Optical Current Sensors Eliminate CT Saturation

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Abstract: **Optical current sensors are achieving increased acceptance and use in high voltage substations due to their superior accuracy, bandwidth, dynamic range and inherent isolation. Once deemed specialized devices intended for novel applications, optical sensors have risen to a performance level exceeding conventional magnetic devices. A specific area where optical current sensors outperform conventional iron core transformers is the measurement of very high currents that occur during a fault on the power system. Conventional instrument transformers utilize an iron core and windings ratio to step down the current measured in the primary to a more manageable current level for secondary devices such as meters and relays. This signal may be distorted due to saturation of the magnetic core. In a pure optical current sensor[1], no such mechanism for saturation exists. However, optical sensors must be used and applied properly to provide distortion free signal replication well into the hundreds of kiloamp region. This paper discusses the characteristics of optical current sensors, specifically for relaying applications where measurement of fault-level currents is required.**

Keywords: **fiber optics, current sensor, current transducer, protection, substation, interface, saturation**

I INTRODUCTION

When faults on a power system occur, they must be isolated quickly to maintain the safe operation of the system, minimize damage to equipment, and maintain stability of the system. Therefore, the accurate measurement of fault current is a critical input to protection relays which monitor the current and/or voltage signals to determine whether the monitored portion is faulted and should be isolated, or whether conditions are normal and should remain closed to maintain the flow of power. If protection relays receive the "true" representation of current flowing on a transmission line, or into transformers, capacitor banks, or reactor banks, they will make decisions based on the current that is actually flowing, not based on a distorted representation of the current which the relay may need to compensate for. An undistorted view could improve the ability of the relay to trip when it should and to prevent false trips. Additionally, analyzing the power system as a whole, optical current sensors make design and analysis easy since no CT saturation will ever be encountered. Optical sensors behave in a simple and predictable manner known for every situation.

II SATURATION IN CONVENTIONAL CURRENT TRANSFORMERS

During fault conditions a well-known phenomenon occurs: the iron core in a transformer "saturates" due to a large magnetic field caused by high fault currents. This saturation of the iron core prevents the transformer from accurately representing the primary current in the current transformer secondary, and therefore distorts current measurement. It is not the intent of this paper to explain saturation or analyze when and why it occurs. Readers not familiar with saturation should reference the many papers, books, and standards that deal directly with this subject in detail to fully understand the phenomena. Additionally, many good reference sources discuss the problems of CT saturation with respect to relaying, avoidance of saturation and methods to deal with saturation. The underlying problem surrounding the phenomena is that essentially all CTs will saturate unless they are built with an excessive amount of steel to prevent it. This method of mitigation is impractical and must be dealt with by knowing how, when, and why a CT will saturate, then taking appropriate measures to prevent any false relay operations.

The mechanism for CT saturation is not a simple relationship. Saturation depends on the physical design of the current transformer, the amount of steel in the "core" of the transformer, the connected burden, the winding resistance, the remanence flux in the iron core, the fault level, and the system X/R ratio (which can cause a larger DC offset to occur). Taken together, these dependencies make the analysis of CT saturation complex. Figure 1 below shows an example of a CT with a saturated output against a plot of actual current. Scale is not given on the y-axis since it could apply to a variety of CTs with various

[1] Pure optical sensor is defined in this paper to be a current sensor which uses only optical sensing methods to measure the current. There are optical sensors available which use iron core or air core transformers to measure the current, and an optical path to bring the signal from high voltage to ground potential.

currents. The plots are shown only to illustrate a saturated CT waveform.

