Portable Fiber Optic CT for Field Calibration Applications

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Introduction

We have developed a portable fiber optic CT for use as a calibration reference, applicable for calibrating both conventional and non-conventional CTs. The unit consists of a window CT head tethered with a fiber optic cable to an electronics processing box. Both the optical circuit and the signal processing used are the same as that used in the NXCT metering solution. The sensor contains 16 turns of sensing fiber spliced into an in-line interferometer optical circuit [1], [2]. The output of the sensor is a linear analog voltage representing the primary current flowing through the sensing window. The performance of the sensor is = ±0.12% scale factor error over a temperature range of –50 to +60 °C (much of the error occurring below –40 °C), and over a dynamic range of 2 to 3600 A. The phase at 60 Hz is accurate over these same extremes to ±3min (with the possible exception of primary currents below 5 A where our measurement uncertainty grows to 10 min). The bandwidth of the sensor is from DC to 6 kHz. No external temperature compensation is needed as the sensor head performs a dual function; it measures both temperature and current. The intrinsic temperature dependence of the current measurement is characterized out using the optically measured temperature.

The sensor is configured to field calibrate any CT having either an analog voltage or current secondary by using a primary injected current to excite both the calibration unit and the CT under test, and comparing the outputs using suitable test equipment such as an Arbiter 931A Power Systems Analyzer. The fiber optic tether connecting the calibration unit sensor head with its electronics processing box allows for calibrating remote outputs of the CT under test, as far away as the length of the fiber optic tether. We have successfully demonstrated tether lengths as long as 660 meters.

The calibration of the portable reference is maintained against a NIST traceable reference, which is an active flux nulling CT produced by JAMB Inc. (certified at NIST to be accurate to better than 100 ppm over the range 5 to 2000 A). The accuracy of the fiber optic CT can be checked immediately before and after field calibration to ensure fidelity of the measurements.

CT Performance

Figures 1 and 2 show the linearity and phase performance of a type test sensor using this design (as measured by Powertech, an independent testing laboratory in Vancouver, B.C.). Over the whole dynamic range of 2 to 3600 A tested, performance remains within the uncertainties of the test equipment.

The field calibration unit is internally compensated for temperature in the sensing head. Compensation is accomplished using optically measured temperature at the sensing head and correcting the scale factor of the sensor with it. The temperature of the sensing head can be determined using the fact that the quarter waveplate in the sensing head varies over temperature. As the quarter waveplate deviates from perfection, some of the light in the sensor ceases to participate in the interferometer and creates an excess background light falling on the photodetector [3]. The amount of “excess light” falling on the photodetector is a direct function of the quarter waveplate action, which in turn is a direct function of its temperature. The excess light on the photodetector is determined in the signal processing chip, and is used there to digitally correct the scale factor of the sensor. The scale factor compensation algorithm uses a linear fit to excess light.

Figure 3 shows a plot of the excess light on the photodetector as a function of temperature over the range –50 to +60 °C. The temperature was run over several cycles to generate this graph. We believe that most (if not all) of the hysteresis that is seen in this graph is an artifact of the thermal time constant of the head. The thermal time constant causes the temperature inside the head to be time-delayed with respect to the recorded temperature, measured outside the head. In fact, the sensor head itself provides its own best measurement of temperature.

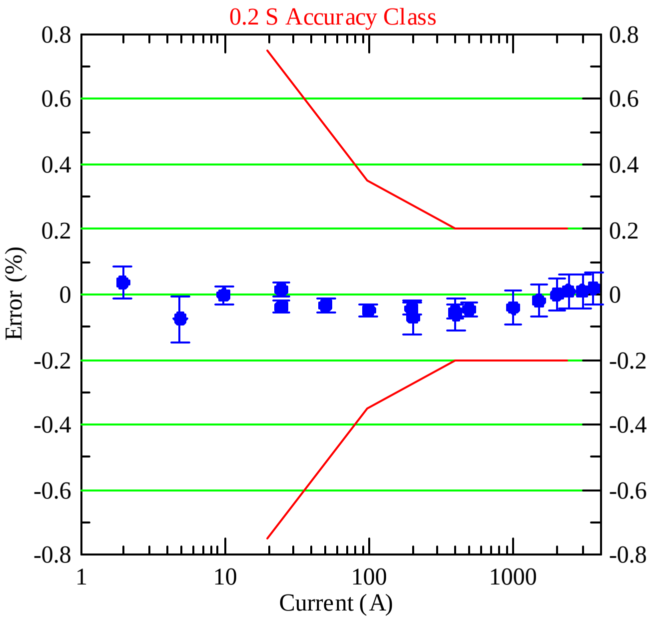

Figure 1 Accuracy error of an optical CT from 2 A to 3600 A. The solid lines show IEC 0.2S requirements.

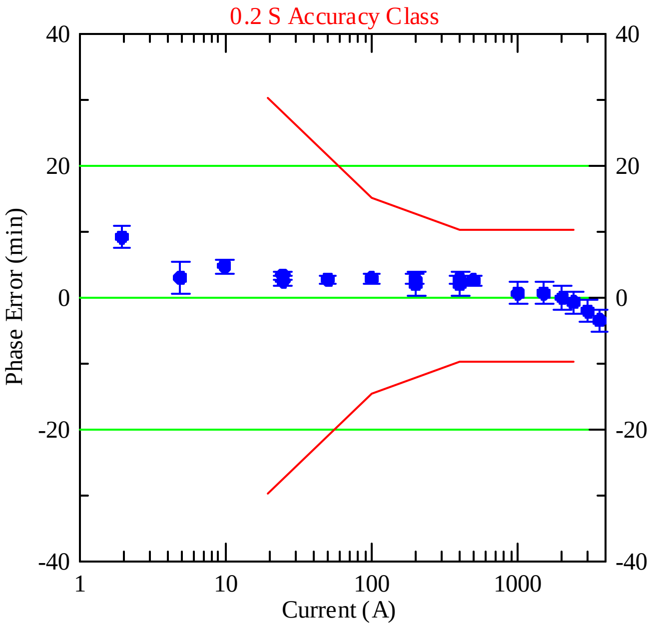

Figure 2 Phase error of an optical CT. Solid lines represent IEC 0.2S class specification.

