presented case may be expressed as

$$P_a = -\frac{\left(P_m + \sqrt{3}Q_m\right)}{2}$$

This relation can be expressed in terms of Total Cumulative energy as:

Active Energy actual = - (Active Energy measured + √3 Reactive Energy measured)/2

For unbalanced case, the phasewise power relations are

$$P_{Aa} = -\frac{\left(P_{Bm} + \sqrt{3}Q_{Bm}\right)}{2}, \quad P_{Ba} = -\frac{\left(P_{Cm} + \sqrt{3}Q_{Cm}\right)}{2}$$

$$P_{Ca} = -\frac{\left(P_{Am} + \sqrt{3}Q_{Am}\right)}{2}$$

The relations indicate that the actual power and hence energy for phase A is to be calculated from the recorded parameters of phase B and so for other remaining phases. It is obvious from the vector diagram also. As we are interested in the total cumulative energy, by adding these three equations we get the same equation presented earlier.

3.1.3 Correct PT sequence, two of the CTs interchanged / Correct CT sequence, two of the PTs interchanged

Another type of error consists of correct PT sequence but two of the CT are swapped.

Assume a connection scenario in which A, B, C terminals of meter are connected with correct PT but with CT sequence as B, A, C. In such case the vector diagram of the inputs to the meter would be as shown below:

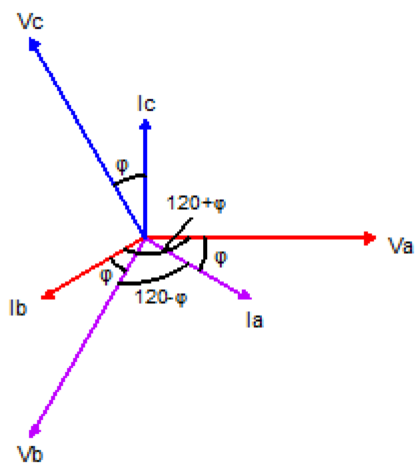

Figure 3.5: 3 phase system with two CT interchanged

The cumulative power/energy recorded by the meter in such a case is found to be equal to zero for balanced load condition but may be small positive or negative value for unbalanced load. The plot of actual power with the measured active is shown below:

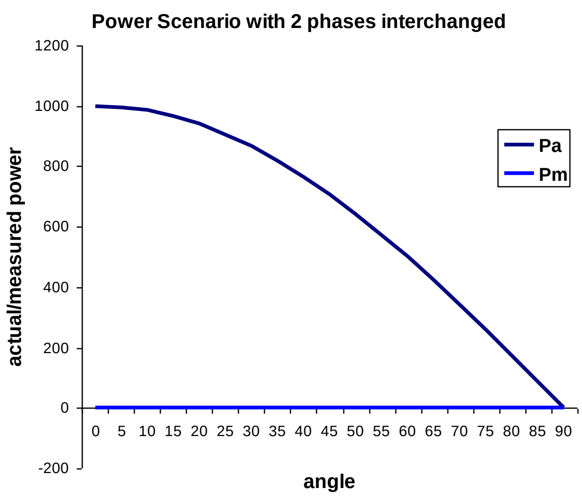

Figure 3.6: plot for actual and measured power

Since the output of the meter is zero in this case there is no way of expressing actual power/energy to the measured power/energy. But as static meters are capable of recording simultaneously many parameters simultaneously, we take advantage of one of the feature of static meters, phase / line wise energy.

The final relation for phasewise/linewise power is as follows:

$$P_{B_a} = -\frac{\left(P_{B_m} + \sqrt{3}Q_{B_m}\right)}{2}$$

$$P_{C_a} = -\frac{\left(P_{C_m} - \sqrt{3}Q_{C_m}\right)}{2}$$

$$P_{A_a} = P_{A_m}$$

The total power can be obtained by adding these individual powers and so for energy.

3.2 Correct PT sequence but two phase CT secondary in series

NEA has experienced such kind of problem in few installations due to poor workmanship and human errors. There are three cases, which are analyzed separately.

3.2.1 CT secondary for Phase A and Phase B in series, (I_a - I_b)

Simply connecting laptop to the meter and looking at the vector diagram, the idea we generally get is a missing current. But thoroughly analyzing the vector diagram which is shown below we can find that the case is much complicated than what is thought. Currents for two phases are superimposed which misleads to missing current.

