OPTICAL CURRENT AND VOLTAGE SENSORS IN EHV SERIES CAPACITOR BANKS APPLICATION

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Summary: *Optical current and voltage sensors were used during staged fault tests of a 500 kV series capacitor bank at BC Hydro's Guichon Series Capacitor Station in British Columbia, Canada. The main purpose of the tests was to verify the control and protection systems. Three optical sensors were used to measure the fault current, and metal oxide varistor (MOV) current and voltage. The optical sensors performed well showing the waveforms of high primary fault currents, low secondary arc currents, MOV currents and voltages and the high frequency ringing following sparkgap operation.*

Keywords: Series capacitor banks; fault testing; optical current and voltage transformers.

1. INTRODUCTION

Series capacitor banks are applied mainly on long EHV transmission lines with the purpose of increasing the power transfer capability of the line by reducing its effective line impedance and to improve system stability. The 500 kV bank at BC Hydro's Guichon Series Capacitor is typical of a gapped – MOV protected scheme (Figure 1). The circuit arrangement consists of three branches as follows:

- The damping circuit (5RX1 and 5R1) in series with the bypass breaker (5CB1) and triggered sparkgap (5SG1). The purpose of the damping circuit is to limit and damp the capacitor bank discharge current when the bypass breaker is closed or when the sparkgap is triggered during a fault on the line and the capacitor is charged to the bank protective level. Current in the sparkgap is detected by 5SGCT1 and immediately initiates closing of the bypass breaker.
- The capacitor bank is split into four sections as shown to enable unbalance protection (5UBCT1) for detecting capacitor failures.

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- The MOV (5MOV1) provides overvoltage protection of the bank in the event of a fault on the line. MOV current is detected by 5MOVCT1 and the energy relay calculates and integrates the energy absorption using the measured current and the V-I characteristic of the MOV. When the energy absorption limit is reached, the sparkgap is triggered and bypass initiated.

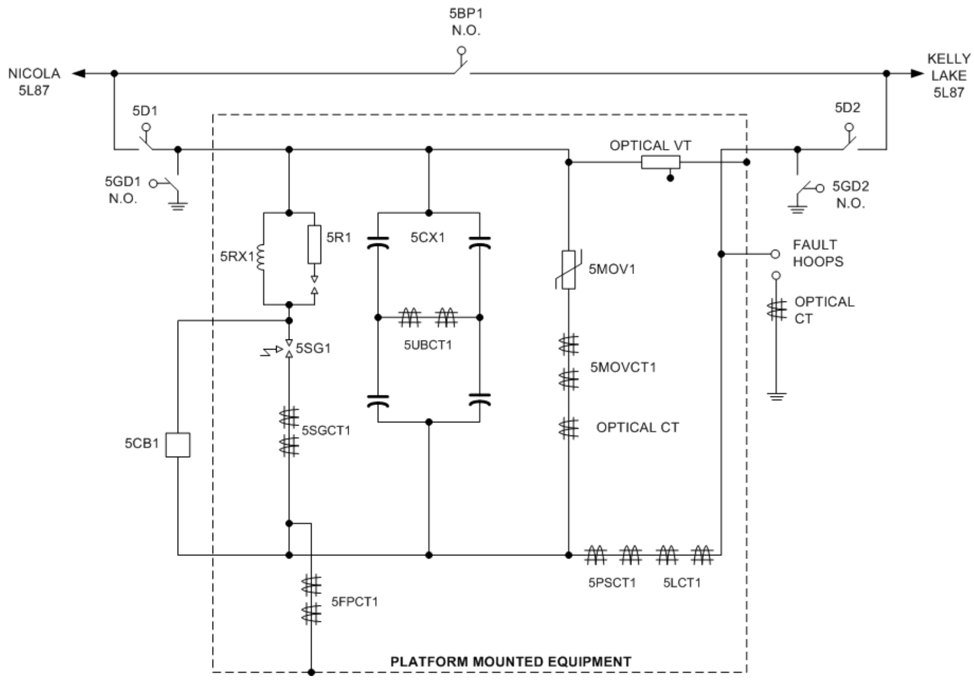

Figure 1. Guichon Series Capacitor Bank one-line diagram.

