Current Transformers: A Tester Survival Guide

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Abstract**-- Proper testing and application of current transformers are necessary for safe and proper use. This paper reviews accuracy selection guidelines and circuit design suggestions for easy in service testing. The dangers of open circuit voltages from open ct circuits will also be discussed. A new in service current test solution is introduced that prevents shock hazards and provides added operator safety associated with open ct's during in service testing.**

Index Terms**—in-service testing, instrument transformer, open circuit voltage, permanent magnetization**

I. INTRODUCTION

Failures of instrument transformers (ITs) can cause malfunction of system devices and, in some explosive failures, damage to nearby power apparatus, or injury to personnel in the vicinity. Along with many other key assets of the electrical grid in North America, the existing IT population in plants and substations is nearing the end of its service life. There are a number of diagnostic methods for assessing the condition of ITs, but in many situations, reliability demands make out of service testing difficult.

In-service testing of current transformers does avoid an outage, but also introduces additional hazards that must be mitigated. This begins with proper selection of the current transformer and design of the application, as well as using the correct tools during testing.

II. CURRENT TRANSFORMER BASICS

There are three primary applications for which instrument transformers (ITs) are used: metering (for energy billing and transaction purposes); protection control (for system protection and protective relaying purposes); and load survey (for economic management of industrial loads)

Depending on the requirements for those applications, the IT design and construction can be quite different. Generally, the metering ITs require high accuracy in the range of normal operating voltage and current. Protection ITs require linearity in a wide range of voltages and currents.

A. Equivalent Circuit

A typical transformer and its equivalent circuit is shown in Figure 1. The leakage flux is shown entering the outer part of the core and is represented by reactance X. The reactance develops voltage applied to the exciting branch Zo, also referred to as X_M, magnetizing reactance, which represents the outer side of the core. The series impedance, $R_P + R_S + j\,(X_P + X)$, is responsible for the loss of voltage in transformation. The loss of current in transformation is due to current drawn by the magnetizing branch. Current transformers are specially designed to keep these by-pass exciting impedances as high as possible. [1]

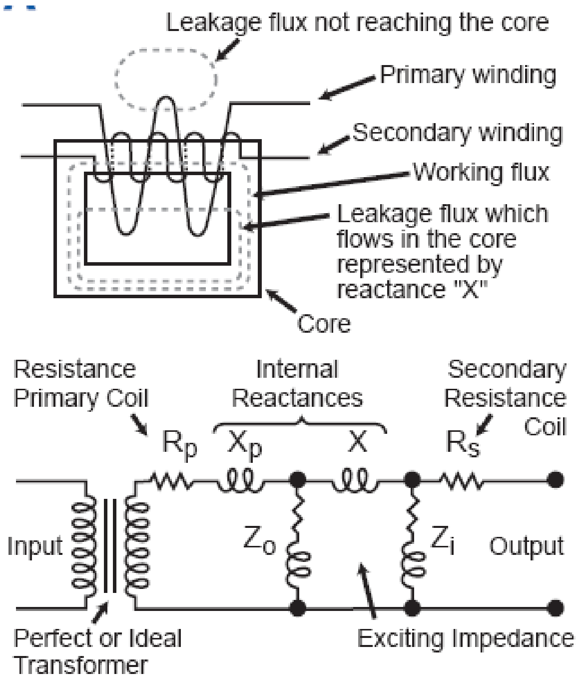

Fig. 1. A typical transformer and its equivalent circuit

B. Accuracy Class

There are two main accuracy classes for ITs, metering and relaying. The metering accuracy class current transformers are mentioned for completeness, but for most applications of the intended audience will be utilizing relaying accuracy class current transformers. Metering ITs require high accuracy in the range of normal operating voltage and current. Protection ITs require linearity in a wide range of voltages and currents.

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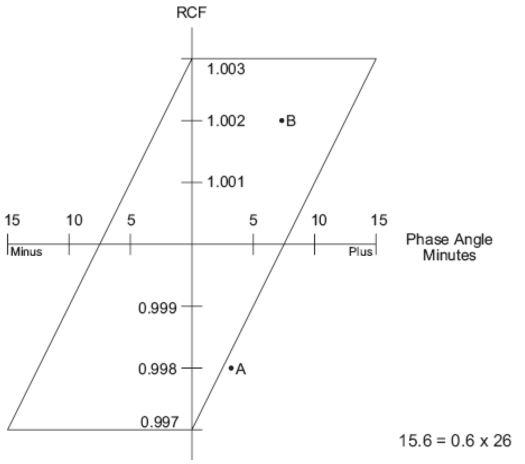

Fig.2-Basic Metering Accuracy Class 0.3 Parallelogram for Current Transformers

Relaying accuracy classes for CTs are defined with a “C” or a “T” classification.

