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Metrological Characterization of Low Power Instrument Transformer Integrated in MV Recloser

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SUMMARY

This paper presents the results of an experimental testing carried out on a low power instrument transformer (LPIT) for medium voltage distribution systems. The aim of the paper is to demonstrate the accuracy tests in accordance with IEC and IEEE standards on a system level in different operating conditions.

KEYWORDS

Low Power Instrument Transformer (LPIT), Switchgear, Accuracy Classes, GUM, Metrology.

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INTRODUCTION

The Grid of the Future will require smarter and more capable equipment, both for transmission and distribution equipment. Distribution reclosers, due to their expanding capabilities, are becoming popular for more than overcurrent protection and reclosing. Improved accuracy of integrated voltage measurement is one of these capabilities. Traditional MV reclosers have either had no integrated LPIT, or if they did, their accuracy was poor limiting their functionality and potential applications. New developments of the LPIT allow for integrated high accuracy measurements in MV recloser systems which were not previously possible.

The measuring system is an exceptionally intricate system, including the LPIT, MV recloser, recloser control, and associated interconnection cables. Due to the complexity of this system, a detailed metrological characterization must be implemented for the LPIT under different voltage, frequency, and temperature. Considerations must be taken for the cabling capacitance and length in order to ensure that the integrated measuring system complies with the accuracy requirement in all operating conditions.

LPIT SYSTEM

The LPIT system under study is a G&W Electric Co. system consisting of Accusense LPIT and Viper-LT MV reclosers. The Accusense LPIT is a capacitive voltage divider with an embedded electronic circuit designed to condition the output signal. The rated voltage ratio is 5000:1 (V:V) and is for use on MV distribution systems up to 38kV. The MV recloser and LPIT are measured and controlled by a SEL-651R-2 recloser control.

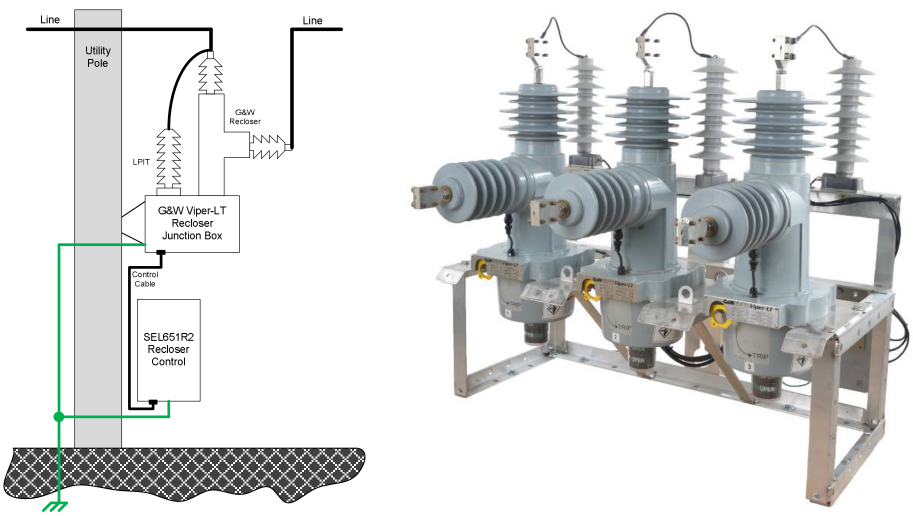

FIGURE 1: (Left) Example of LPIT and MV Recloser Installation. (Right) Photograph of MV Recloser with LPIT.

METROLOGICAL CHARACTERIZATION SETUP

To understand how voltage measurement errors are introduced in the LPIT recloser control system, a detailed study including a metrological characterization was performed. This included test setups in both hardware and software, designed to measure the primary voltage using a second highly accurate measuring system and assume it as a reference in comparison to the LPIT.

In this paper the focus will be on two accuracy tests which have been carried out, a basic accuracy test and an accuracy test versus temperature. Each test needed a particular setup design. The setups are based on a shared theory, developed in compliance with [1], [2], [3], and [4]. Two main components of the setup are in hardware and software.

HARDWARE SETUP

All the test setups are based on the same hardware design shown in Figure 2.

