Journal of ELECTRICAL ENGINEERING, VOL 59. NO 7/s, 2008, 94-96

THE PHASE DISPLACEMENT OF DC TOLERANT CURRENT TRANSFORMERS UNDER DC BIASING

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The most of the electronic static energy meters employ current transformers for current sensing. The current transformer has to fulfil some requirements according to international standards. Accuracy, together with the immunity against the dc current, is one of the requirements. Therefore manufactures of energy meter use the dc tolerant current transformers with linear hysteresis loop. These types of sensors have constant parameters and behaviour in very wide range of dc biasing. Second type of current transformers employs two cores with different parameters. But the parameters and behaviour vary with dc biasing. This paper deals with the changes of phase error of current transformers under dc biasing and describes the consequences of these changes.

Keywords: current transformer, phase displacement, dc biasing

INTRODUCTION

Current transformers (CT) are the most widespread current sensors in static watt-hour meters. They are rather cheap, precise and they need no external electronic circuits. However they have to fulfil European and International Standards ([1,2]) to be employed in energy meters. Beside the accuracy requirements, the standards define the immunity of whole device against external disturbances *ie* EM radiation, dc component of current, magnetic field *etc*.

The three contradictory parameters – price, accuracy and robustness – are important for manufacturers. Most of them use the dc tolerant CT with narrow and almost linear B-H loop, which fulfils the criteria for CT for energy meters; unfortunately they are quite expensive. Therefore some manufacturers use cheaper CT that consists of two ferromagnetic cores. The first core has high permeability, which ensures accuracy, and second one has low permeability but high saturating intensity of magnetic field, that is necessary for immunity against dc magnetic field.

As can be seen in [3] this type of CT can cause the additional error in mains with non-resistive load. The error is caused by change of phase between voltage and secondary current due to change of phase displacement of CT, which is indirectly dependent on permeability of the core. As can be seen in [4], the sign of additional error can be both positive and negative for inductive and capacitive load respectively.

EXPERIMENTS

Two types of current transformers were used for experiments. The first one was a dc tolerant CT (#50) with linear hysteresis loop and the second one was a double core CT (#70). Table 1 summarizes the main parameters of sensors.

As was mentioned above, the source of the additional error in power measurement is the change of phase displacement. Therefore indirect method was used (method is described in more details in [5]) for the measurements of the phase displacement with dc biasing. DC current source and second primary winding N_3 (in this case $N_3 = 1$) was included to the original method circuit. Block diagram of measurement setup is on Fig. 1. The inductance L increases the impedance of the third winding that is required for indirect method of measurement.

Table 1. Parameters of tested CT

	CT #50	CT #70
Number of rings	one	two
Rated current (A_{rms})	60	80
DC tolerance (A)	60^{*} / 80^{**}	80^{*} / 130^{**}
Core dimensions D x d x t^{***} (mm)	23.4 x 15.8 x 8.1	26.6 x 18.5 x 6.6 26.6 x 18 x 7.4
Average length (mm)	61.6	70.4
Cross-section (mm^2)	30.8	58.7
Permeability	~750	~260000 / 1600

* value declared by manufacturer
** measured value
*** outer diameter x inner diameter x thickness

First measurement was done with CT #50. The linear hysteresis loop ensures almost constant reversible permeability in wide range of dc magnetic field that induces no changes of phase displacement with dc biasing as can be seen on Fig. 2.

The phase displacement is almost constant up to 120% nominal primary current and for dc current up to 20 A (in one turn winding). The differences among the phase displacement in these conditions are in range of 0.2 deg. That small change can theoretically cause additional error less than 1% for power factor (PF) greater than 0.3.

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ISSN 1335-3632 © 2008 FEI STU

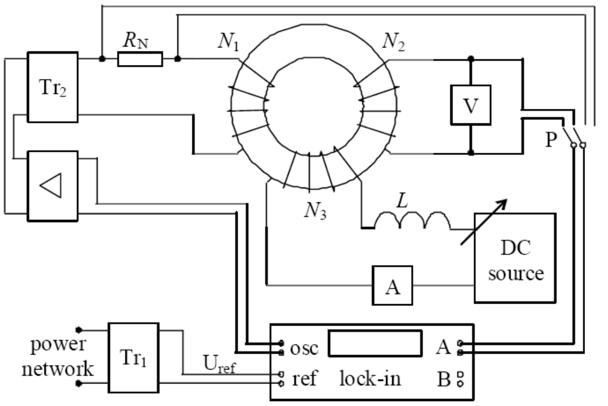

Fig. 1. Block diagram of indirect method

For higher dc current the operating point is near to saturating intensity. Then one half of period of magnetizing current (it is equal to primary current because there is no secondary current [5]) saturates the ferromagnetic core and it causes phase displacement increment (see the curve for 24 A$_{dc}$ on Fig. 2).

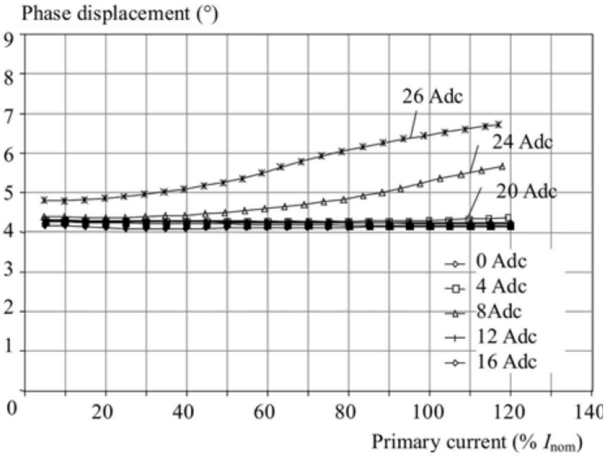

Fig. 2. Phase displacement vs. primary current and dc biasing current – single core CT

The same experiment was done with second CT (#70). The results can be seen on Fig. 3. The phase displacement of CT is strongly dependent on dc current. The change of phase varies from almost 0 deg without dc current up to 9 deg for dc current 44 A.