Figure 4 shows the temperature performance of the portable fiber optic CT measured in our Phoenix laboratories. This data was taken using a primary injection current of 70 A, which is 3.5% of the 2000 A rating on this CT. We note that at this current level, measurement accuracy is not as good as it is at higher current levels (200 A and above). The reason is that quantization errors in the D/A converter, that converts the digital representation of the current into the analog output, slightly corrupt the fidelity of the signal. At higher currents, more bits are used, causing individual bit errors to average out. Much of the error over temperature occurs below –40 °C. However, field calibrations are unlikely in such cold weather; in reasonable weather the field calibration accuracy remains better than 0.1%.

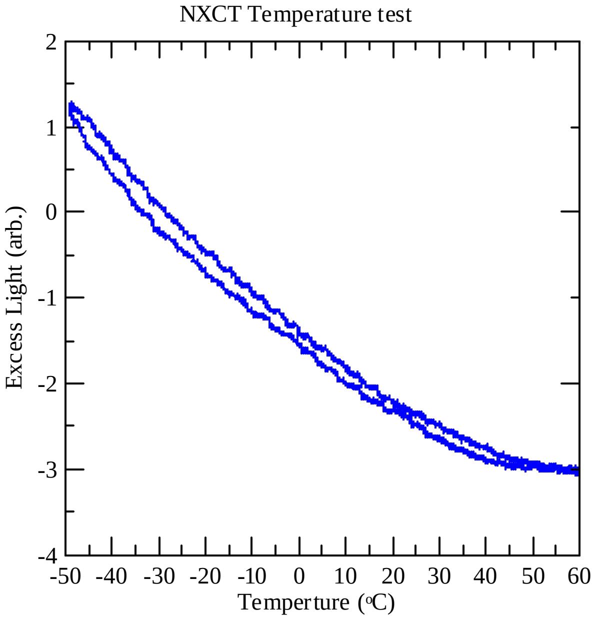

Figure 3 Excess light level in the field calibration unit versus temperature.

Field Experience

We employed the portable CT field calibration unit to check the accuracy of our 600 A rated metering grade optical CTs upon installation at a 120 kV site in Montreal for Hydro Québec. We used a *Programma* CSU600A portable current source to provide up to 300 A of current. The *Programma* itself is capable of putting out 600 A, but the generator supporting it during the outage tripped above 300 A. We calibrated the three phases in less than 1 hour in the wind and rain. Our results showed that phase B agreed with the calibration unit to within 0.00%, phase C agreed to within 0.07%, and phase A agreed to within 0.29%. Some inaccuracy in phase A was expected as we had discovered and corrected a minor wiring error after factory calibration and before installation. We elected to adjust the scale factor of only phase A, and that only by 0.22%, as we felt that the uncertainty in the measurements

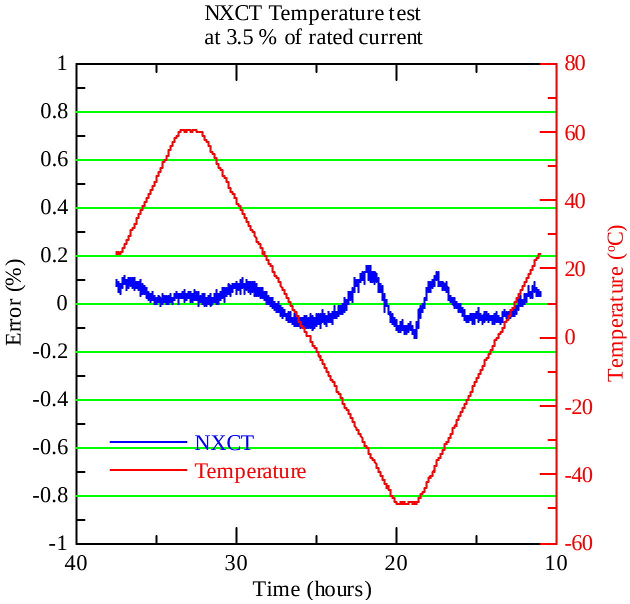

Figure 4 Temperature performance of the field calibration CT.

could be up to 0.07% (the delta seen in phase C). It should also be noted that we checked the field calibration unit against the NIST traceable JAMB before and after the field calibrations, finding 0.07% shift in the field calibration unit itself. This corresponds well with temperature variations experienced during testing. The initial calibration against the JAMB was done at 23°C, but the outside temperature was about 3°C; the calibration unit cooled from one to the other during the testing.

Conclusions

We have built and demonstrated a portable optical field calibration CT for use in calibrating both conventional and optical CTs. The procedure is simple and takes less than 1 hour (after taking an outage) to calibrate 3 phases. The accuracy of the procedure is such that in normal weather conditions calibrations can be performed to better than 0.1% and 3 minutes of phase. At the date of this writing our equipment is capable of maintaining this accuracy over a dynamic range of about 50 to 3600 A. We believe it is only a matter of certification testing to increase the upper end to 8 kA (though finding a current source to provide the current may be problematic). Though the field calibration unit itself is certifiably accurate down to 2 A, extending the lower end down to this level requires more specialized comparison equipment than the Arbiter 931A, as the Arbiter does not provide the low level signal accuracies needed. Future work will be directed toward incorporating such low-level signal analysis into the portable unit.

References

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