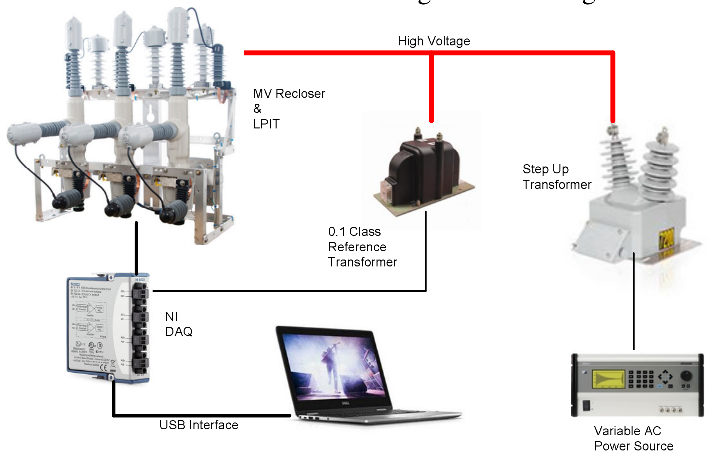

FIGURE 2: Diagram of test setup showing equipment used.

High voltage is generated using a step up transformer and an extremely stable variable AC voltage source. The reference system is a specialized 0.1 class reference transformer and a differential resistive divider. This was selected to achieve an overall ratio compatible with the data acquisition system (DAQ). The burden has been designed to meet the requirements of the 0.1 class output and interface with the input impedance of the DAQ. For the DAQ, a National Instruments (NI) 9239 was selected. It has a $\pm 10V_{peak}$ and 24 bits of resolution with a standard USB interface.

Extreme care has been taken in order to reduce the noise impact on measurements in that all cables not part of the LPIT were chosen to be shielded twisted pairs. All components related to the measurement system were enclosed in metallic enclosures and grounded. A star point was used for all grounds at the source transformer in order to avoid ground loops.

SOFTWARE SETUP

Specialized software is required to properly measure and condition the signals as well as perform calculations according to the GUM [1] and [2]. National Instruments LabVIEW software was selected for this function.

The NI LabVIEW routines have been designed to evaluate the voltage magnitude error and the phase error uncertainties according to [1] and [2]. The overall uncertainty is given by the contribution of two different kinds of uncertainties: Type A uncertainty and Type B uncertainty evaluation. Type A uncertainty evaluation is a method of evaluation of uncertainty by the statistical analysis of series of observations. Type B uncertainty evaluation is a method of evaluation of uncertainty by means other than the statistical analysis of series of observations [6]. The NI LabVIEW routines are designed to compute these uncertainties, an example of which is given below for the Temperature Accuracy test, described later in this document.

The LabVIEW routine for the temperature accuracy testing is programmed to:

- Acquire 12500 samples of the reference voltage transformer from the DAQ
- Propagate the error induced by the DAQ and the reference voltage transformer
- Use a serial communication script to get voltage measurements from the recloser control
- Calculate voltage ratio and phase error 95% Type B uncertainty of the system
- Calculate mean value and Type A 95% uncertainty of both voltage magnitude and phase error of the system.
- Display and save results and the overall 95% uncertainty of the system.

Next the Type A and Type B uncertainty calculation routines per [#] will be detailed.

TYPE A UNCERTAINTY

A diagram of the Type A uncertainty evaluation implemented in LabVIEW is shown in Fig 3.:

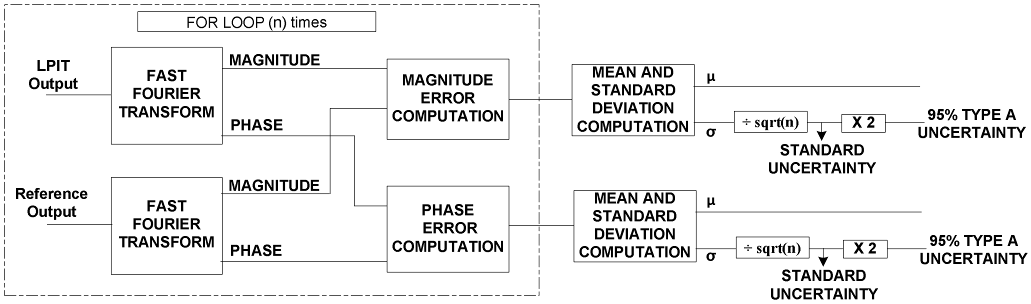

FIGURE 3. Type A uncertainty evaluation method implemented in LabVIEW

The Type A uncertainty evaluation is based on the central limit theorem (CLT). The most efficient way to reduce the effect of noise is to repeat the voltage magnitude error and phase error measurement several times (n samples, considered as random variables) and then compute the mean value and standard deviation based on a normal distribution. The GUM [1] and [2] defines the obtained standard deviation as “standard Type A uncertainty” and defines “expanded Type A uncertainty” as the standard Type A uncertainty multiplied for a “coverage factor” of 2.