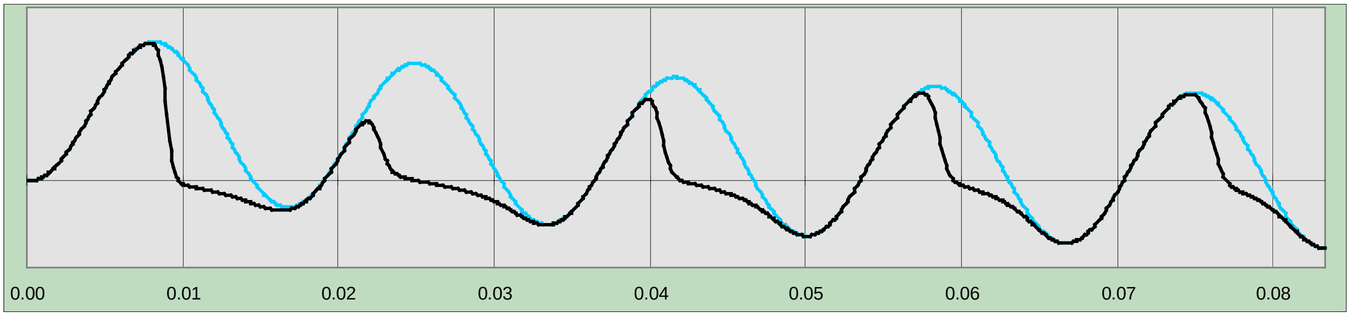

Figure 1: Saturated and non-saturated CT secondary output – conventional instrument transformer.

III MEASURING CURRENTS USING OPTICAL TECHNOLOGY

The problem of CT saturation in iron core instrument transformers can be avoided altogether by using an optical current sensor. Optical current sensors contain no magnetic components and do not have any saturation effects associated with them. Optical current sensors also have no iron core to saturate. Depending on the design of the sensor, these types of sensors have the ability to give a near perfect representation of the primary current.

An optical sensor uses light to measure the magnetic field surrounding a current carrying conductor and, based on this measurement, electronics associated with the optics calculate the current flowing in the conductor. If done optimally, an optical measurement of current has the ability to measure fault currents exceeding 400 kA_{peak}. Additionally, using advanced techniques, both AC and DC currents can be measured to this level.

An optical current sensor using light to measure the magnetic field surrounding a conductor has a transfer function with a sine wave characteristic. With normal load current flowing on the conductor, the measurement of the magnetic field by light is maintained essentially within the linear portion of the sine wave. Once the current increases substantially (for example, when a fault occurs) the transfer function of the light no longer traverses the linear portion of the sine wave, but enters a non-linear portion. In this non-linear portion of the sine wave, the electronics compensate for the non-linearity. Since this non-linear "sine wave" characteristic is well defined, electronics can easily adjust, in order to maintain overall linearity of the current measurement throughout the dynamic range.

Although this compensation technique permits excellent accuracy, it has an inherent limit. As the current reaches the "end" of the sine wave (or at an angle of plus and minus π radians) and continues to increase, the electronics may interpret the current to be higher than its previously measured current, or may interpret the current to be at the opposite end of the sine wave transfer function. The sensor will show a severe jump in the measurement of the current to a current of negative polarity with respect to its previous value. This phenomena is illustrated in Figures 2, 3 and 4 which show sensor outputs for 1 fiber turn, 3 fiber turns, and 5 fiber turns. As more fiber turns are added to the sensor design, the signal-to-noise ratio of the output increases, though not detectable in the Figures. A better signal to noise ratio has certain distinct advantages, especially in metering applications [1]. However, as the fiber turns are increased and the fault level is maintained at a constant level, operating range on the optical transfer function approaches the limit of plus and minus π radians. If exceeded, the sensor can record a current "jump", or move to the next optical "fringe" and thus appear as a different current value. To avoid this situation, which cannot be tolerated by relays, either special processing algorithms can be introduced to keep track of which fringe the sensor is on or the sensor can be designed to reduce possibility of such an occurrence. Fortunately, for typical fault current levels, reducing the probability of the sensor exceeding the "fringe" is simple, since the point at which the optical sensor reaches this point is precisely known based on the number of fiber turns used in an optical current sensor. This would eliminate the distortions seen in Figures 2 and 3, provide an accurate current waveform representation free from saturation effects, and provide a high signal-to-noise ratio so the signal is also optimized for metering and power quality analysis applications. To a user of fiber based optical current sensors, the situation will never be observed unless a sensor is driven to a value beyond its specifications.