“C” indicates that the transformer ratio can be calculated. These are transformers which are constructed so that the effects of leakage fluxes on its performance are negligible, such as bushing current transformers with uniformly distributed windings.

“T” indicates the transformer where the leakage flux has an appreciable effect on the ratio. Since the calculation of the excitation current by-passed is a tedious process, the performance of the transformer can only be determined by test.

The basis for classification of performance for relaying is an error limit of 10% at any current from 1.0 to 20 times normal. The accuracy class is the description of how much voltage the transformer can supply to the output circuit (burden), without the CT core going into saturation.

For example, a transformer that can supply a 2 ohm output circuit (burden) at 100 A [20 times normal current (5 A)] or 200 V, without saturating the core and within a 10% error limit, is classified as 200 accuracy class. Refer to Fig. 3.

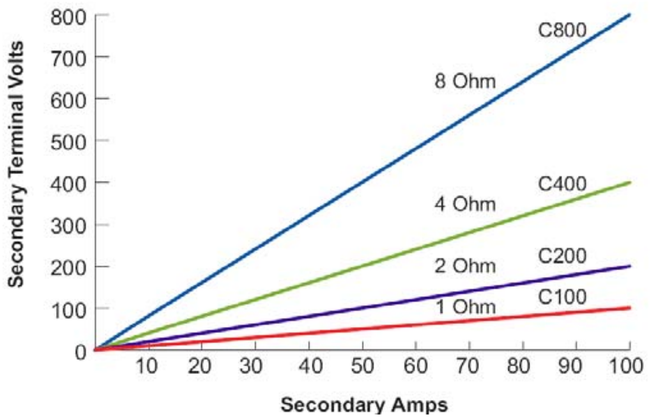

Fig.3 – Relaying Accuracy Standard Chart for Class C Current Transformers

III. CIRCUIT DESIGN FOR TESTING

Solid state and microprocessor based relays provide lots of extra features that electromechanical relays lacked, but one feature that electromechanical relays still have a good benefit is the built in design of test switches. Microprocessor relays may have self diagnostics to continuously monitor the health of the relay, but if test switches are not included in the design then there is no way to easily test the current transformer or isolate the relay without de-energizing the equipment. Fortunately separate test switches can be incorporated in applications that use microprocessor relays

A. Test Switch Usage

Test switches provide a quick and safe means of testing relays. Test switches are especially important wherever secondary current transformer circuits may need to be temporarily reconfigured to facilitate testing or where the relay must be temporarily disconnected from service. Accidental opening of a CT secondary circuit can result in extremely high voltage and arcing, creating a dangerous hazard. Test switches eliminate this possibility by diverting the secondary current to an alternate path before opening the connection to the relay. This sequenced operation is inherent to the design of the current-shorting poles of a test switch.

One example shown in Fig. 4 is a high impedance bus differential scheme. [2]

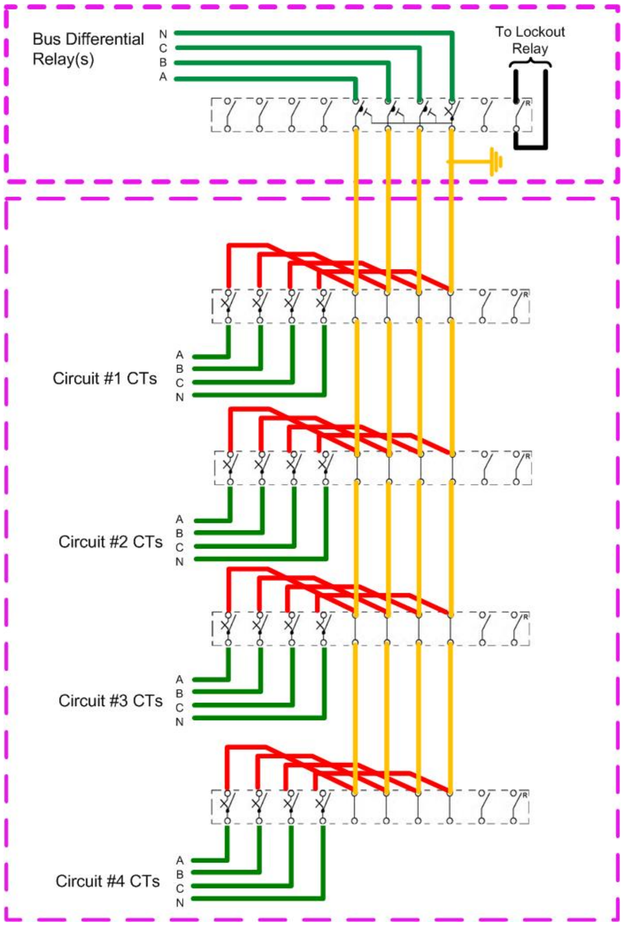

Fig.4 – Sample High Impedance Bus Differential Scheme with test switches for each set of CTs.

