WEAK POINTS OF CURRENT SENSORS IN STATIC ENERGY METERS

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Currently the measurement of consumed energy is one of the most important measurements in residences, factories and other facilities connected to public power network. Due to growing costs of electrical energy some consumers try to tamper the energy meters in order to measure less energy. Well-known trick (which works even with electromechanical energy meter to slow down the rotating disc) is to put strong permanent magnet on energy meter close to current transformers and saturate their cores. This article deals with the problem of dc magnetic flux in the core of current transformers and shows that this attack upon energy meter can cause the opposite effect – the energy meter can measure greater consumption than in reality.

Keywords: current transformer, energy meter, dc tolerance, dc magnetic field

1 INTRODUCTION

Measurement of energy consumption is one of the most important measurements in all objects with electronic or electric devices *eg* factories, houses, administrative buildings and so on. The modern static energy meters generally use current transformers (CT) for current sensing. The special kind of current transformers is used in this field because the sensors have to fulfil some requirements. Some of them are defined in European and Internationals Standards (e.g. accuracy, dc tolerance) and some resulted from manufacturers of the energy meters (price, availability, competitiveness).

According to previous requirements the main two types of current transformers are used: linear dc tolerant current transformers and dual core current transformer. Both of them have some benefits and some drawbacks. This article compares the both sensors and shows their weak points mainly caused by external or internal dc magnetic field.

2 SOURCES OF PROBLEMS

The accuracy of the CT can be defined by ratio error ε_I and phase displacement φ_I of CT that can be expressed

$$\varepsilon_I \doteq \frac{Bl\sin\delta}{I_1\mu_0\mu_{app}}100\,, \tag{1}$$

$$\varphi_I \doteq \arctan\left(\frac{Bl\cos\delta}{I_1\mu_0\mu_{app}}\right), \tag{2}$$

where B is flux density in the core, l is average length of the core, δ is loss angle of the ferromagnetic material, I_1 is primary current, μ_0 is permeability of vacuum and μ_{app} is apparent permeability (modul of complex permeability).

As can be seen from the expressions (1) and (2), both errors indirectly depend on (except others) permeability of the core. That is the reasons that core of precise current transformers are made of very high permeability material that guarantees very small ratio error and phase displacement.

In despite of this fact these current transformers can not be used in energy meters because it is very easy to saturate them with dc magnetic field from external sources or from dc component of measured current. Next paragraphs describe main two types of CT that are used in energy meters and the permanent magnet that has been used for testing of robustness of current transformers.

3 MEASUREMENT SETUP WITH PERMANENT MAGNET

The commercially available NdFeB permanent magnet has been used in some measurements below. It is a cylindrical permanent magnet with diameter of 50 mm and 20 mm thickness. Flux density is about 400 mT on surface of the permanent magnet. The measurement setup for testing of effect of permanent magnet on current transformers in dependence on their distance is shown in Fig. 1.

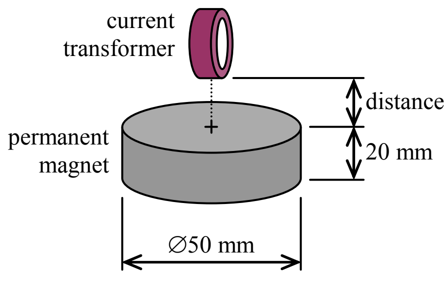

Fig. 1. Measurement setup

4 LINEAR TRANSFORMERS

Linear current transformers consist of high quality ferromagnetic core made of nanocrystalline materials annealed in axial magnetic field. This process brings very narrow and practically linear BH loop (see Fig.2.) with high saturation intensity of magnetic field. Therefore the

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permeability is almost constant in very wide range of intensity of magnetic field (in this case, approx. up to 490 Am^{-1}) that is the important for the errors.