TYPE B UNCERTAINTY

The Type B uncertainty is related to the instrumentation errors and a diagram for the Type B uncertainty evaluation implemented in LabVIEW is shown in Fig.4:

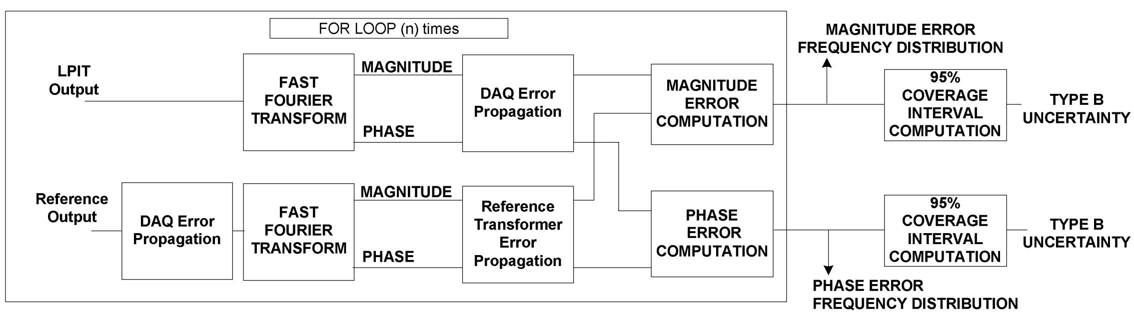

FIGURE 4. Type B uncertainty evaluation method implemented in LabVIEW

Instrumentation errors are usually reported in the equipment’s datasheets, but they might not represent the actual error of the instrument being used here since the manufacturer typically tests only a few of units and reports the worst performance. The supplement 1 of GUM [2] introduces an innovative method to calculate the Type B uncertainty using the Monte Carlo method.

The errors are assumed as random variables following rectangular probability distributions and their extremes are the error values reported in the datasheets. With this method the routine simulates the operation of multiple different instruments of the same model, each one with a different error.

As a result, a voltage magnitude error and a phase error frequency distributions are obtained, which includes all the instruments errors contributions. Using a 95% coverage factor, the Type B uncertainty is calculated as half of the shortest coverage interval.

BASIC ACCURACY TEST

A basic accuracy test was performed using the test setup described previously at room temperature and at rated frequency (60 Hz). A sample of LPIT was tested in three different cable configurations:

without control cable, with a 10' cable and with a 100' cable. According to [3] the tests must be performed at 80%, 100%, and 120% of the rated voltage.

Vapp (kV)	No Cable		10' Cable		100' Cable	
	Magnitude Error (%)	Phase Error (mrad)	Magnitude Error (%)	Phase Error (mrad)	Magnitude Error (%)	Phase Error (mrad)
12.5	0.28	1.8	0.28	1.8	0.28	1.8
15.6	0.28	1.9	0.28	1.9	0.28	1.9
18.7	0.29	1.9	0.29	1.9	0.29	2.0

FIGURE 5. Tabular results of basic accuracy testing with various cable lengths.

The table shows the voltage magnitude error (%) and the phase error (mrad) with different cables and under different primary voltages. The results shown are the worst results out of the entire sample LPIT and all measurements. It can be observed that the different cable lengths and primary voltages cause negligible variations.

ACCURACY VERSUS TEMPERATURE TEST

The test setup design is similar to the basic accuracy test setup, with some modifications to include the whole system, as shown in the figure below. One key difference in this test is that this test setup includes the recloser control; as it is important to understand its impact on uncertainty.

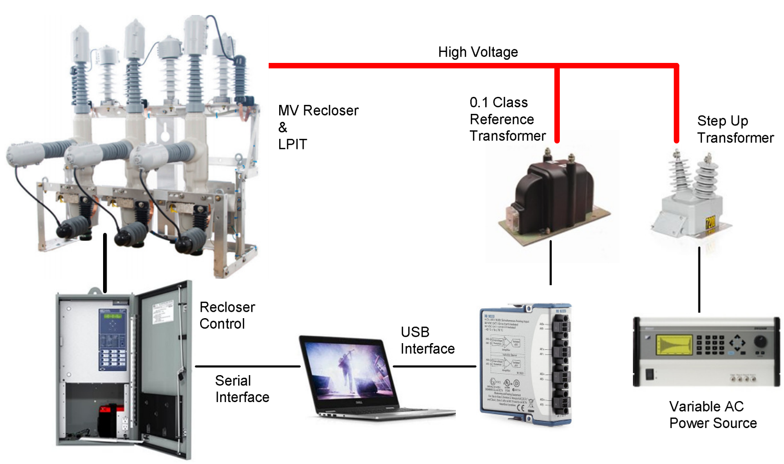

FIGURE 6. Test equipment setup for temperature accuracy testing.

