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Study Committee A3

Transmission and Distribution Equipment

Paper 10104_2022

Photonic Combined Voltage and Current Transformers – Demonstration for the Nepalese Grid

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Motivation

This paper provides highlights of recent progress in the development of photonic voltage and current transformers and their application to supporting the expansion of hydro generation capacity and digitalisation in the Nepalese grid. It is shown how the passive distributed sensing system can provide real-time synchronised measurements, which can be used to provide detailed assessment of harmonics, earth faults, and other phenomena over a wide area. It is also shown how new grid connections can be conveniently monitored and protected with unit protection to allow continued expansion of renewable generation while ensuring safe and efficient operation. The platform technology improves grid visibility, enables targeted system response to improve energy transport efficiency, enables new connections of distributed generation to improve availability of supply, and supports grid digitalisation in Nepal. Sensor hardware for this trial is presently under construction by the project partners, with installation date targeted for 2022. Following installation, the system will be operated over several months during which data will be streamed to Nepalese Energy Authority (NEA) for evaluation and recorded for further analysis and development of further applications.

Nepalese grid infrastructure

The substation to be used for the field trial provides electricity to 35,000 customers. Records show that the average power outage in this area is almost 20 to 25 hours per month, typically resulting from earth faults on the incoming and outgoing feeders. This is due to the challenging combination of long length of feeders through harsh topography, dense vegetation, and unpredictable weather. The field trial will prove the viability of the combined current and voltage sensor technology, which can be expanded to include many more measurement locations. This will enable clear visibility of the system to rapidly identify and respond to earth faults and other operational challenges.

A system, comprising three combined voltage and current transformers and a dedicated interrogator, will be deployed on 33 kV level within a substation in the Tansen district in Nepal and constitutes a unique, digital sensor platform for transmission networks that allows a large number of measurements to be acquired over a wide area with relatively low capital expenditure. The point of the system installation on a Nepalese grid is shown in the figure above.

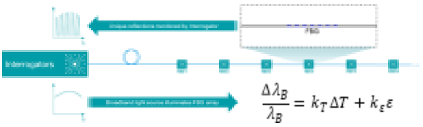
Combined Photonic Voltage and Current Transformer (cPVCT)

The presented novel combined photonic voltage and current transformers (cPVCT) consist of an assembly of the following components:

- Photonic voltage transformer (PVT) – combining an FBG, piezoelectric transducer and capacitive voltage divider (CVD)
- Photonic current transformer (PCT) – combining an FBG, piezoelectric transducer and current transformer (CT)
- Interrogator

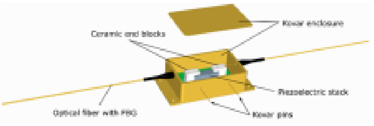
Fibre Bragg gratings technology

A fibre Bragg grating (FBG) sensor is formed by exposing a 5-10 mm section of an optical fibre to an Ultraviolet (UV) light of modulated intensity to create a periodic alteration of the refractive index. When broadband light is projected through the FBG, it reflects a range of wavelengths of the incident light with a distinctive peak at so called Bragg wavelength, λ_B. The peak wavelength is determined during production of the FBG and is a function of the grating period, and the effective refractive index of the fibre. Both variables are functions of temperature and strain affecting the optical fibre; therefore, FBGs can be utilized to measure temperature and strain directly or, other quantities, such as voltage, current, magnetic field, indirectly. The change in the reflected FBG peak wavelength is due to change in temperature, ΔT, and strain, ε.



Low voltage transducer

The low voltage transducer (LVT) construction comprises a low-voltage piezoelectric multilayer stack with a bonded FBG sensor. The FBG is suspended between two ceramic arms attached to a rectangular block of PICMA® stack from Physik Instrumente (PI). The LVT voltage range is ±30 V and it has a resonant frequency of 70 kHz.



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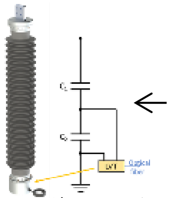
Photonic Voltage Transformer (PVT)

The photonic voltage transformer (PVT) consists of a combination of a capacitive voltage divider, housed in a composite insulator, to which a low voltage transducer (LVT) is connected on the secondary terminals, as well as an electronic unit, the interrogator, which converts the optical transmitted signals from the LVT into IEC 61850-9-2 conformed sampled value (SV) measurements.

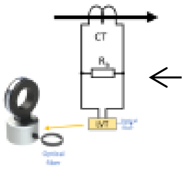


The PVT underwent successfully tests against the power frequency and lightning impulse withstand voltages and partial discharge tests, meeting the IEC 61869 standard requirements.

The CVD has a varying dividing ratio between primary and secondary terminals, depending on nominal primary voltages. The devices suitable for 33 kV and 132 kV networks have been designed.

Photonic Current Transformer (PCT)

The Photonic Current Transformer (PCT) consists of an industry standard iron-core current transformer (CT), to which an LVT is connected at the secondary terminals. A precision burden resistor is employed to convert the secondary current into a low voltage measurable by the LVT. The CT design is based on conventional current transformers with a steel or nanocrystalline core and copper windings. The current ratio is determined according to the system parameters, in this case a ratio of 160/1A. The output voltage, at full load current, is 1 V which is developed across a 1 Ω burden resistor (Rb). The protection class is 5P30 with the output being accurate to 5% up to 30 times full load current. Depending on the application, the PCT is placed on a standalone composite insulator suitable for either 33 kV or 132 kV.