The equipment as shown within the dashed lines in Figure 1 is mounted on a platform isolated from ground. The platform is at the line potential: the Kelly Lake side of the bank is connected to the line. The purpose of 5FPCT1 is to detect faults to the platform. Current transformer 5LCT1 monitors the line current through the bank and 5PSCT1 provides platform level power for sparkgap firing purposes.

The bank is connected to the line through two isolating disconnectors 5D1 and 5D2. 5BP1 is the bypass disconnector. To insert a bypassed and isolated bank, 5D1 and 5D2 are first closed, then 5BP1 is opened to commutate the current through the bypass breaker and damping reactor circuit. The bypass breaker, 5CB1, is then opened to transfer the current to the capacitor bank.

For purposes of fault testing, a 145 kV optical voltage sensor (VT) was installed between the high voltage side of the bank and the platform to measure the voltage across the bank during steady state and fault conditions (Figure 1). An optical CT was installed in series with the MOV to measure MOV current. A total of five faults were created by firing a projectile trailing a fuse wire between two hoops; one at ground potential and the second at line potential as shown on the right side of Figure 1. The lower hoop was isolated from ground and an optical CT was installed to measure the primary fault and secondary arc currents. The latter currents occur due to single pole tripping of the line.

The paper describes the optical sensors and a comparison is made between the outputs of the bank standard protection and those from the sensors. The future use of optical sensors in series capacitor applications is discussed.

2. OPTICAL SENSORS

The optical VT used was an NXVT-145, deploying a distributed electric field sensor architecture, see [1] for details. The NXVT was programmed to have a scale factor of 20,125:1 and was set up for measuring voltages between –230 kV and +230 kV. It also had a wide bandwidth, capable of measuring signals between 0.001 Hz and 40 kHz. The fiber optic CTs used were all-dielectric, window type, NXCTs, having an in-line interferometric design, see [2] for details. Both NXCTs for measuring the MOV current and the fault current had scale factors of 1200A:1V and were set up to measure currents between –14 kA and +14 kA. The bandwidth of the NXCTs used was 6 kHz. Optical fibers, ~ 100 m long, connect the passive sensor heads to the associated electronics in the control room. The digital voltage and current measurements were converted to analog low energy voltages in the sensor electronics chassis. The outputs were sampled at 100,000 samples per second and stored using a multi-channel isolated data acquisition system.

The main reasons for using optical CTs and VTs for this test were the following:

- Wide bandwidth: fault current, MOV current, and MOV voltage were all expected to be very distorted waveforms, rich in frequency content;
- Linearity and wide dynamic range: very wide range of currents and voltages were to be measured without signal distortion. The primary and the secondary fault currents were expected to be about 12 kA and 40 A, respectively, and the wide dynamic range of the NXCT was critical for measuring both signals;
- Galvanic isolation from the HV line: optical isolation from the platform made the installation of the light weight test sensors easy and safe; and
- Galvanic isolation between various ground levels: since the fault was being created in the substation itself, the use of optical fibers solved the safety issue with the rising ground potential in various locations in the substation during the testing.

3. FAULT TEST RESULTS

Traces from the hybrid and optical measuring systems are shown in Figures 2 and 3, respectively.

Figure 2 shows the line current and MOV current measured by the protection system. The MOV current measured by optical sensors is also shown in figure 2. The voltage across the capacitor bank is shown by two curves: one measured by the optical VT (brown) and the other calculated from the MOV current measured by the optical CT, utilizing the MOV V/I characteristics given by the manufacturer. The MOV energies are calculated by two different methods, one using hybrid MOV current and V-I characteristics and the other optical current and voltage. Comparing MOV energies measured by the optical and hybrid system shows that the difference between the results is not significant. The calculated energies were 13.48 MJ measured by NxtPhase optical sensors, and 13.51 MJ measured by Nokian Capacitors protection system. The difference is well within accuracy specification of the devices used for measurements. The measured voltage was slightly higher than the voltage calculated by the hybrid system using the V/I characteristics.

