A Laboratory Investigation into the use of MV Current Transformers for Transient Based Protection.

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Abstract – **The practical implementation of transient based protection and its application to power system protection schemes depends on the availability of transducers suitable for providing access to the higher frequency transients produced by faults and other system disturbances.**

This paper presents the results of a laboratory investigation into the suitability of using MV distribution system current transformers as transducers for accessing the high frequency transients used in transient based protection schemes.

The investigation has concentrated on the frequency range of 1 to 100 kHz and examined a variety of current transformers of different types and ages. These included standard distribution system CTs, class X CTs and split core CTs. The ages of these CTs varied from new devices that had recently been manufactured to units that had been withdrawn from service after thirty or more years in the field.

In addition to examining the high frequency response of the current transformers while they were operating with standard power system frequency signals, the investigation also examined their high frequency response when their cores were saturated.

Keywords – power system protection, transient based protection, current transformers, high frequency performance.

I. INTRODUCTION.

The higher frequency transient signals generated as a result of a power system fault or disturbance provide the basis for an alternative approach to power system frequency relaying. Several advantages in speed of response and discrimination are offered by using these transients, but one major challenge is the need to ensure that the transients can be faithfully monitored by the protective system.

One of the first problems to be addressed using the detection of high frequency transients was earth fault protection for isolated earth networks. This work was reported 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].
More recently, the introduction of numeric protection relays and high speed signal processing has lead to high frequency transients being used for a wide range of relays for EHV, HV and MV systems [7,8,9]

As well as protection applications, several researchers have used high frequency transients for finding the position of a fault on transmission line and distribution feeders [10,11].

Several of these protection and fault location schemes have been based on monitoring high frequency current signal. The success of these techniques relies on the availability of suitable transducers. Hence the interest in examining the conventional current transformer.

An IEEE report into the transient response of current transformers [12] and the work of Douglass [13], examined the characteristics of conventional CTs and provided an insight into their high frequency performance. Douglass examined two distribution system current transformers and found that for frequencies less than 20kHz, their ratio errors were less than 3% of their power system frequency response.

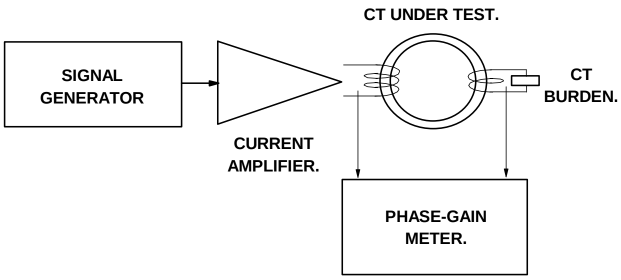

Figure 1. High Frequency Laboratory Test System.

The frequency range required for transient based protection is wider than that considered by Douglass. For this investigation, the frequency band from 1 to 100 kHz was chosen, with the tests being extended to the range from 500 Hz to 500 kHz.

II. Laboratory Tests.

The laboratory tests used the experimental scheme as shown in figure 1. A signal generator and high fidelity amplifier were used to provide the current to an input winding, 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.

The operating range of the experimental system was from 500 Hz to 500 kHz, ensuring that the results were accurate in the range of interest.

Resistive burdens were used to avoid the complications of reactive burdens and high frequency attenuation in the load circuit.

The potential problems of capacitive coupling were minimized by including earthed screens between the primary and secondary windings. These screens were designed to ensure that they did not introduce a shorted turn into the system. These measures, together with the careful layout of the test equipment and associated wiring, were used to avoid parasitic coupling so that the tests would only reflect the current transformer action between the primary and secondary CT circuits.

III. Test Results.

A selection of distribution system current transformers were characterized including new transformers which had not been used in service and others which had only recently been removed from the system after many years of service. The units tested included, 5P5, 5P10, dual secondary 5P10, a selection of class X CTs with a variety of knee point voltages, solid core earth fault passage indicator CT and split core earth fault passage indicator CT.

The tests on the split core CTs were of particular interest since these could be fitted to an existing installation without disrupting that installation. These units could therefore be used for field investigations into the operation of future designs of transient based protection for distribution network applications.