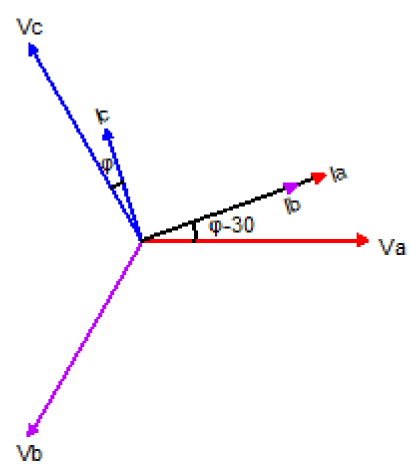

Figure 3.7: 3 phase system with two CTs in series, (I_a - I_b)

The final relation for cumulative power is as follows:

$$P_a = \frac{3\left(P_m - \sqrt{3}Q_m\right)}{4}$$

3.2.2 CT secondary for Phase A and Phase B in series, (I_b - I_a)

The case may be different when resultant current is not I_a-I_b but I_b-I_a. The vector representation is as follows:

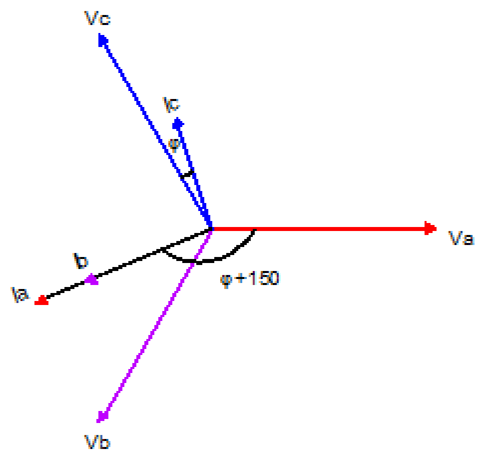

Figure 3.8: 3 phase system with two CTs in series, (I_b - I_a)

The final relation for cumulative power is as follows:

$$P_a = \frac{3\left(P_m + \sqrt{3}Q_m\right)}{4}$$

3.2.3 CT secondary for Phase A and Phase B in series,(Ia + Ib)

The case may be different when resultant current is neither I_a-I_b nor I_b-I_a but I_a+I_b. The vector representation is as follows:

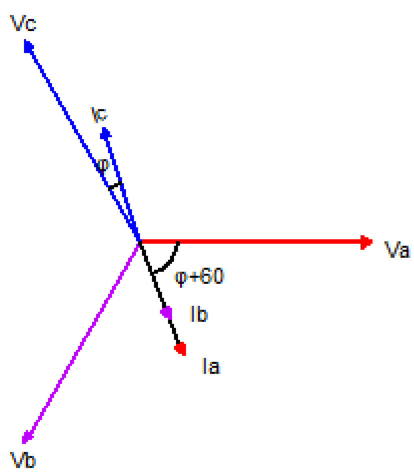

Figure 3.9: vector representation for 3 phase system with two CTs in series, case for I_a + I_b

The final relation for cumulative power is as follows:

$$P_a = \frac{3P_m}{2}$$

4. Effect of Harmonics on Energy Measurement

Proliferation of harmonics in power distribution systems, which are using increased nonlinear loads, have become a power quality problem for both customers and suppliers. The harmonics effectively increase the losses of the transformer as well as it may have adverse effect on metering.

NEA has experienced many instances where, despite of correct installation of meter and metering equipments, the energy meter records the energy in reverse direction. Almost all of such cases are found to occur in the installation where metering is put before the transformer. Transformer, itself being a non linear load, at saturation, is source of harmonics [5]. In this study the effect of nonlinearity on distribution transformer on direction of energy consumed by it is simulated with MATLAB.

The simulation is done with 3 single phase 25kVA, 11/0.4 kV transformer connected in delta-star with negligible or no load connected to it. The direction of power thus energy consumed by the transformer is found to be very responsive to the flux density. It is found from simulation that for full load flux density of 1.68T, the power and hence energy consumed by the transformer swings between positive and negative value and thus recording negative value in energy meter installed. The plot of simulation is presented below:

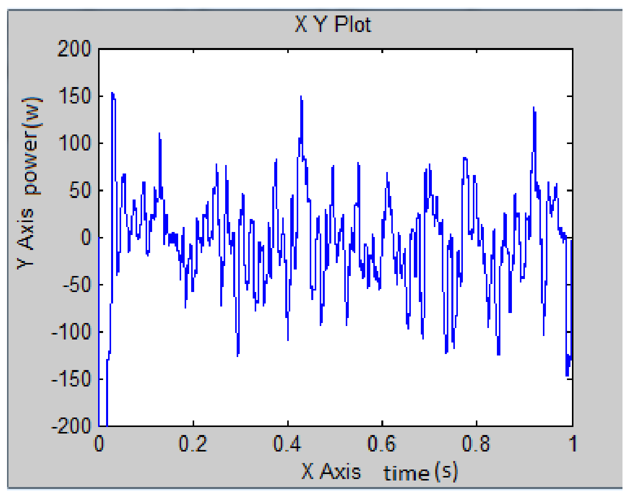

Figure 3.10: power consumed by saturated transformer wrt time

5. Conclusion

The impact of incorrect installation of meter and metering devices on actual recorded energy is immense and has often point of trouble & legal dispute between electricity consumer and utilities when additional billing is made for unaccounted energy. Though, the analysis for common incorrect installations has been devised and is being practiced in NEA, this paper analyzed two new abnormal conditions. The outcome of this analysis would certainly help the utility to easily calculate the actual energy under the referenced incorrect installations.

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