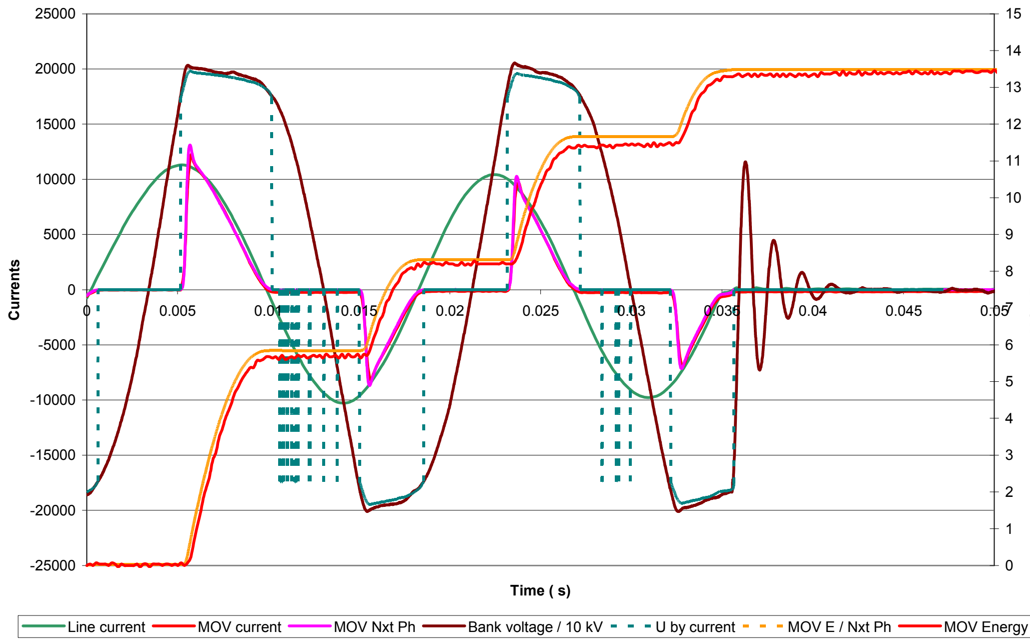

Figure 2. Fault, capacitor and MOV currents and MOV energy.

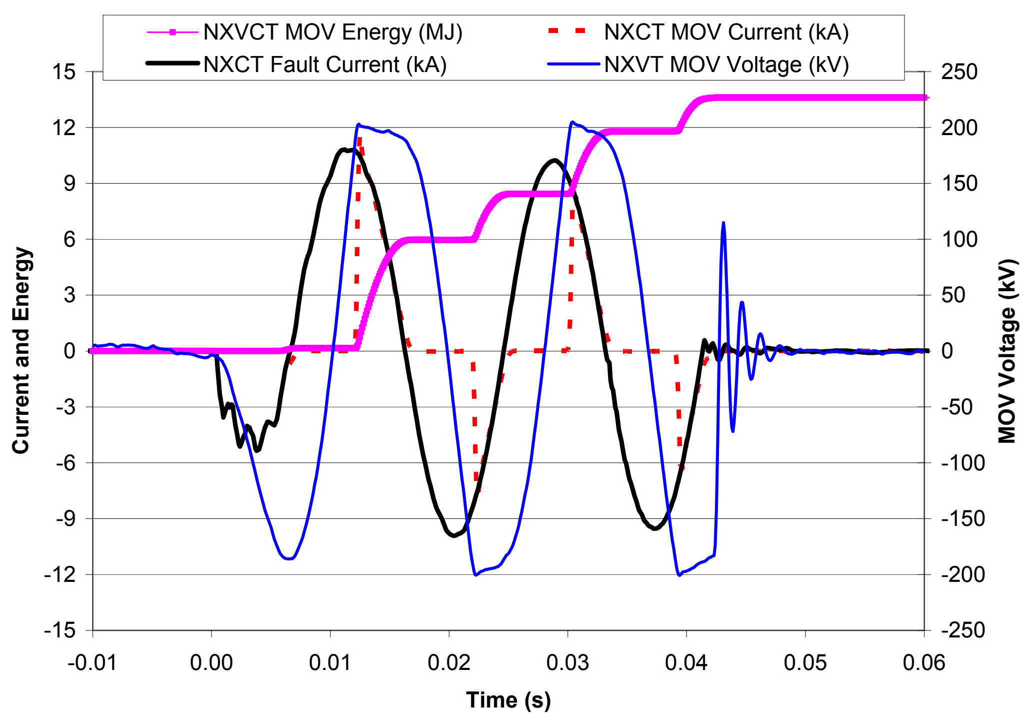

Figure 3. Fault current, and MOV voltage, current and energy measured by optical sensors.