A. 5P5 CT.

The results from the tests on an 11kV, 1200/5A , 5P5 distribution current transformer are shown in figures 2 and 3. For these tests, the CT's output winding was loaded with a 1.0 ohm resistive burden and the two tests shown were conducted at 2.82 and 7.96 AT respectively.

The measurements of the Ratio Correction Factor against frequency are shown in figure 2 and reveal a virtually flat response from 1 to 100 kHz. The deviations were limited to less than 5 percent. The Phase Error results are shown in figure 3, and reveal a falling characteristic as the frequency rises. At 1 kHz, the phase error was approximately 7 degrees. This fell to zero at approximately 5 kHz, and to nearly – 2 degrees at 100 kHz.

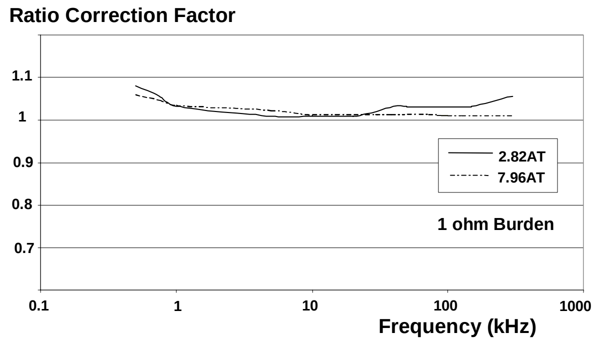

Figure 2. Ratio Correction Factor Vs Frequency for an 11kV, 5P5, 1200/5 Current Transformer.

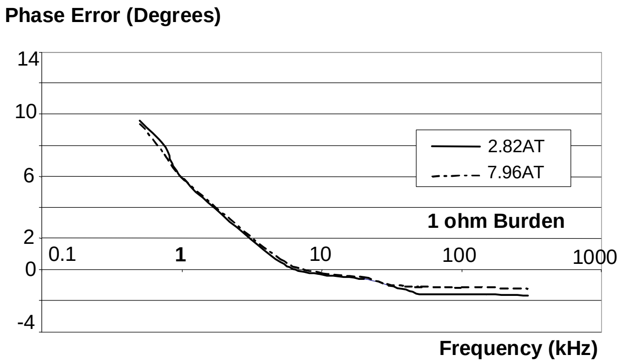

Figure 3. Phase Error Vs Frequency for an 11kV, 5P5, 1200/5 Current Transformer.

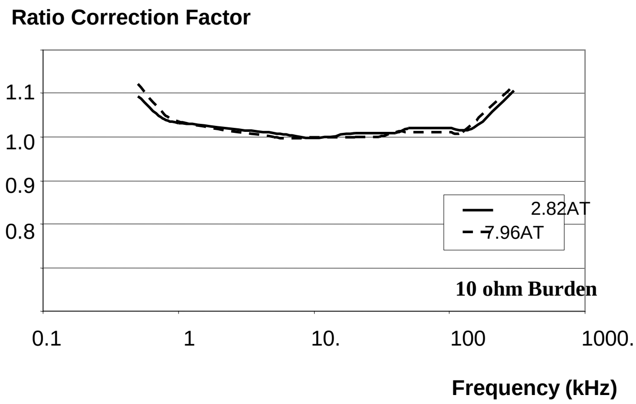

Figure 4. Ratio Correction Factor Vs Frequency for an 11kV, 5P5, 1200/5 CT. with a 10 ohm Burden.

The Ratio Correction Factor measurements for a similar test but using a 10 ohm resistive burden are shown in figure 4. These are similar to those with a 1 ohm burden, however for frequencies above 100 kHz, there was a marked increase in the errors. These were in the order of 10 percent at 500 kHz.

B. 5P10 Dual Secondary CT.

A similar series of tests were conducted on a 5P10 dual secondary current transformer. For this test, the output of one of the secondary windings was used for the characterization and the other one was short circuited. The results are presented in figures 5 and 6.

