The Application of Distribution System Current Transformers for High Frequency Transient Based Protection.

M A Redfern, S C Terry, F V P Robinson and Z Q Bo
University of Bath UK ALSTOM T&D EAI Ltd UK

Abstract:-

Wound current transformers are used in virtually all protection schemes associated with power system plant. The potential for using them as the primary transducer for monitoring high frequency currents as well as power system frequency components has provided the basis for extensive research into the use of transient based protection using current signals.

This investigation has examined the response of a representative sample of 50 Hz distribution system current transformers to signals in the range of 1 kHz to 100 kHz. This will provide an insight into whether or not they can be used reliably to detect signals in that frequency band.

The performances of a variety of current transformers of different types were examined. These included standard distribution system CTs, class X CTs and earth fault passage indicator CTs. The ages of these CTs varied from new units to those that had been withdrawn from service after thirty or more years service in the field.

The results have shown that distribution system current transformers have a good accuracy in the range of frequencies from 1 kHz to 100 kHz. It is therefore concluded that such current transformers can be used as an appropriate interface for transient based protection using current signals.

1. INTRODUCTION.

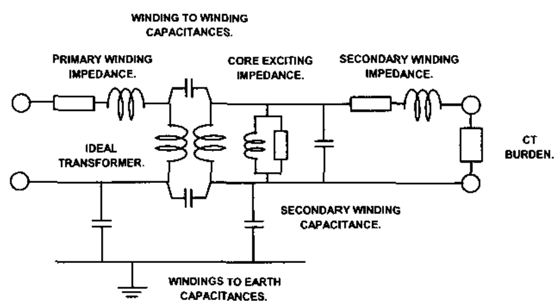
All power system faults and disturbances generate high frequency transient signals and these contain a wealth of information about the events affecting the power system. This coupled with recent developments in digital signal processing systems and powerful signal processing algorithms have facilitated research into new protection schemes.

Work on protection techniques using high frequency components is not new. Protection schemes based on these principles were available in the mid 1930s [1,2]. In the 1970s, several researchers used them for the ultra high speed protection of EHV transmission lines [3,4,5,6] and practical relays based on these techniques were commercially available. More recently, schemes based on high frequency signals are being proposed for a wide range of relays for UHV, EHV, HV and MV systems [7,8]. Several of these use high frequency current signals.

The transient responses of wound current transformers were considered by an IEEE working group in the mid-1970s [9]. In the mid-1980s, D A Douglass [10] demonstrated that widely used, wound, 60 Hz distribution system current transformers had an excellent ratio correction factor, RCF, of less than one percent for frequencies up to 10 kHz. The phase errors were less than one degree at 10 kHz. Douglass's work concentrated on two widely used standard 4000:5A window type, distribution system, current transformers and a third unit of a similar rating and fitted with an anti-remanence gap.

2. HIGH FREQUENCY CT MODEL AND THE LABORATORY TESTS.

Based on Douglass's work and an analysis of the capacitive coupling between windings and between the windings and earth, the equivalent circuit of the



transformer can be represented as shown in figure 1.

Figure 1. High Frequency Model of a Current Transformer.

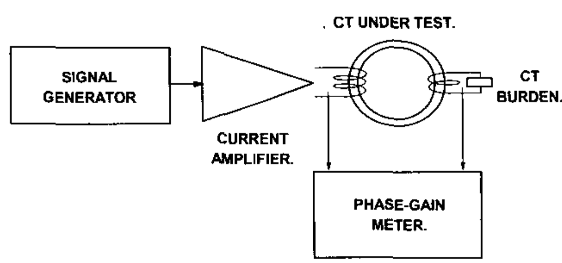


Figure 2. Laboratory Test Scheme.

The greatest influence on the current transformer's performance in the operating range from 500Hz to 500 kHz is provided by the secondary winding and load capacitances. The windings to earth capacitive coupling and winding to winding capacitive coupling have common mode effects that do not contribute to the

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current transformer action. In the laboratory studies, the test system was deliberately isolated from earth and measures were taken to minimise this type of coupling.

The laboratory tests used the experimental scheme as shown in figure 2. A signal generator and high fidelity amplifier were used to provide the current to an input winding, which was wound around the CT core. One of the standard output windings of the CT was used to provide the output current to a burden circuit. A high precision phase-gain meter was used to measure the magnitude and phase displacement errors between the primary and secondary current signals. From these the Ratio Correction Factor, RCF, and the Phase Error were measured.

