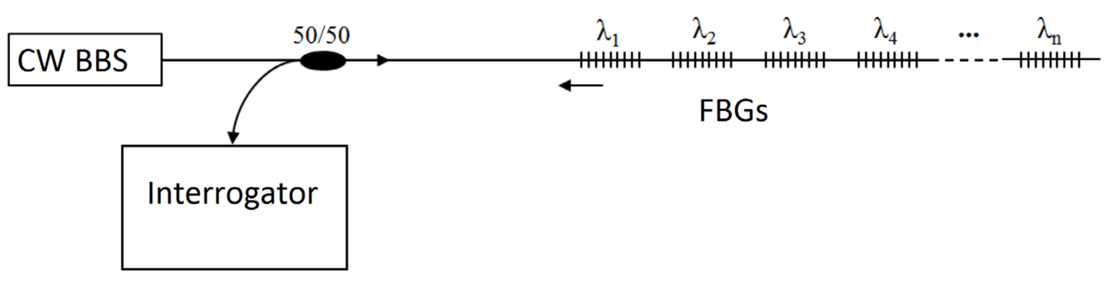
Optically-interrogated current and voltage sensors

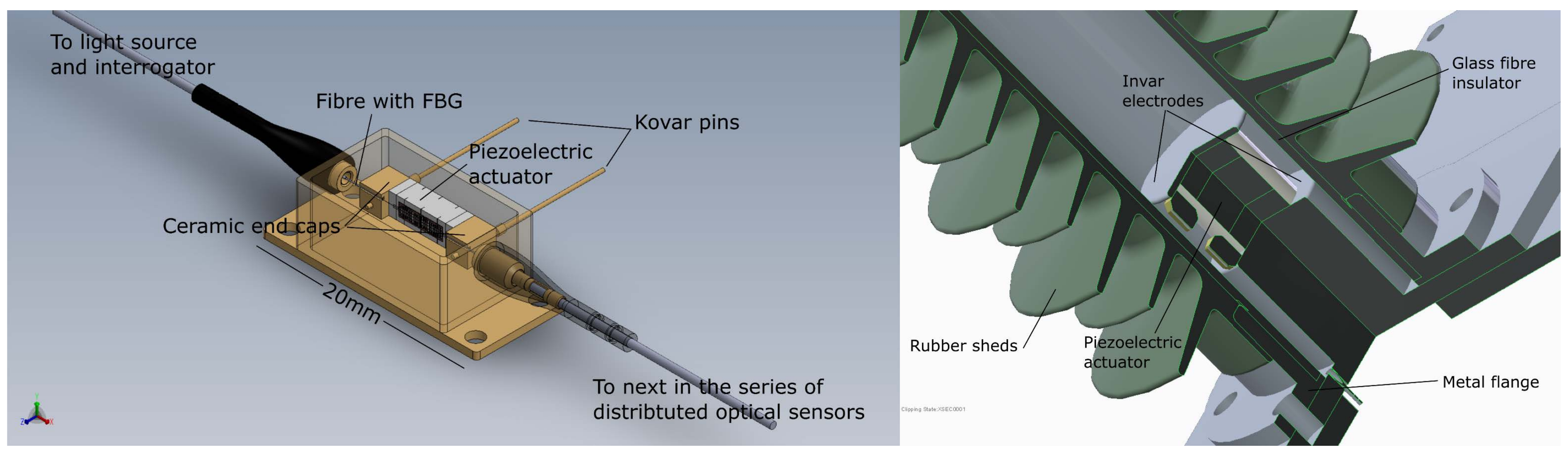
John Nelson, Grzegorz Fusiek, Paweł Niewczas