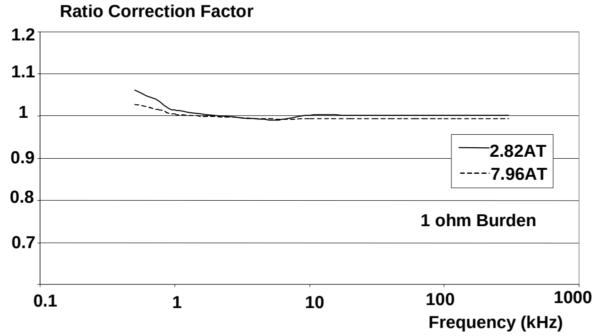

Figure 5. Ratio Correction Factor Vs Frequency
Current Transformer 5P10 Dual Secondary.

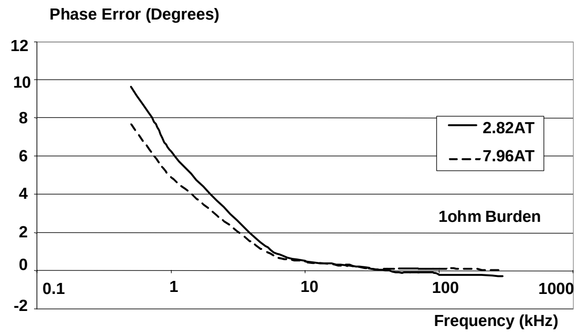

Figure 6. Phase Error Vs Frequency
Current Transformer 5P10 Dual Secondary.

The Ratio Correction Factor results above 1 kHz demonstrated a virtually perfect transformation. Below 1kHz, the errors rose with lower frequencies. The Phase Errors, were shown to be within 1 degree above 5 kHz, and these too rose as the frequency was reduced. Other tests using a 10 ohm burden produced similar results, but with ratio errors within 5 percent and similarly low phase errors above 10 kHz.

C. 800/1 A Class X CT.

This class X current transformer was chosen since it had the largest core of the samples available for test and hence the greatest amount of iron. It also had the highest knee point voltage and the lowest losses. The transformer's knee point voltage was 191 V.

The measurements of the Ratio Correction Factor and the Phase Errors with respect to frequency are shown in figures 7 and 8 respectively.

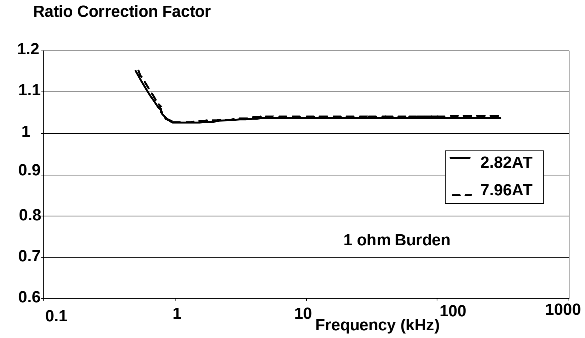

Figure 7. Ratio Correction Factor Vs Frequency
Current Transformer Class X 800/1 191 V knee point.

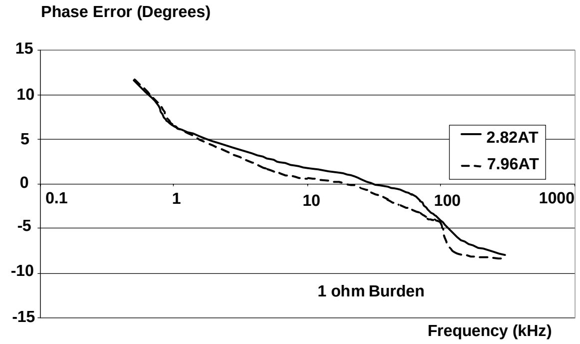

Figure 8. Phase Error Vs Frequency
Current Transformer Class X 800/1 191 V knee point.

The measurements for the Ratio Correction Factor were found to be within approximately 5 percent over the frequency range from 1 to 500 kHz. This error was virtually constant over this range, demonstrating the repeatability of the result. The Phase Errors fell as the frequency rose, falling from +6 degrees at 1 kHz to –5 degrees at 100 kHz.

D. Solid Core Earth Fault Passage Indicator (EFPI) CT.

The unit tested was an 11kV device. It had a larger core than the standard distribution system current transformers, but it only had 55 secondary turns.