The CTs from each circuit are routed through a set of nonshorting CT switches. These switches provide a means of measuring the current contribution from each individual CT with a separate series test plug. Between the junction point and the relay is a different FT-1 switch with four shorting switches for shorting each paralleled phase sum and neutral, thereby isolating the relay for separate source current injection testing.

However not all test switches are created equal. Tests showed that numerous factors affect the intended functionality of test switches. Some of those factors include, but are not limited to design, the relative height location of the test switch vs. end user reach, angle, the insertion and removal speed, switch configuration, number of poles, connected load, current transformer ratio and class, currents in the secondary and voltage levels. [3]

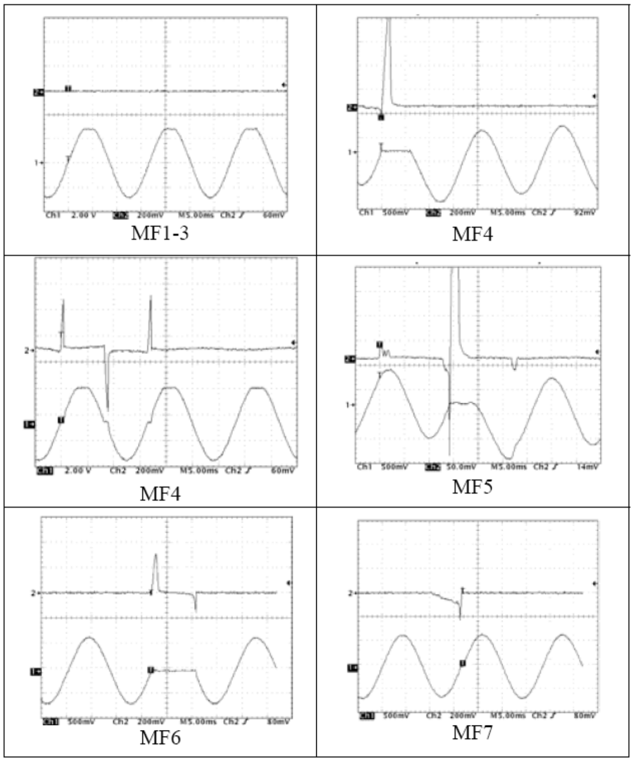
MF1-3
MF4
MF4
MF5
MF6
MF7

Fig.5 - Test results of Make Before Break Operation in CT circuits of sample test switches[3]

When considering test switches for current transformer circuits the key performance feature is the make before break sequence to avoid an open circuited secondary. Figure 5 illustrates that not all manufacturers' test switches perform this function without some error. Voltage spikes can be seen on 5 out of 6 test samples. The voltage spike is a clear indication of a momentary opening of the current transformer secondary circuit. The consequences of this misoperation are discussed later.

IV. REASONS FOR IN-SERVICE TESTING

Most ITs associated with power transformers in North American utility stations are about 30 years old and are fast approaching the end of their expected service life. Their failure rate is expected to increase over the next few years.[4]

Also problems with Generator CTs and associated monitoring, and control instrumentation can result in very expensive and costly outages. Un-expected outages are very expensive in terms of lost generation capacity, replacement power costs, and labor and materials. Therefore it is imperative that GCTs be extremely reliable and perform as designed at all times, and that their condition be known throughout their life.[5]

Other rationale can be attributed to:

Competitive Electric Utility Market
- More power wheeling/power needs
- Control of supply chain resources
- Requires reliable power delivery
- Equipment availability

Deregulation of Electric Power
- GENCO to TRANSCO separation
- ISO activity requires metering
- Need to use existing ITs

Bottom-line Focused
- Billing and current swings
- Must verify performance of ITs

V. SAFETY CONSIDERATIONS OF IN-SERVICE CT TESTING

Even with all the appropriate safety precautions accidental opening of current transformers can occur during in-service testing due to many potential test meter problems:

- Blown Fuse in test meter
- Disconnected leads
- Defective leads
- Defective equipment
- Incorrect Connections
- Incorrect meter mode selected

The major consequences of an open circuited CT are the hazardous voltage exposed to the operator, signal discontinuity to relay and permanent magnetization of the CT.