Figure 3 shows the fault current, MOV current, and MOV voltage measured by the optical system during the fifth staged fault test. As expected, all waveforms were very rich in frequency content. Figure 3 also shows the MOV energy calculated by integrating the product of MOV voltage and MOV current measured by the optical sensors. The figure shows that the MOVs operate effectively to limit the magnitude of the voltage across the capacitor bank to less than 200 kV; peak currents are about 11 kA.

Figure 4 shows the secondary arc current after the primary fault is cleared by the single pole tripping of the faulted phase. Voltage on neighboring phases induce sufficient electric field to support a lower energy arc for several hundred milliseconds after the primary fault current arc has created an ionized path between line and ground.

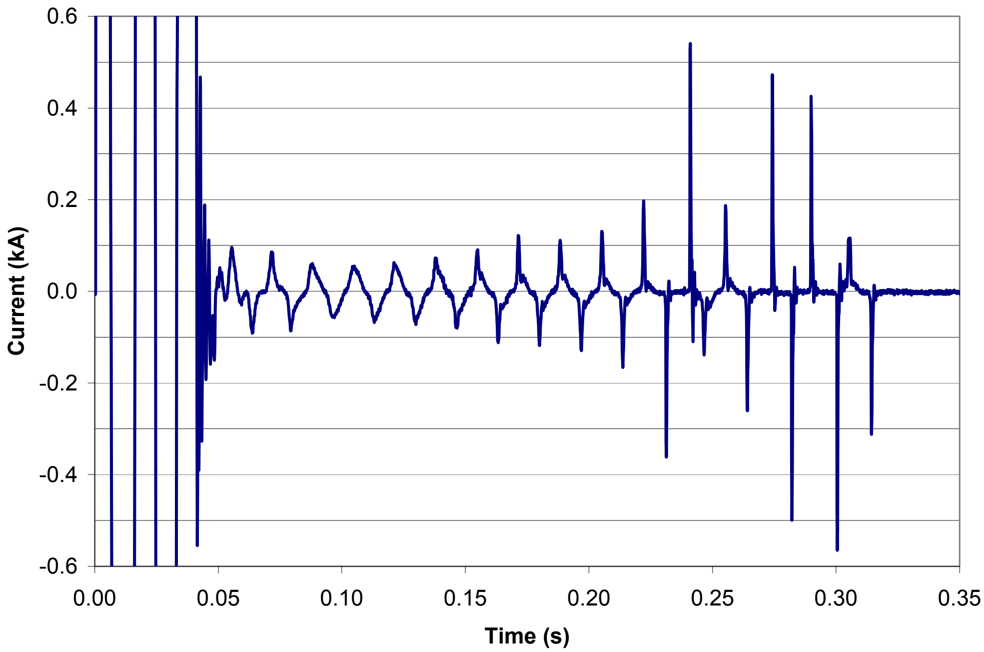

Figure 4. Secondary arc current.

4. HYBRID AND OPTICAL PROTECTION SCHEMES

Figure 5 shows two different ways to replace the hybrid system with the optical system. The left column shows main components of the hybrid system and the next two columns show use of the optical system. The hybrid system consists of traditional current transformers together with signal transmitting electronics on the platform and signal receiving electronics at ground level. The optical system has passive optical CT and PT on the platform and signal processing electronics only at the ground level. A hybrid system can easily be upgraded using the solution described in the middle column of Figure 5. The traditional CTs will be replaced by optical CTs and ground level electronics will be replaced by NxtPhase electronic units. For new series capacitor applications, the use of a fast serial link will be most attractive since this avoids signal conversions from "digital to analog" and back from "analog to digital."