The Ratio Correction Factor measurements for this current transformer are shown in figure 9 and reveal a similar response but more variable characteristics than the standard distribution current transformers. The errors were about 5 percent at 1 kHz falling to 1 percent at 100 kHz.

The Phase Error measurements are shown in figure 10 and again reveal a similar response to the distribution current transformers. At 1kHz, the errors were 8 degrees and these fell to between zero and –1 degrees at 100 kHz.

These results suggested that the construction of the transformer and in particular the distribution of the secondary windings had a significant effect on the high frequency characteristics of the current transformer.

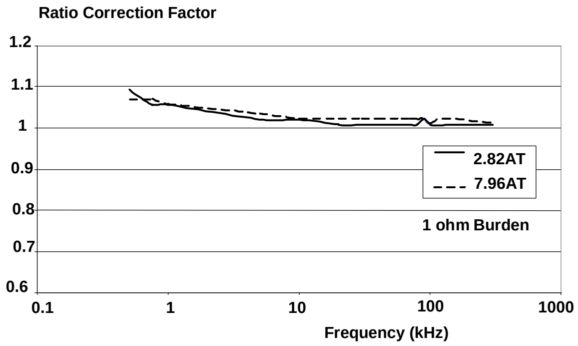

Figure 9. Ratio Correction Factor Vs Frequency
Solid Core EFPI Current Transformer.

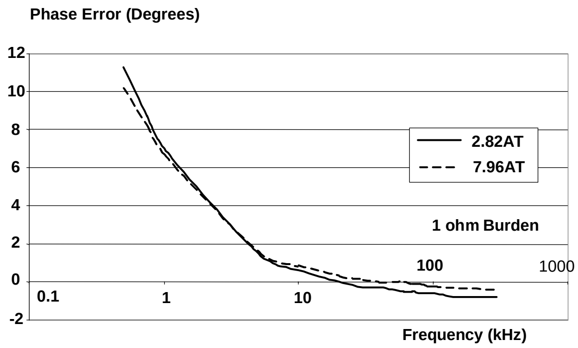

Figure 10. Phase Error Vs Frequency
Solid Core EFPI Current Transformer.

E. Split Core Earth Fault Passage Indicator (EFPI) CT.

A split core earth fault passage indicator current transformer was tested since this would be the type of transformer used for any field tests to investigate the levels and propagation of high frequency transients on a distribution network.

The unit tested had a similar specification to the solid core earth fault passage current transformer above. It was also designed for operation on 11kV systems and had 55 secondary turns.

Both the measurements for the Ratio Correction Factor and the Phase Errors were found to be larger than for the solid core unit. The ratio errors, as shown in figure 11, were within 1 percent at 1 kHz but rose to 15 percent at 100 kHz. The phase errors, shown in figure 12, fell as the frequency was increased. At 1 kHz the error was +8 degrees and at 100 kHz they were -8 degrees. At 5 kHz, the phase errors were virtually zero.

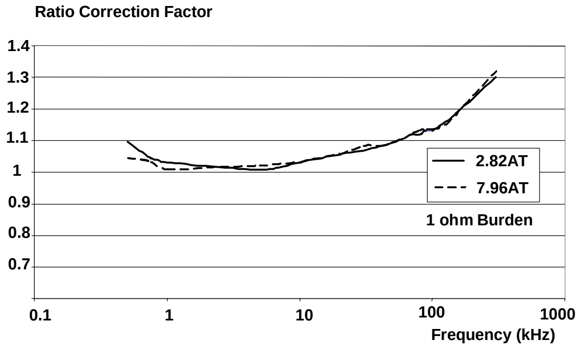

Figure 11. Ratio Correction Factor Vs Frequency
Split Core EFPI Current Transformer.