Sensor concept and design

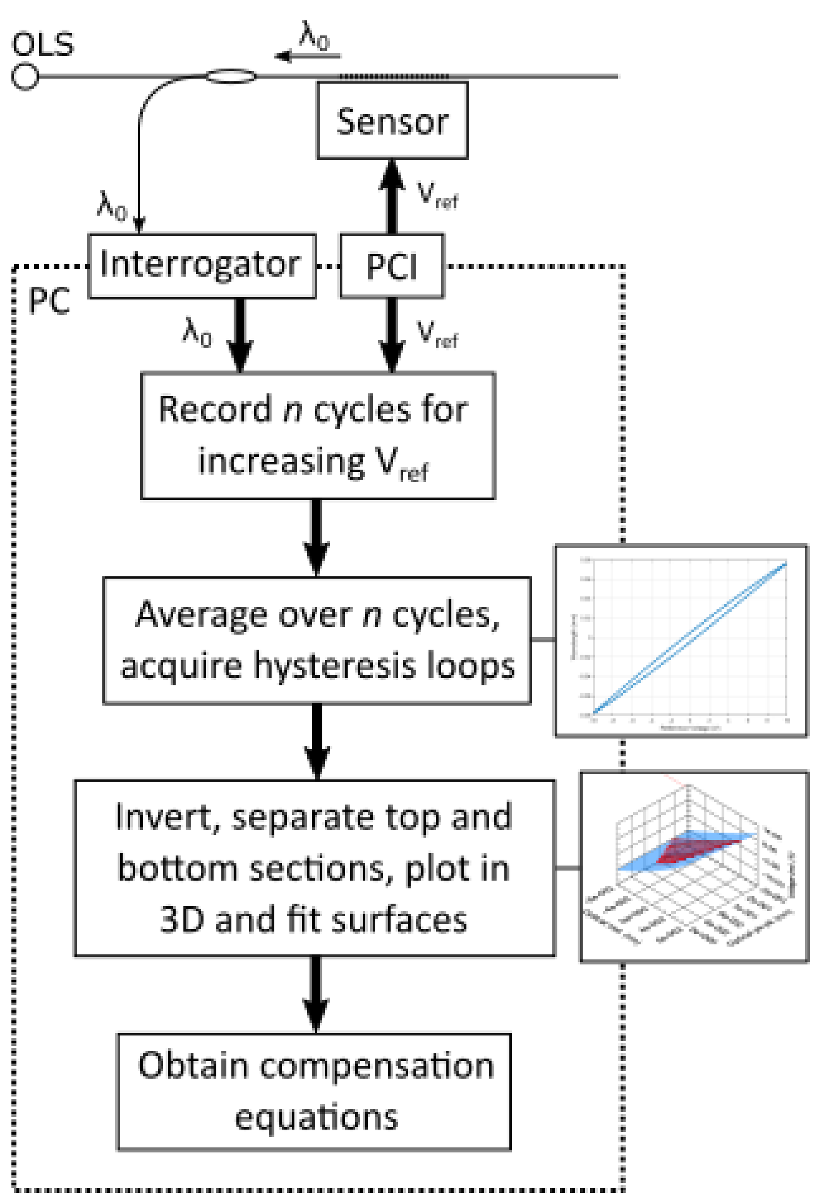
The figure below illustrates the concept of a distributed fibre Bragg grating (FBG) sensor system. It shows multiple FBGs illuminated by a continuous-wave broadband source (CW BBS). The reflected signals from the FBGs are received and interpreted by the interrogator. The FBG sensors measure strain, temperature, vibration, current or voltage.



FBG sensors work by measuring the change in wavelength of the reflected light and relating it to the physical measurement of interest. For instance in temperature measurements, thermal expansion of the FBG causes the grating period to increase, leading to an increase in the wavelength of the reflected light. Shown below left is a low voltage transducer (LVT) which translates the output of a current transformer (CT) into a strain on the FBG caused by the varying length of a piezoelectric actuator; this is interpreted by the interrogator to reconstruct the primary current. An optically-interrogated voltage sensor (OVT), shown below right, has been designed for 11 kV transmission lines, where the piezoelectric actuator is driven directly by the line voltage.