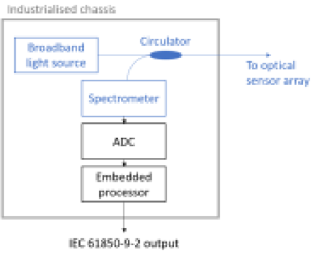
The PCTs are encapsulated in epoxy resin to ensure excellent weatherproof protection and terminated within the terminal box having IP65 rating.

Interrogator

The Interrogator developed for this work consists of a thermally stabilized spectroscopic fibre interrogator and associated optical components integrated with custom readout electronics and deployed within a high-performance EMC chassis.

Interrogator

The Interrogator samples the complete optical spectrum at standard rates of 4 kHz, 4.8 kHz, and 14.4 kHz for compliance with the standard rates dictated by IEC 61869-9. Optical measurements are extracted and converted to the measurand (voltage or current) using a powerful embedded system and published in the IEC 61850-9-2 Sampled Value (SV) format on up to six gigabit Ethernet ports for interoperation with other 61850-enabled substation equipment. Each Interrogator can monitor up to 30 individual PCTs and PVTs simultaneously, with total processing time from sampling to SV output of 1 ms, which makes it suitable for application in protection, metering and power quality use as per requirements defined in IEC 61869-9. In readiness for deployment in a substation environment, the Interrogator will be qualified against the relevant IEC standards for product safety, electromagnetic compatibility, and climatic and mechanical vibration effects. The main standards being considered are IEC 60068, IEC 60255 and IEC 61000. The Interrogator accepts time synchronization in pulse-per-second (PPS) and Precision Time Protocol (PTP, IEE 1588). Since the time of flight of the optical signal from each sensor can be accurately measured, this enables each measurement to be accurately and centrally timestamped without requiring GPS receivers at the measurement locations.



Combined Photonic Voltage and Current Transformer (cPVCT)

The complete cPVCT for a 132 kV network, with one primary sensor and the interrogator on the secondary side. This kind of hybrid instrument transformer combines the advantages of known and proven components such as CVDs, hollow core CTs as well as the FBG and piezo elements, combined with an optical fiber as a means for signal transmission. Considering the passive nature of the primary components, this system is immune to external perturbations.

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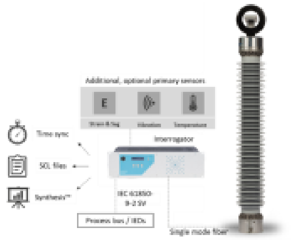
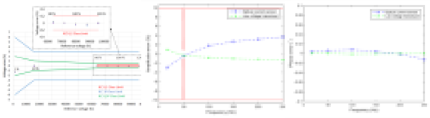
Furthermore, signal transmission via fibre can enable measurement up to a nominal maximum distance of 60 km (extensible using fibre amplifier schemes) allowing multiplexing of up to 30 different sensors in one fibre while using only one Interrogator. Hence, this approach allows for highly efficient, cost-effective asset management as well as decentralized protection schemes with centralized electronics, the Interrogator.



Measurement system performance and compliance with standards

- The performance of the photonic voltage and current transformers was previously verified experimentally in the laboratory. Accuracy tests were performed according to the relevant parts of IEC 61869.
- PVTs compliant with 3P protection and 0,2 metering classes
- PCTs compliant with 5P protection class



Potential applications to the Nepalese grid

- The proposed photonic system can offer passive, distributed and remote voltage and current measurements on the 33 kV or 132 kV power lines and is ideally suited for monitoring and control of the section of the Nepalese grid.
- The system is suitable for multi-terminal protection applications and centralized optical protection that can operate over wide areas reducing the number of the required devices and the related communication traffic.

Potential applications to the Nepalese grid

- Protection of MV or HV transformers in the substations.
- Measuring other parameters with the use of distributed mechanical sensors, such as line tension, sag, temperature, and vibration, delivering full electrical and mechanical monitoring capability for the grid assets.

Trial installation

The trial system comprises three combined photonic current and voltage transformers and a dedicated sensor interrogator. This sensor scheme will be deployed on the 33 kV network within the Palpa substation in the Tansen district of Nepal. This trial system will constitute the first live installation of this novel passive sensor technology for combined voltage and current measurements. The sensors will be qualified to the 5P protection class per IEC 61869-10, with sensor data provisioned to the Nepal Energy Authority for examination throughout the winter and summer periods following installation. The system is representative of the hardware that would be installed for any of the multiple potential applications discussed above and is readily extensible up to 30 individual sensors per 60 km of fibre optic. Sensor hardware for this trial is presently under construction by the project partners, with installation date targeted for 2022. Following installation, the system will be operated over several months during which data will be streamed to NEA for evaluation and recorded for further analysis and development of further applications.

Conclusion

- A suite of combined photonic voltage and current transformers together with a dedicated interrogator have been presented.
- The system was designed to ensure remote monitoring of 33 kV network with the interrogation distance up to 60 km from the substation.
- The system collects sensor signals, digitises them at a high sampling rate, and publishes measurements in accordance with the IEC 61850 digital process bus communications standard.
- The sensors performance was verified in accordance with IEC 61869.
- Future work will focus on the installation of the proposed measurement system on a 33 kV line in Nepal and the relevant field trials at various electrical faults scenarios.