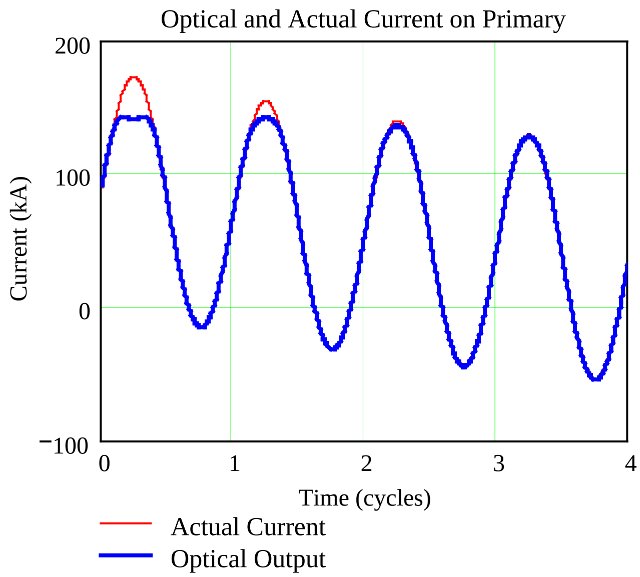

Figure 2: Non-optimized Optical Current Sensor with 3 Fiber-turns, showing the distortion of a sensor without fringe management algorithms.

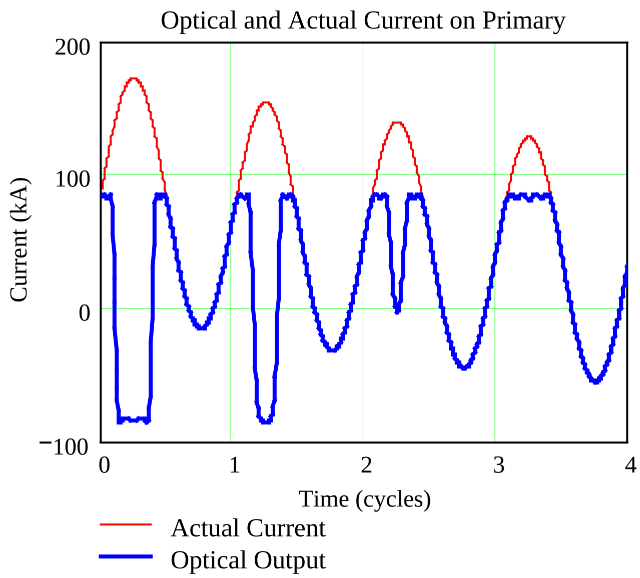

Figure 3: Non-optimized Optical Current Sensor with 5 Fiber-turns, showing even more distortion when fringe management is not employed.

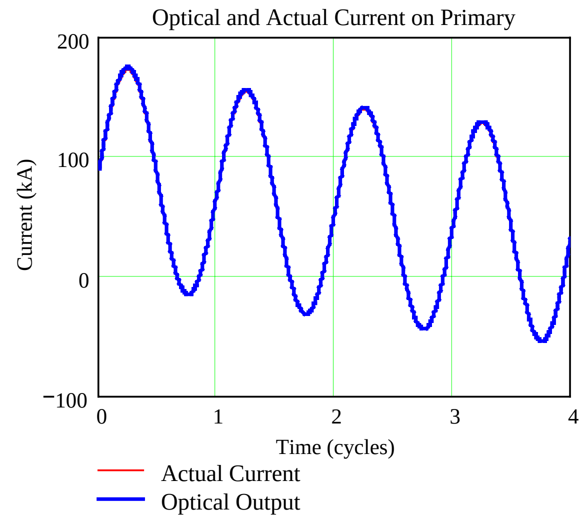

Figure 4: Optical Current Sensor with 1 Fiber-turn or Optimized Output, showing the ability to measure large fault currents without distortion.