Resistive burdens were used to avoid the complications of reactive burdens and high frequency attenuation in the load circuit. These were connected at the CT's terminals to avoid any influence from the wiring circuits.

3. High frequency Characteristics of the Test Current Transformers.

A sample of twelve distribution system current transformers was examined in the investigation. A selection of results is presented below.

a. 5P5 1200:5 11kV CT.

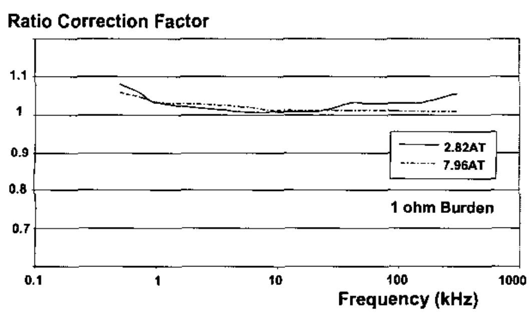

Figure 3. Ratio Correction Factor Vs Frequency Current Transformer 5P5 1200/5

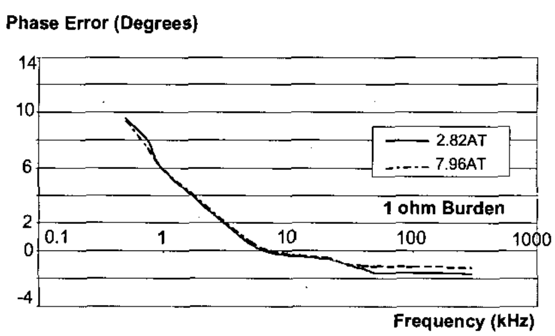

Figure 4. Phase Error Vs Frequency Current Transformer 5P5 1200/5.

This current transformer represents the most widely used unit in distribution systems. It is a compact design with the secondary winding evenly distributed around the core.

The Ratio Correction Factor, RCF, and phase displacement results for a 5P5 1200/5 11 kV distribution current transformer with a 1.0 ohm burden are shown in figures 3 and 4 respectively. The tests were done at a variety of high frequency current levels and those corresponding to 2.82 and 7.96 AT have been presented. Although these levels were relatively low when compared to possible power system frequency current fault levels, they were considered appropriate to the levels of high frequency components expected.

The results for the ratio correction factor measurements revealed that the CT had an accuracy of better than five percent from 1 kHz to 100 kHz and that the phase error was better than ±2 degrees from 3 kHz to 100 kHz. In the range from 1 kHz to 10 kHz, the phase error was positive with a maximum of 10 degrees at 1 kHz. The phase errors were found to be reduced as the frequency was increased.

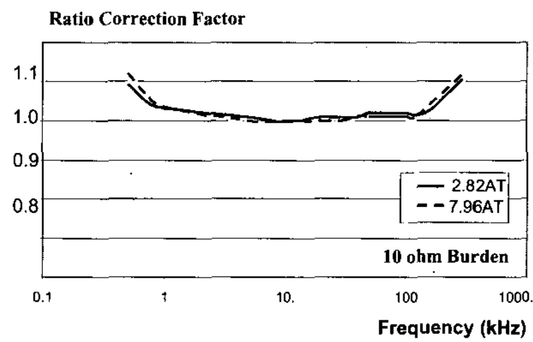

Figure 5. Ratio Correction Factor Vs Frequency for an 11kV, 5P5, 1200/5 CT. with a 10 ohm Burden.

Increasing the burden to 10 ohms produced the Ratio Correction Factor errors as shown in figure 5. These are similar to those using a 1 ohm burden as shown in figure 3. However for frequencies above 100 kHz, there was a marked increase in the errors. These were approximately 10 percent at 500 kHz.

b. Class X 800/1 191V knee point 11kV CT.

