Optical Voltage Transducers for High-Voltage Applications

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Optical methods for the measurement of current and voltage in high-voltage (HV) environments have been attracting more and more attention in the recent years. This is mostly due to the advantages that they offer over conventional instrument transformers. They provide immunity to electromagnetic interference, are typically non-intrusive, provide excellent galvanic isolation, are much lighter and, therefore, easier to transport and install. Early work on optical current and voltage sensing in the HV environment started in the 1970's [1-5] leading to more practical and accurate systems developed in the 1980's and 1990's [6-13]. Also, at the commercial level, current sensing technology (both for technical and economical reasons) led voltage sensing technology. In this paper, we present results obtained using NxtPhase's optical voltage transducer, NXVT.

Most practical optical voltage sensors use electric field sensors that operate using the linear electro-optic (or Pockels) effect. It should be noted that the sensors themselves are, strictly speaking, electric field sensors and not voltage sensors. However, various means of getting a one-to-one relationship between the voltage applied and the electric field sensed are used to derive voltage. For example the entire voltage can be applied across the electro-optic crystal, or a capacitive divider can be used to apply a well-known fraction of the voltage to be measured across an optical electric field sensors. There are advantages and disadvantages to each of these methods. Nevertheless, most successful devices in the past have used optical fibers for the transmission of light, bulk electric field sensors as sensing elements, and SF_6 gas for insulation.

The NXVT introduced here combines the typical benefits of optical sensing technology with some additional features that provide further benefits to the user. For example, it does not use SF_6 or oil-paper insulation, making it more environmentally friendly and much safer to use. The NXVT uses multiple miniature electric field sensors inside a high-quality post insulator, in a proprietary manner, to measure voltage with high accuracy. We will describe the NXVT and present the results of some HV tests to demonstrate its operating principle.

The NXVT uses a proprietary method of measuring electric fields at several points and dynamically combining the results to obtain the voltage difference across its terminals. It consists of a hollow HV insulator with miniature electric field sensors mounted inside the insulator column. The location of the electric field sensors inside the column and the mathematical function combining the measurements to obtain voltage are both determined so that changes in the environment and other phases of a 3-phase system, namely external influences, will not affect the voltage measured. Electric fields measured can change substantially due to these external influences; nevertheless, the way in which the measurements are combined and the positioning of the electric field sensors results in a voltage measurement which is virtually insensitive to these influences.

After a great deal of numerical modelling, a prototype 230 kV class NXVT was fabricated and tested to prove the concept. It consisted of a high-quality 2.3m polymer insulator with metallic electrodes and flanges at its two ends and housing three electric field sensors. See Figures 1, 2, and 3. The electric field sensors used were integrated optics Pockels cells (IOPC) [14, 15]. The IOPCs were located at specific locations inside the column, one near the top, one close to the middle, and the third close to the bottom of the column. The insulator column was filled with air.

The transducer was tested at Powertech Labs, (BC Hydro's research subsidiary) in April 1999. The analog and digital electronics were housed inside a copper box, right underneath the column which was mounted on a ~2.5m support structure. Optical fibers from the sensors inside the column passed through a hole at the bottom of the column and were connected to the electronics. Digital data representing the electric fields measured by the three sensors and the voltage measured (obtained from the electric fields measured) by the digital electronics were transmitted to a data acquisition computer (DAQ) at a high rate of ~66kHz. For reference, a signal measured from a highly accurate standard capacitor was digitized using a specially calibrated analog-to-digital converter circuit (calibrated for accuracy at 60 Hz) and transmitted to the DAQ simultaneously (and synchronously) with the NXVT results. Dedicated test software developed in LabView[â] was used for comparing NXVT results with the reference. It should be emphasized that the intention of these tests was to show that the method works, i.e., the electric fields measured can change substantially without the voltage measured changing (erroneously) significantly. The test and the electronics used were not intended for absolute accuracy tests, i.e., they could introduce variations of ~1%.

As mentioned above, external influences such as the other two phases of voltage in a 3-phase environment or a nearby moving metallic object (e.g. a truck) can affect the electric field present at one point. To demonstrate the immunity of voltage measurement done by the NXVT to such influences, a grounded metallic mesh/plane was used to severely disturb the electric field near the NXVT under test. This particular disturbance represents a perturbation that is much worse than what is typically allowed (based on safety considerations) in a HV substation. In one test (see Figure 1) the ground plane was located ~1.5m from the center of the column and ~50cm from the corona ring at the top of the NXVT column. The NXVT was energized to 170kV rms (line-to-ground), which represents ~120% of rated voltage. Table 1 shows the results of the electric fields measured by each electric field sensor at its respective location as well as the voltage output of the NXVT as compared to the reference standard cap. The values are given in percent of their respective values when the ground mesh was not present. Even though the electric field distribution is severely disturbed by as much as 20%, the change in the voltage measured by the NXVT is less than 1%.