To understand the impact as temperature changes, the temperature profile below was used. It allowed for data to be taken in 20°C steps to better understand any errors due to temperature.

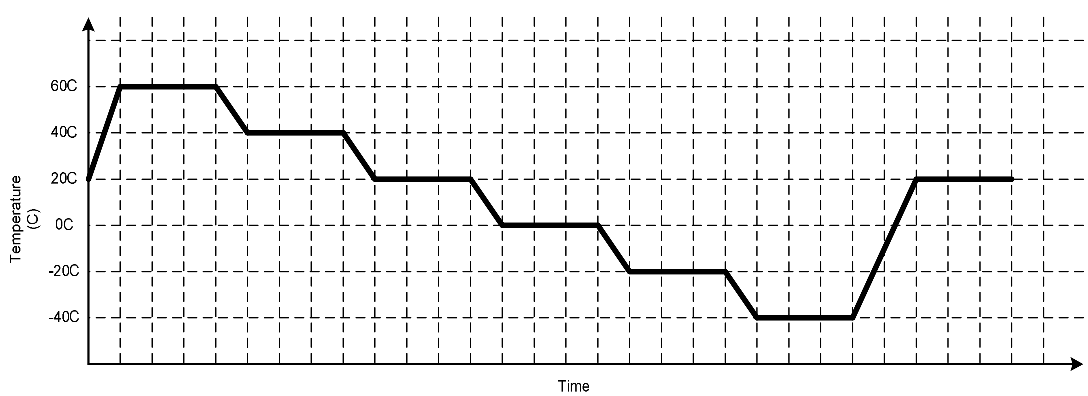

FIGURE 7. Temperature profile used for temperature accuracy testing.

For this test, three LPIT were tested using the 10' and 100' control cables at rated voltage and frequency. Refer to the section on Software Setup for more information on the LabVIEW routine used to measure and calculate results. The results are shown in graphical form below in Fig 8.

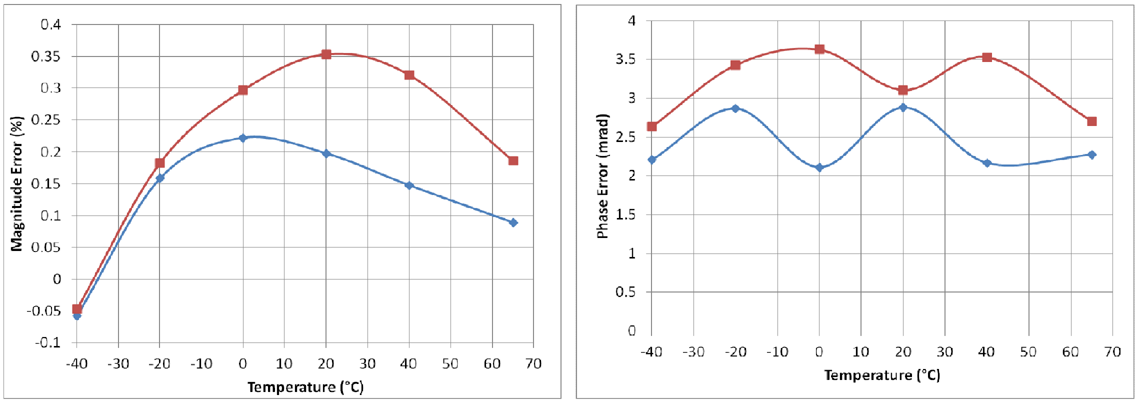

FIGURE 8. (Left) Magnitude Error versus temperature results. (Right) Phase Error versus temperature results.

As shown in Fig. 8, only two LPIT results are displayed in each: the best and the worst. The voltage magnitude error is significantly affected by the temperature, but not affected by the cable length. All magnitude errors are still within class 0.5 per [3]. The phase error demonstrated negligible effects of both temperature and cable lengths.

CONCLUSIONS

A test setup has been created to allow for a complete metrological characterization of an LPIT MV recloser system in accordance with the GUM. The basic accuracy and temperature accuracy tests have been completed in different conditions to prove compliance with 0.5 accuracy class per applicable IEC standards [3]. It can be seen from the above that this type of study is a non-trivial task. A deep understanding of the system including the LPIT, cables, control, etc. is required to be able to guarantee compliance with 0.5 class. These types of setups can be used for future work including more extensive testing versus harmonics, frequency, and other major sources of influence on the accuracy.

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