A. Hazardous Voltage

Since open circuit voltage is limited by saturation of the core, the RMS value measured by a voltmeter may not appear to be dangerous. However as the current cyclically passes through zero, the rate of change of flux at current zero is not limited by saturation, and is very high indeed. This induces extremely high peaks or pulses of voltage. Lab measurements of up to 15 kV have been reported.

These high peaks of voltage may not register on the conventional voltmeter, but they can break down insulation and are dangerous to personnel. Current transformers are insulated to withstand, for emergency operation, secondary peak voltages up to 3500 volts.

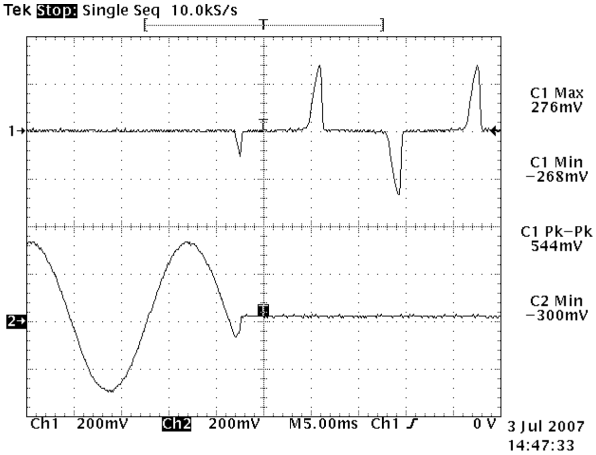

Fig. 6 – Voltage spikes occur at every half cycle until the open circuit condition goes away.

B. *Signal Discontinuity to the relay*

If the secondary circuit of the current transformer is opened, the current to the relay will go to zero as seen in Fig.6. If the open circuited current transformer is part of a differential scheme, then the restraint currents would become unequal and cause a false trip, or possibly a blackout depending on the criticality of the circuit.

C. *Permanent Magnetization*

If the secondary circuit of the current transformer is accidentally opened, the flux density will become very high and even if the circuit is immediately closed again, the core may be left with permanent magnetization. The final result is that the effective exciting current, which causes ratio error and phase angle, is increased if the core becomes permanently magnetized.

D. *Solution to Open CT dangers during In-Service Testing*

A smart current test plug with open CT protection has been developed to prevent shock hazards, outages, and erroneous meter readings associated with open CTs. When an open CT is detected, the test plug shorts the CT to protect the operator and minimizes waveform distortion to prevent false trips and maintain signal continuity.

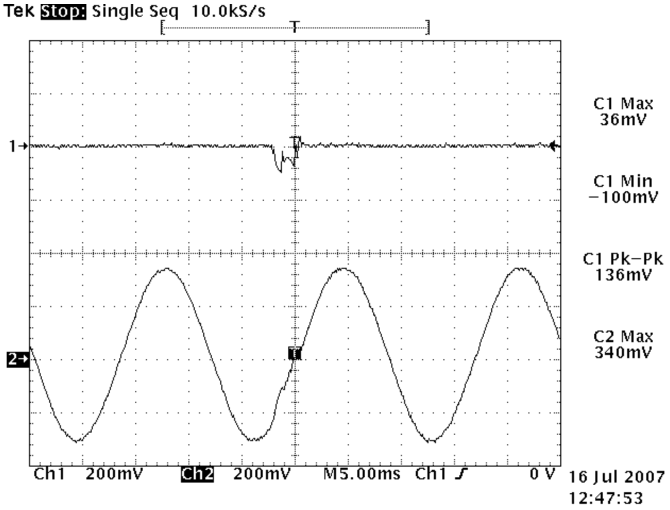

Fig.7 - Open CT using test plug with open CT protection

As can be seen in Fig.7 in comparison to Fig.6 current signal integrity to the relay is maintained, to prevent incorrect operations. The open circuited current transformer is shorted within 100 microseconds. Also the voltage spike is limited to the first occurrence and is limited to 35 Volts thus eliminating a shock hazard.

VI. CONCLUSIONS

Safely prolonging the life of installed ITs will require an accurate condition assessment, while reliability concerns will push for more in-service diagnostic techniques. Given those circumstances, open CT conditions are a very likely event.

Such open circuited CT events lead to shock hazards, outages, and incorrect readings long after the condition is eliminated due to magnetization.

Test switches are recommended for all installations with current transformers, especially at critical asset locations.

A new smart test plug device eliminates the risks due to operator error, incorrect equipment or risks arising due to normal practices and procedures.

VII. REFERENCES

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