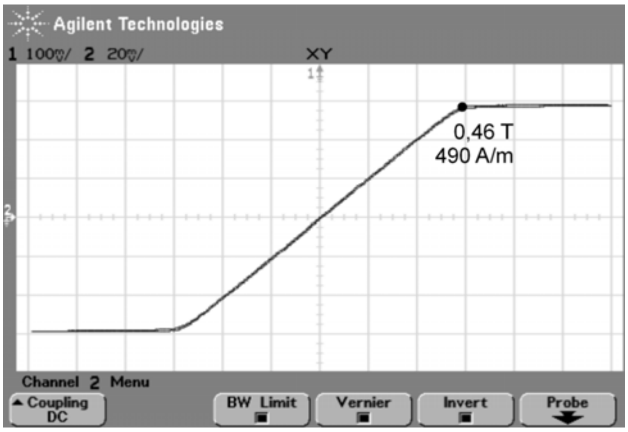

Fig. 2. BH loop of linear current transformer

The current transformers with low permeability core have relatively high phase displacement (units of degree). Due to linear BH loop (and constant permeability) the constant phase displacement can be compensated in the next processing chain.

This type of current transformers has the nominal current and dc tolerance (definition see [1]) in the order of tens of amps (typically 20 A up to 120 A). Therefore they can be able to measure current dc component due of half-wave rectifying. The effect of the dc magnetic field in the core is described in [2].

But some problems can occur when the consumers try to steal the energy by saturating the ferromagnetic core by strong permanent magnets (PM) that are available on the market. Next figure shows the error of current measurements in dependence on distance between permanent magnet and current transformer. The measured current was 25 A and nominal current as well as dc tolerance of CT was 60 A.

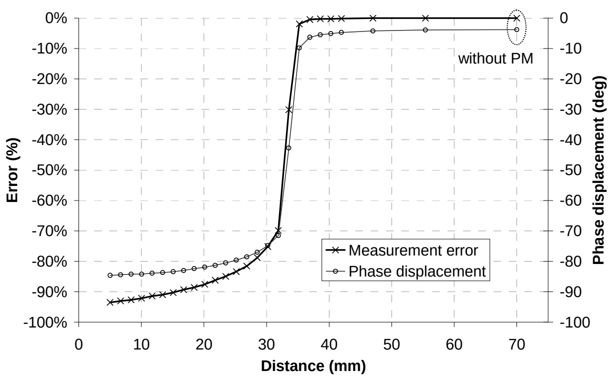

Fig. 3. Effect of permanent magnet on current transformer

Step change of error can be seen from measurements results. It is due to saturation of the core. As can be seen permanent magnet is able to corrupt energy measurement (for used CT) for any distance shorter than 30 - 35 mm.

According to the above statements the linear dc tolerant current transformers are suitable for energy meters if they are used with some detection of strong magnetic field or they are used with some mechanical barrier. But it increases their price. They are more expensive then the dual core current transformers that can more or less fulfil all requirements as will be stated in the next paragraph.

5 DUAL CORE CURRENT TRANSFORMERS

Dual core current transformers are made of two separated core rings that are placed side-by-side and the windings are wound around both. The cores are made of different materials. First one is made of ferromagnetic material with very high permeability that ensures high accuracy and almost zero phase displacement as was mentioned above. The second one brings high immunity against dc magnetic flux because it is made of low permeability material. When the high permeability core is saturated by dc magnetic flux, magnetic flux goes through the low permeability core and transformer works on.

Advantage of this arrangement is surprisingly the price. Both materials can be low quality (and still fulfil all requirements) and therefore their combination is cheaper than linear dc tolerant current transformer. Similarly, the dual core current transformers have the nominal current and dc tolerance in the order of tens of amps (typically 20 A up to 120 A).

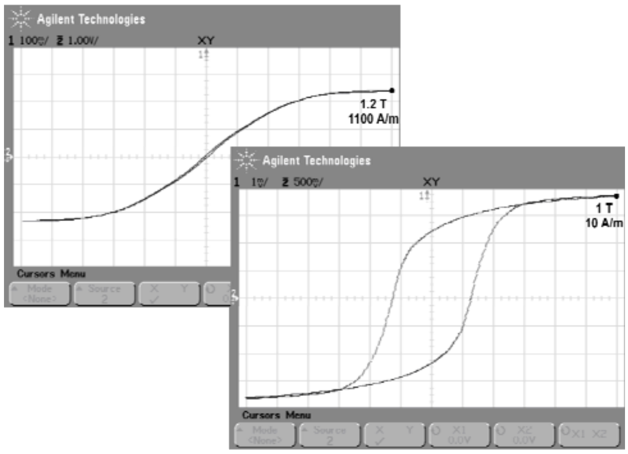

Fig. 4. BH loops of dual core current transformer (low permeability above, high permeability below)

The same measurement with the permanent magnet has been done. The results are shown in figure 5 and they are similar to previous example. Only the rapid growing of the error is shifted to lower distances. It is due to almost twice larger cross-section area of combination of both cores compared to core of linear CT (nominal current as well as dc tolerance of dual core CT was 80 A).