IV. FIBER OPTIC CURRENT SENSOR TECHNOLOGY

A fiber optic current sensor (as shown in Figure 5) consists of a light source, photo detector, optics and electronics coupled to a fiber sensor head wound around a current carrying conductor. The optical phase modulator is the "heart" of the current sensor technology and it, along with the electronics and optics, provide a highly accurate measurement of current.

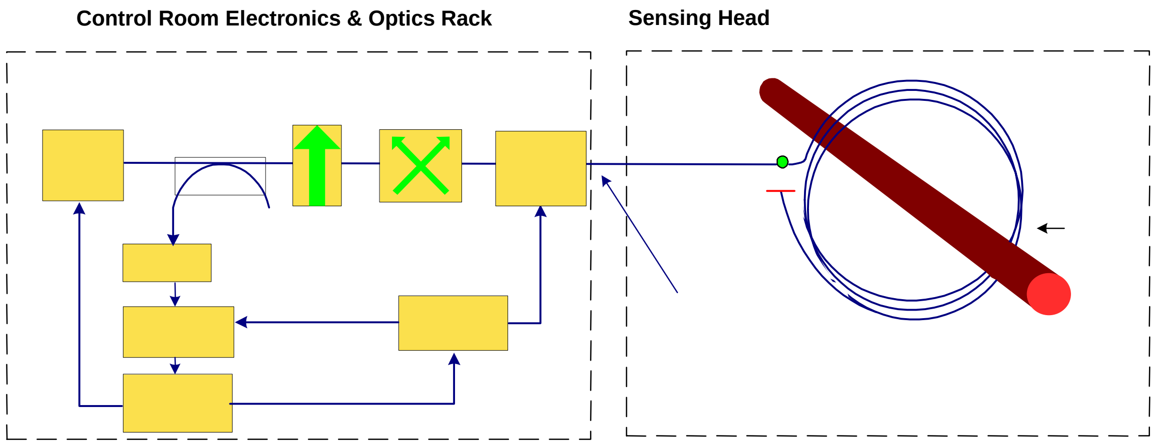

Figure 5: Fiber Optic Current Sensor Optical Block Diagram

1. A light source sends light through a waveguide to a linear polarizer, then to a polarization splitter (creating two linearly polarized light waves), and finally to an optical phase modulator.
2. This light is then sent from the control room to the sensor head by an optical fiber.
3. The light passes through a quarter waveplate creating right and left hand circularly polarized light from the two linearly polarized light waves.
4. The two light waves traverse the fiber sensing loop around the conductor, reflect off a mirror at the end of the fiber loop, and return along the same path.
5. While encircling the conductor, the magnetic field induced by the current flowing in the conductor creates a differential optical phase shift between the two light waves due to the Faraday effect.
6. The two optical waves travel back through the optical circuit and are finally routed to the optical detector where the electronics de-modulate the light waves to determine the phase shift.
7. The phase shift between the two light waves is proportional to current and an analog or digital signal representing the current is provided by the electronics to the end user.

IV CONCLUSION

Optical current sensors provide a reliable method of measuring very high fault currents with significant DC offsets without any type of saturation, as is understood with conventional current transformers. Depending on the design of the sensor, several turns of fiber can be wound around the conductor to increase the signal to noise ratio of the sensor. This gain in signal to noise ratio is traded with the ability of the sensor to measure extremely high fault currents without fringe management algorithms. However, if desired, advanced processing techniques such as fringe management techniques can be implemented in sensors, and high signal to noise ratios and high fault current measurements can be achieved simultaneously.

VI REFERENCES

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BIOGRAPHIES

James Hrabliuk graduated from the University of Manitoba in 1989 with a Bachelor's Degree of Science in Electrical Engineering. After graduating, he worked at Manitoba Hydro for 11 years primarily as a Substation Design Engineer, and later as a Protection Design Engineer. In March, 2000 James joined NxtPhase Corporation as an Application Engineer. He is a member of the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) and the IEEE.