Piezoelectric actuators are inherently hysteretic. The polarisation of the actuator depends on both the applied voltage and its history. Accordingly, hysteresis is observed between the applied voltage and the optical signal derived from the LVT, which manifests as varying amplitude and phase errors between the two, thus limiting the accuracy of the measurement. In order that the applied voltage be faithfully reproduced at the optical interrogator, this hysteretic effect must be compensated for. The LVT undergoes an initial calibration procedure (shown below) and the compensation can then be applied during live operation. Interestingly, this approach could also be applied to the complete current sensing system to reduce hysteresis effects from iron core CTs.



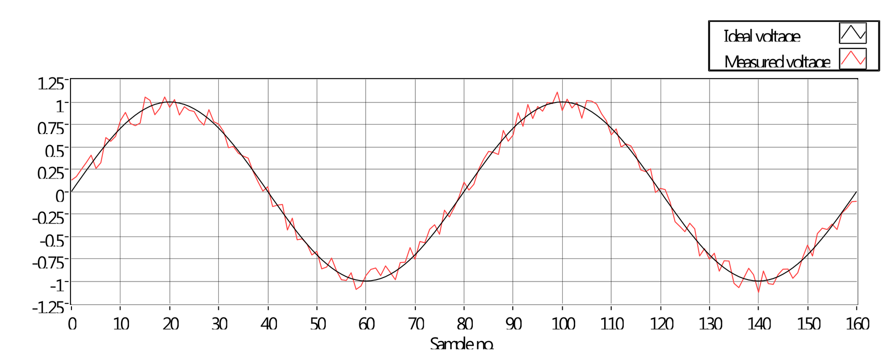
Accuracy requirements

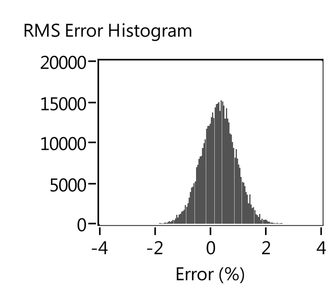
The accuracy requirements for Electronic Current Transformers and Electronic Voltage transformers (the existing devices to which our sensors are most closely related) are described in IEC-61689, the overarching standard for Instrument Transformers. There are separate accuracy requirements for the metering and protection classes of device. As an example, the metering class requirements are shown below alongside the simulated performance of the optical current sensors. We expect our current and voltage sensors to meet the requirements of the most stringent classes for both metering and protection.

Metering class requirements

	Amplitude error (%)				Phase displacement (minutes of arc)			
% of rated current	5	20	100	120	5	20	100	120
0.1 class	0.4	0.2	0.1	0.1	15	8	5	5
0.2 class	0.75	0.35	0.2	0.2	30	15	10	10
Simulated performance	0.7	0.17	0.03	0.03	6	6	6	6

We have established experimentally the noise floor of our optical interrogation scheme is $10\text{n}\varepsilon/\sqrt{\text{Hz}}$. Based upon this, we have developed a software model which statistically analyses the ability of the interrogator to accurately reconstruct the primary current or voltage. Using this model we have shown that the LVT will be capable of meeting the 5P30 protection class and the 0.2 measurement class, with an integration time of only 0.02 seconds. Increasing the integration time will decrease the amplitude error. The figures below show the simulated performance at the 5% current limit (left) and the result of 500000 simulations (right). Similarly, the OVT is found to be capable of meeting the 3P protection class and 0.2 metering class requirements with a 0.02 second integration time.





The designs for both OVT and LVT have been finalised. The OVTs are currently under construction.

Test facility commissioning

In order to characterise the finished devices and test them against the standards outlined above, we have constructed a high current test facility (shown below). The test facility comprises a programmable AC power source, a bespoke power transformer and a busbar system which runs through an environmental chamber. Thus it will be possible to test the devices at a range of currents (up to 10 kA), frequencies (between 15 Hz and 1.5 kHz) and temperatures (-70°C to 180°C). Field trials will also be carried out at the Power Networks Demonstration Centre.