	With Ground Plane Perturbation (as percentages of values measured under no disturbance)
V	100.6%
E_{Top}	119.1%
E_{Middle}	95.4%
E_{Bottom}	77.1%

Table 1: Measured values of voltage and electric fields under a severe field disturbance as compared to the respective values under no disturbance. Test accuracy was ~1%.

Rain and water flow may also affect the field distribution around a HV line. Figure 2 shows the test set up at Powertech Labs for examining the effects of rain on the accuracy of the NXVT. Table 2 includes the results of the measurements using both ANSI/IEEE and IEC water flow (rain) specifications. It also shows the results of measurements when the column was wet but no rain was simulated. As demonstrated in Table 2, the presence of water caused no significant changes in the calibration (within the accuracy of the measurements), mainly because there were minimal effects on the electric field distribution as compared to a dry condition.

	Wet, without Water Flow	Wet, with Water Flow (IEC)	Wet, with Water Flow (ANSI)
V	100.1%	100.0%	99.9%
E_{Top}	100.6%	99.9%	100.4%
E_{Middle}	100.1%	100.2%	100.0%
E_{Bottom}	99.7%	100.1%	99.6%

Table 2: Measured values of voltage and electric fields by an NXVT under water/rain related disturbances as compared to the respective values under no disturbance. Test accuracy was ~1%.

Similar tests were repeated on another NXVT using a thinner column, in June 1999 (see Figure 3). The results were similar to those obtained from the first NXVT, confirming the accuracy is maintained with a range of column diameters.

Subsequent to successful demonstration of the operation of the prototype NXVTs at Powertech Labs in 1999, highly accurate electronics and opto-electronics to be used as integral parts of the NXVT have been developed. Also various parts of the NXVT, including the electric field sensors, have been going through extensive temperature cycling in the past few months. The technology is now ready for field trial.

The first field installation of a 3-phase, 230kV, 0.3% accuracy class metering NXVT system is scheduled at BC Hydro for April 2000. The voltage sensors actually share the column with the NXCT Optical Current Transducer. The combined unit is know as the NXVCT.

Figure 4 shows a schematic of the field trial installation which will consist of three NXVCTs mounted on existing support structure within Ingledow substation. Fiber optic cables will connect the sensors to the opto-electronics package remotely located in the control building. The field optics are completely passive for greatest reliability and ease of maintenance.

Digital outputs from the sensors will feed a PC based data acquisition system for monitoring of key line parameters, event capture, data logging and remote data access. Low level analog outputs will feed a commercially available power meter. High energy analog outputs will drive a separate power meter to allow comparison between the two different methods of interfacing with the sensors. An interface to a protective relay is also planned for the project.

A few months of further refinements based on field trial experience will be required before the products are at a state of commercial readiness. NxtPhase expects to launch the product in September 2000.

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Figure 1. The NXVT together with a ground plane for testing the effects of field distribution changes on the NXVT measurements.