These huge changes of phase displacement cause large additional error in power measurements. For example, the change from 0 deg to 5 deg (at 20 A$_{dc}$) induces a theoretical additional error greater than 5.5% for PF = 0.8, and it rapidly grows in dependence on decreasing of power factor.

The highest examined values of dc current for both experiments correspond to average values of primary current that determine the dc tolerance of CT. The dc tolerance is defined as an amplitude I_{max} of half-wave rectified current that causes the power measurement error greater than predefined level (mainly 3% or 6%). The average value of the current is I_{max}/π (more details can be found in our previous work [6]). In other words, the manufacturer defined that higher dc current have not be applied on CT to keep the declared accuracy.

Fig. 4 shows the dependence of phase displacement change on dc current (both curves are for 20 A$_{rms}$ primary current). From this graph, the linear CT #50 has almost constant phase displacement up to 24 A$_{dc}$ (magnetizing current is quite low). On the other hand, there are two explicit rapid changes on the second curve (double core CT).

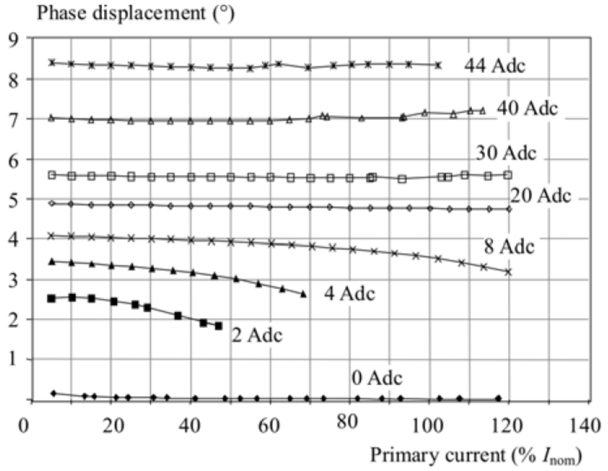

Fig. 3. Phase displacement vs. primary current and dc biasing current – double core CT

The first one, on beginning, is caused by saturating of high permeability core. Increasing the magnetic flux flowing through the low permeability core, in order to keep the same induced voltage, the magnetizing current increases; therefore the phase displacement grows.

The second greater change is about 40 A$_{dc}$. This is caused by slow saturation of low permeability core where the permeability gets closer to permeability of vacuum.

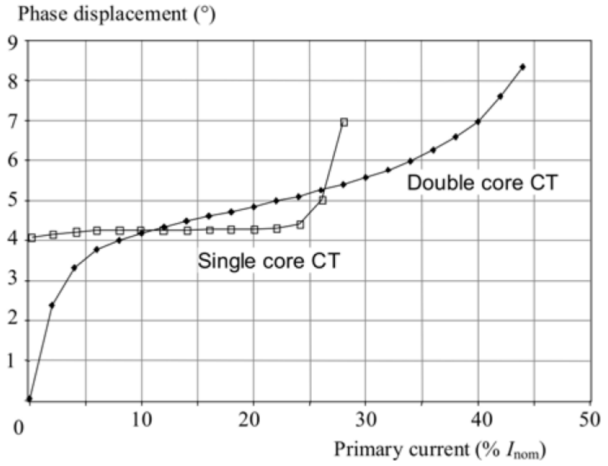

Fig. 4. Phase displacement *vs* dc biasing current (20 A$_{rms}$ primary current)

CONCLUSION

Previous results show that the changes of phase displacement can be quite large and can cause problems in power consumption measurement.

Additional measurement of power consumption was done to validate previous results. The double core current transformer was used as current sensor for watt-hour meter.

Three types of load – resistive, capacitive and inductive (PF = 0.8 for both case) – were powered through a diode. Than the half-wave rectified current run through. The dc component of current biased the core.

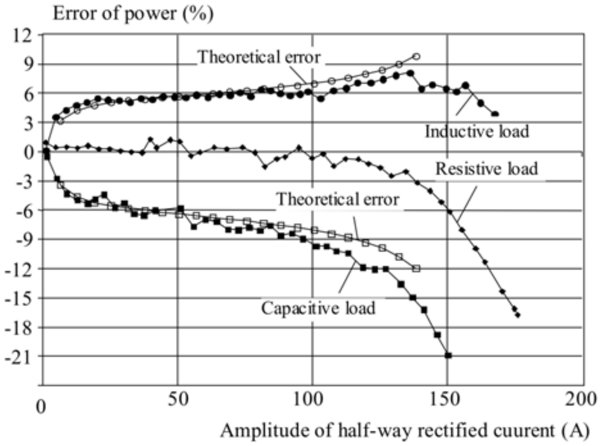

Fig. 5. Comparison of theoretical errors with real experiments

Two watt meters measured the power – on primary and secondary side of CT. Measured values were compared and the errors are on Figure 5. Next curves on this graph are the theoretically computed errors due to change of phase displacement as were previously measured. It is evident that the theoretical curve and experimental results match very well.

Acknowledgement

The research of Parameters of Current Sensors was supported by the research program No. MSM684 0770015 "Research of Methods and Systems for Measurement of Physical Quantities and Measured Data Processing " of the CTU in Prague sponsored by the Ministry of Education, Youth and Sports of the Czech Republic.

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Received 28 September 2008