5. CONCLUSIONS

The fault tests demonstrated the capability of the optical voltage and current sensors to measure highly non-linear signals. While the use of a voltage transformer does not appear to significantly increase the accuracy of the MOV energy calculations in this case, it is anticipated that future series capacitor bank applications will adopt the optical CT technology due to its excellent performance, ease of installation, higher reliability and lower maintenance cost (no electronics on the platform).

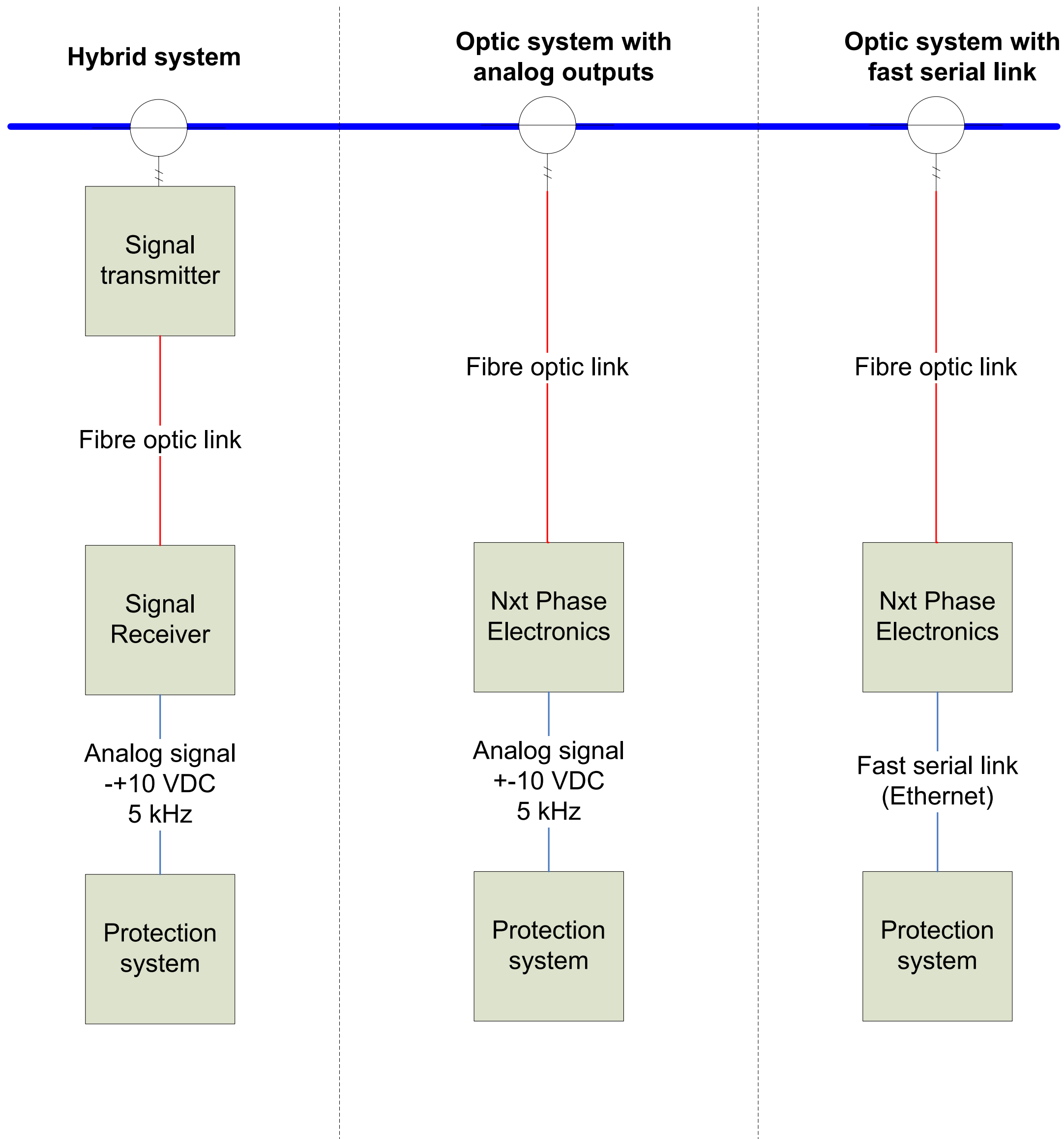

Figure 5. Hybrid based and optical based protection schemes

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