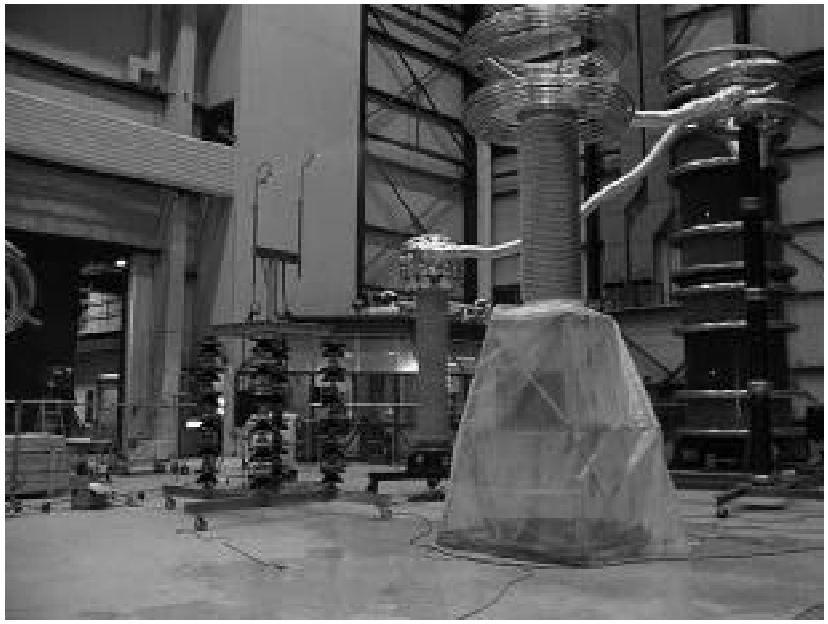

Figure 2. Wet tests on the NXVT.

Figure 3. A 12-inch diameter NXVT

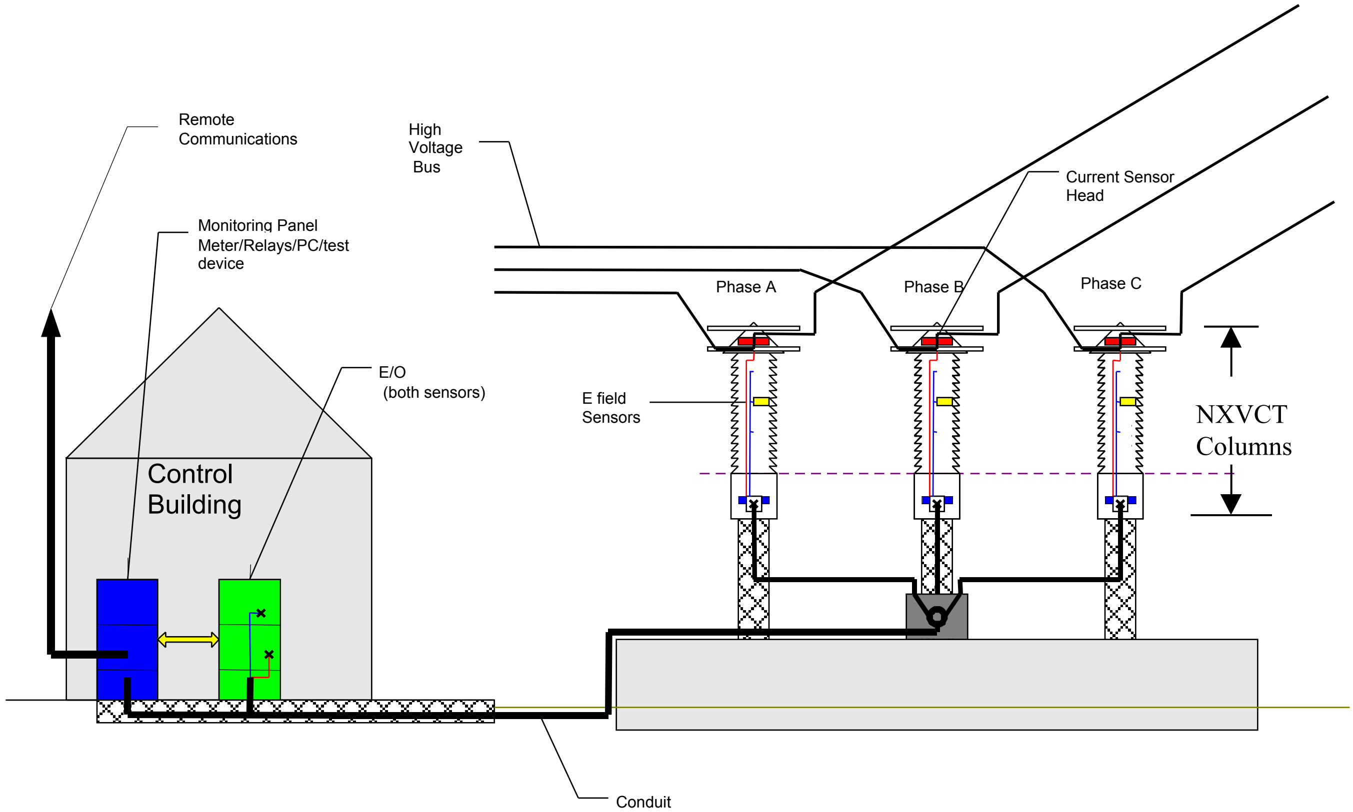

Figure 4. Field Trial Schematic