From the figure above can be seen almost zero phase displacement for case without PM (or in sufficient distance) in contrary to linear CT where the phase displacement is around 4 deg.

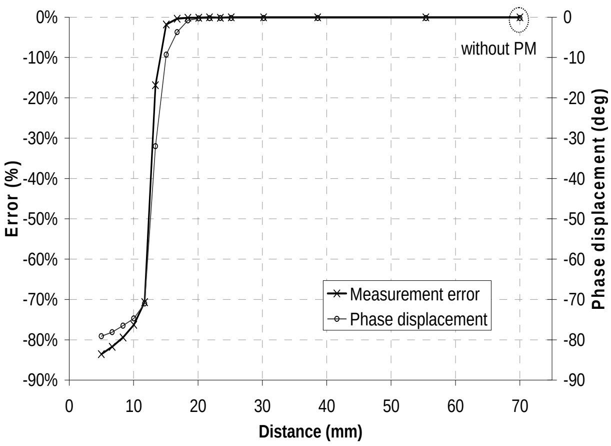

Fig. 5. Effect of permanent magnet on current transformer

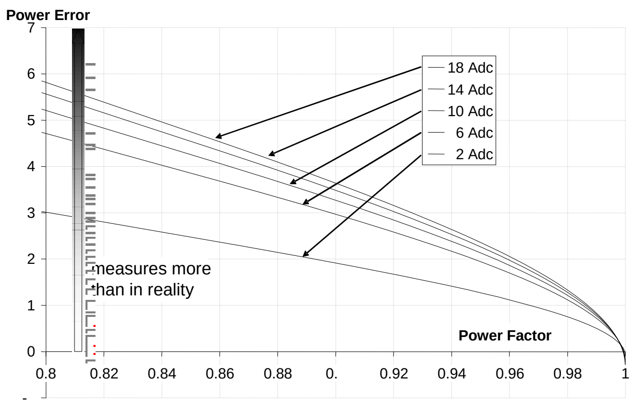

Fig. 6. Additional power error vs. power factor and dc current – inductive load

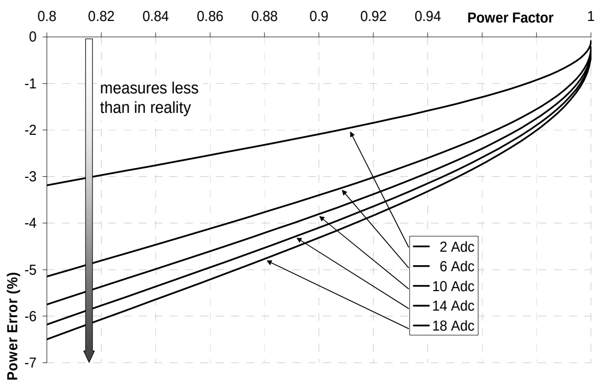

Fig. 7. Additional power error vs. power factor and dc current– capacitive load

6 PROBLEMS WITH NON-RESISTIVE LOAD

Main problem of the dual core current transformer occurs when energy meter measures the electric consumption of inductive or capacitive load with some dc magnetic field, as can be found in [3]. Then the additional error appears in order of units of percent. The source of the error is described in our previous work [4].

Shortly, the additional error is caused by rapid change of phase displacement of dual core CT when the high permeability core is saturated. Then the phase displacement changes from almost zero degree to units of degree and due to low quality material the phase is not constant. This phase displacement is added to phase shift of the load. The change can not be considered negligible for load with lower power factor.