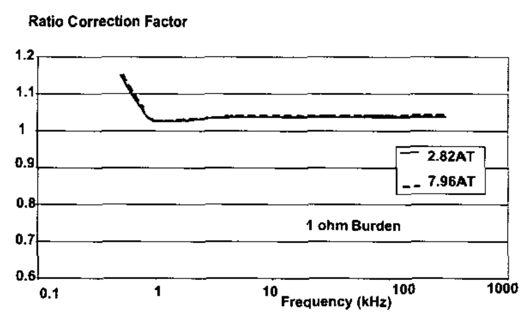

Figure 6. Ratio Correction Factor Vs Frequency Current Transformer Class X 800/1 191 V knee point.

This 800/1 class X current transformer was physically the largest unit in the sample with the greatest volume of core. Of the class X transformers examined, it had the highest knee point voltage and the lowest losses.

The results of the Ratio Correction Factor tests for this class X CT are shown in figure 6 and revealed that in the range from 1 kHz to 100 kHz, the current transformer accuracy was within five per cent. At lower frequencies, below 1 kHz, the errors were greater and there was the suggestion that the error rose as the frequency fell.

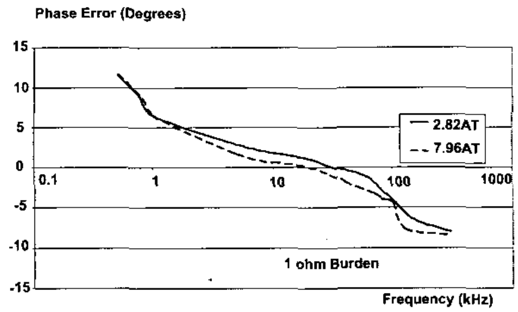

Figure 7. Phase Error Vs Frequency Current Transformer Class X 800/1 191 V knee point.

The phase errors, shown in figure 7, fell from about +6 degrees at 1 kHz to –5 degrees at 100 kHz.

Overall both the ratio correction factor and the phase error tests demonstrated that the class X transformers had similar characteristics to the standard protection current transformers tested. However, in all of the tests the errors for the class X transformers were marginally greater than for the standard protection transformers.

c. Solid Core Earth Fault Passage Indicator CT.

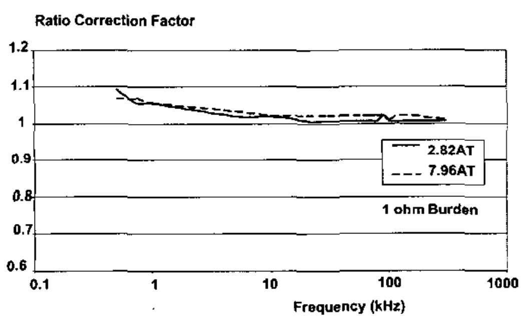

Figure 8. Ratio Correction Factor Vs Frequency Solid Core EFPI Current Transformer.

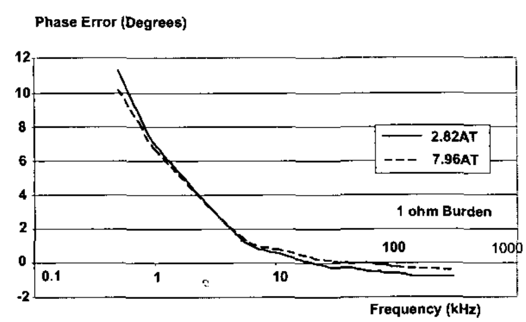

Figure 9. Phase Error Vs Frequency Solid Core EFPI Current Transformer.

This 11 kV solid core earth fault passage indicator current transformer had 55 secondary turns. The secondary turns were evenly spaced around the CT core. It was physically larger than the standard protection units and had considerably less turns.

The high frequency response characteristics were similar to those of the other transformers tested. As shown in figure 8, for most of the frequency range from 1 to 100 kHz, the ratio errors were less than five percent. The phase errors, as shown in figure 9, were just less than 7 degrees at 1 kHz and reduced to zero between 20 and 70 kHz. The actual value was dependent on the current magnitude. At 100 kHz, the phase error was less than –1 degree.

d. Saturated Core Tests using the Solid Core Earth Fault Passage Indicator CT.

An investigation into the effects of a saturated core on the high frequency characteristics of the current transformer was carried out by adding an additional winding and injecting dc current. Tests using high values of power system frequency ac currents were found to be unsatisfactory due to the high currents required to ensure saturation and the need to separate the periods of saturation and non-saturation. For mechanical reasons, the solid core earth fault passage indicator current transformer was used for these tests and the results are shown in figures 10 and 11.