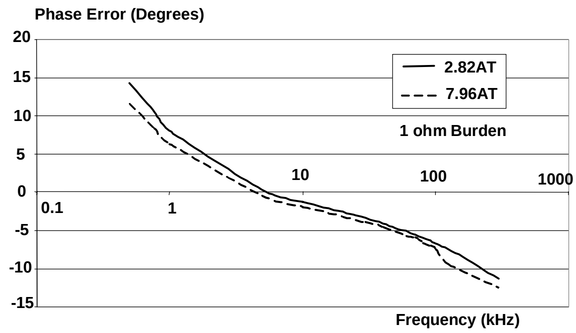

Figure 12. Phase Error Vs Frequency
Split Core EFPI Current Transformer.

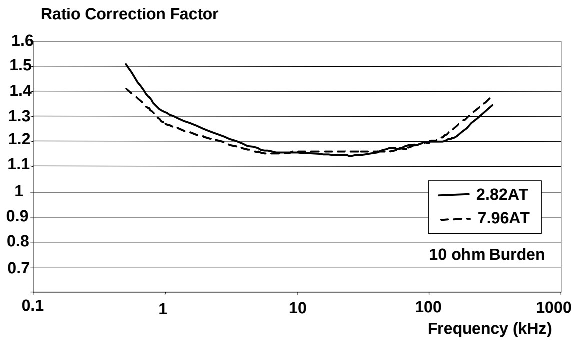

Figure 13 Ratio Correction Factor Vs Frequency
Split Core EFPI Current Transformer
with 10 ohm Burden.

Increasing the burden to 10 ohms had a more marked effect with this current transformer. The ratio errors were increased across the band, with errors of nearly 30 percent at 1 kHz and 20 percent at 100 kHz. The lowest errors were approximately 15 percent over the frequency range of 8 to 80 kHz. These results are shown in figure 13.

F. Saturated Core Tests.

An investigation into the effects of a saturated core on the high frequency characteristics of the current transformer were carried out by adding an additional winding and injecting dc current. Tests using high values of 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 split core earth fault passage indicator current transformer was used for these tests and the results are shown in figures 14 and 15.

Figure 14 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 as the frequency was reduced. This produced very high errors at frequencies lower than 1 kHz.

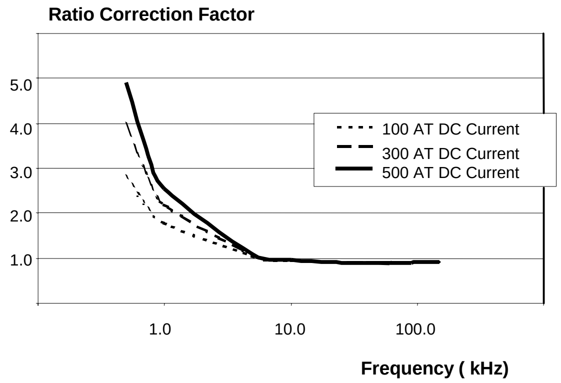

Figure 14. Ratio Correction Factor Vs Frequency
Solid Core EFPI Current Transformer
with DC Saturation Current.

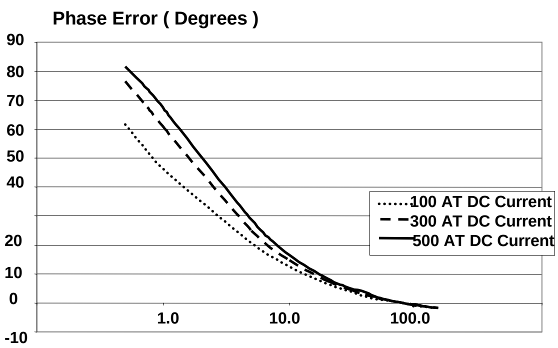

Figure 15. Phase Error Vs Frequency
Solid Core EFPI Current Transformer
with DC Saturation Current.

The phase errors for the saturated core tests are shown in figure 15. 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.

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.

VI. Conclusions

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 frequencies lower than 7 kHz in the unit tested. Since all of the current transformers tested revealed similar characteristics, this type of response would be expected for the other distribution current transformers.

The characterization of the split core earth fault passage indicator current transformer revealed that the ratio and phase errors were greater than those for the solid core equivalent. However, with the prudent choice of the current transformer's burden and the frequency range used by the protection technique, these units could also provide an acceptable interface for detecting high frequency current transients.

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.

Acknowledgments

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