There is no difference whether the high permeability core is saturated by dc component of measured current or by permanent magnet. Several measurements of phase displacement have been done with dual core CT and the dc current has been applied. According to the results the additional errors due to phase displacement change have been computed ([4]) in dependence of power factor. The results are displayed in Fig. 6 and Fig. 7.

Relationship between dc current and dc tolerance is defined:

$$\mathrm{DC}_{tolerance} = I_{\max} = \pi I_{DC} \tag{3}$$

where $I_{\max}$ is amplitude of half-wave rectified current.

Previous results show that applying of dc current to dual core CT can bring the additional errors in the range of units of percent and both polarity – positive for inductive load and negative for capacitive load. And in case of stealing energy it can cause the opposite effect that the energy meter measures more then is the real consumption.

Same calculation can be done when the permanent magnet affects on CT. The change of phase displacement can be found from results in Fig. 5. And relevant computed power error can be found in Fig. 8 and Fig. 9.

The power errors are added to the current measurement errors and increase total error of measurement. Accepting the fact that magnetic field of permanent magnet rapidly grows with decreasing distance, the interval, where the high permeability core is saturated whereas high permeability core is not, is very close. The interval is about 15 – 20 mm for used dual core current transformer (the phase displacement greater then 20 degrees are cause by saturating of low permeability core in Fig. 5).

For the distance greater then 20 mm the additional errors are negligible and permanent magnet has no effect on current transformer. In distance less then 15 mm the error due to saturating of low permeability core is dominant and so huge that the measurement is inapplicable.

7 CONCLUSIONS

This article shows that two types of current transformers that are used in static energy meters, behave in different ways in the presence of dc magnetic flux in their cores. Both of them can work with dc component of measured current up to defined level (dc tolerance = 20 - 120 A). Furthermore, the dual core current transformers bring additional errors when they are used for measurement of

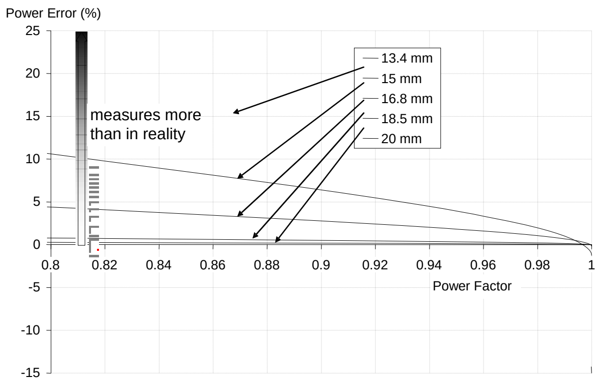

Fig. 8. Additional power error vs. power factor and distance between CT and PM – inductive load

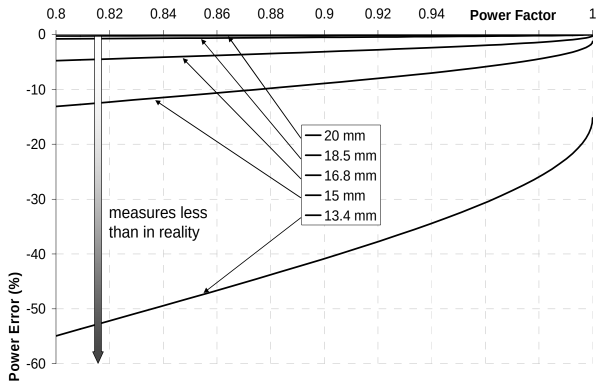

Fig. 9. Additional power error vs. power factor and distance between CT and PM – capacitive load

consumption of non-resistive loads (power factor < 1) in presence of dc component of current.

Both types of current transformers can be very easily affected by strong permanent magnet. Even in the distance about few tens of millimetres the permanent magnet can completely saturate sensor and degrade the measurement of energy consumption.

It is very difficult to defend against magnetic field of permanent magnet. Using of larger boxes for energy meters or shielding covers or larger cross-section area cores are impracticable because the manufacturers are limited by space of the energy meters, their price and so on.

One of the cheap solutions is to employ some magnetic sensor inside the energy meter to detect external magnetic field and warning the distributors of electricity about the invasion.

Acknowledgement

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