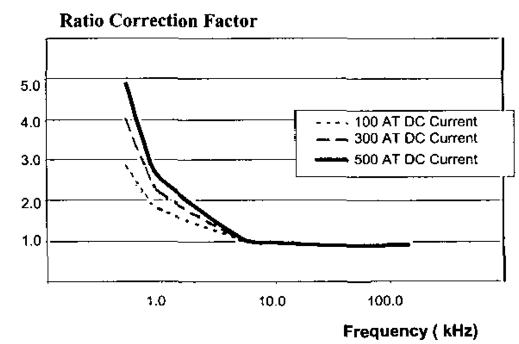

Figure 10. Ratio Correction Factor Vs Frequency Solid Core EFPI Current Transformer with DC Saturation Current.

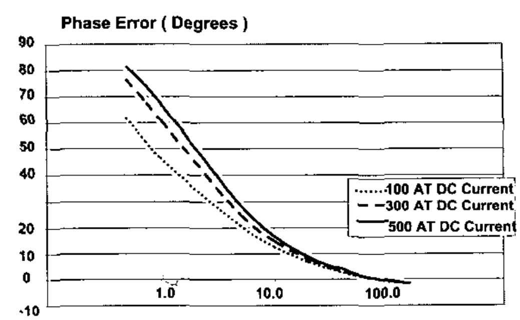

Figure 11. Phase Error Vs Frequency Solid Core EFPI Current Transformer with DC Saturation Current.

Figure 10 shows the Ratio Correction Factor characteristics and reveal that for frequencies above 7 kHz, core saturation had little effect on the transformation accuracy of the current transformer. However for frequencies lower than that, there was progressively higher attenuation of the high frequency signals with reduced frequencies. This produced very high errors at frequencies lower than 1 kHz.

The phase errors for the saturated core tests are shown in figure 11. At 1 kHz, the phase errors varied from 40 to 70 degrees, depending on the level of saturation, and reduced to virtually zero as the frequency rose to above 100 kHz. Above 7 kHz, they were within 20 degrees.

The effects of saturation are clearly shown by comparing the results shown in figures 8 and 10, and figures 9 and 11 respectively.

4. GENERALCOMMENTS.

These results show that standard wound current transformers can be used for monitoring high frequency current signals over a useful range suitable for several proposals for transient based protection. The responses in the higher frequency range are generally better than that demonstrated by Douglass. This is in part attributed to the lower turns ratio of the units tested compared to the 4000:5 units used by Douglass. Also in these tests, the lower secondary winding and load capacitances encountered were lower that that reported by Douglass.

The possible influence of the load capacitance on the available operating frequency range suggests that a further examination of the effects of the load circuit is required.

Continuing Douglass's analysis, these results support the suggestion that at higher frequencies, skin effects concentrate the magnetic fluxes into the surface of the core. Therefore as the frequency rises, core saturation has a reduced effect on the transformer action. At higher frequencies, in excess of 100 kHz, capacitive action have a greater effect reducing the effectiveness of the transformer.

Field trials are being undertaken to examine the high frequency current signals associated with power system faults at by Professor Dong and his colleagues at Tsinghua University in China. These and other trials are the logical next step in the development of transient based protection using current signals.

5. CONCLUSION AND COMMENTS.

The characterization of the high frequency characteristics of a selection of distribution system current transformers has revealed that over the range from 1 to 100 kHz, they can provide a suitable interface for transient based protection. The standard protection current transformers, the class X transformers and the solid core earth fault passage indicator transformer have all been found to have reasonable ratio and phase errors at these frequencies.

Current transformer saturation has been shown to degrade the transformer action, but this was found to be restricted to low end of the range considered. For the results presented, this was limited to frequencies lower than 7 kHz. Since all of the current transformers tested revealed similar characteristics, this type of response would be expected for the other distribution current transformers.

The results support the viability of using conventional current transformers for the basis of transient based protection of distribution networks. Even in situations where the current transformers are liable to saturate, the higher frequency primary signals can be accurately reproduced in the secondary circuits.

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7. CONTACT ADDRESS

Dr M A Redfern

Department of Electronic and Electrical Engineering

University of Bath, BATH, BA2 6SQ, UK

Email: m.a.redfern@bath.ac.uk