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OPTICALLY POWERED CURRENT TRANSFORMERS

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INTRODUCTION

Optical fibre sensors have been the subjects of much research effort in recent years, but very few commercial products have reached the market place. Introducing optical current sensors has received significant attention by number of research groups around the world as next generation high voltage measurement devices, with a view to replacing iron-core current transformers in the electric power industry. One approach to avoid the difficulties associated with all optical sensors, while obtaining the benefits of optical communications has been the 'hybrid' optical fibre sensor. The sensor itself is of a conventional type, usually electrical, but interfaced to an optical fibre communication system. Such an approach requires electrical power to be supplied to the sensor head to power the sensor and the interface electronics. The power may be derived from batteries, or optically, with power transmitted either along the same fibre that carries the data, or along a separate fibre.

A number of authors have described optically powered hybrid optical fibre sensors using “conventional” electrical sensing elements. Some of these sensors have been single point measurement systems while others have used a bus structure to enable several sensors to be powered from an optical “power bus” and may use either the same optical fibre or separate fibres to provide address and data buses [1].

OPTICAL POWER SUPPLY

There are 3 basic techniques for fiber-optic transmission of power from a base station to a remote station (sensor node) and conversion of optical to electrical power at the remote station [2]. To provide power at a useful voltage for active silicon devices it is necessary either to connect several photodiodes in series and split the light equally between them, or to employ some form of voltage conversion.

In the first technique Fig.1, steady light is sent to an array of photodiodes, connected in series to build up the output voltage to the required level.

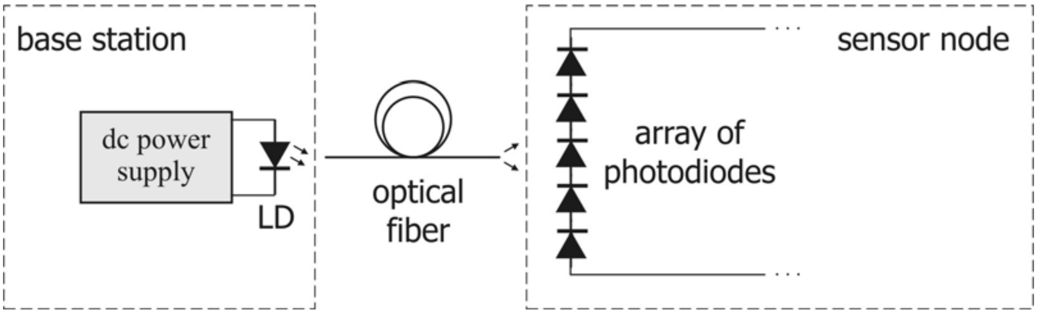

Figure 1.Steady light sent to an array of photodiodes
(LD – laser diode)

The disadvantage of this technique is rather high cost an array of photodiodes, and there can be significant losses in the coupling of light from the optical fiber to the array, depending on the shape of the array.
In the second technique Fig.2, steady light is sent to a single photodiode, and the output steady voltage of the photodiode is increased to the required higher level by a chopper, a step-up transformer, and a rectifier.

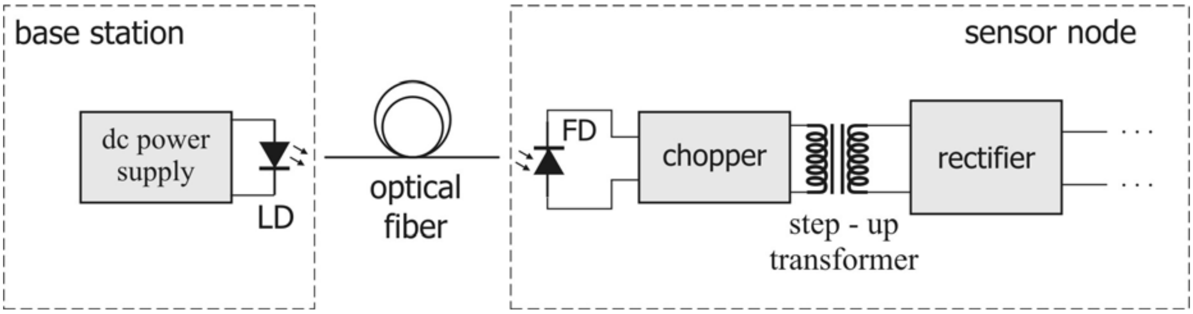

Figure 2. Steady light sent to single photodiode with chopper, step-up transformer and rectifier
(LD – laser diode, FD - photodiode)

The disadvantage of this technique is that the chopper consumes a substantial part of the power, thereby reducing the overall power-conversion efficiency of the remote station.
In the third technique, the optical power is modulated at the source in the base station, where efficiency is somewhat less of a consideration because power is more abundant there, Fig.3. Preferably, the light is either modulated with a sine wave or is chopped into square pulses ("on" during the first half cycle, "off" during the second half cycle).

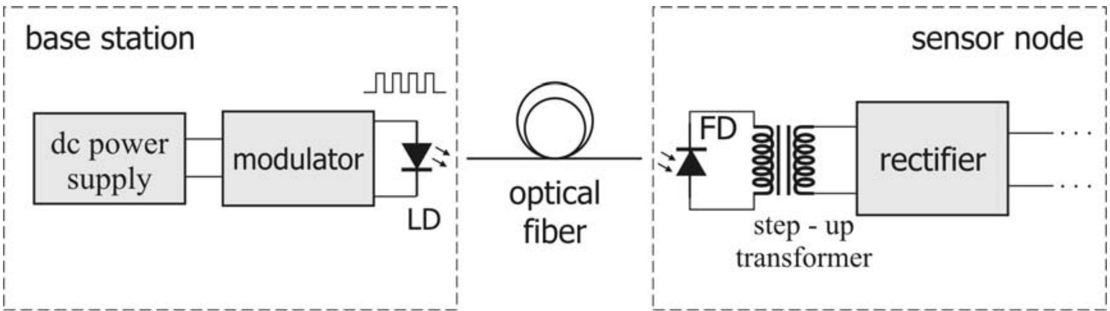

Figure 3. Modulated light sent to single photodiode with step-up transformer and rectifier
(LD – laser diode, FD - photodiode)

In order to step up the voltage from the photodiode it is necessary to switch the power on and off, so that standard DC-DC conversion techniques may be employed. With only 0.4-0.5 V available from the photodiode this power switching must be done at the optical source. For maximum power transfer it is desirable that the ratio of the 'on' to 'off' time should be maximized, since it is generally the peak power, which is limited. It is also necessary to ensure that, while the light is 'on', the photodiode current is reasonably constant and close to the value for optimum power transfer from photodiode to load.

The modulated light illuminates a single photodiode, the output of which is now modulated. The modulated output of the photodiode is fed directly to a step-up transformer; because of the modulation, there is no need to process it through a chopper. Therefore, the chopper is eliminated and the power-conversion efficiency correspondingly increased. In practice, the conversion efficiency will not be high unless care is taken in the design of the step-up transformer and the rectifier circuit. Techniques to recover the magnetic energy in the transformer that are similar to those used in chopper circuits should be used.
The circuit in Fig.4 is for a flyback converter, the operation of which is essentially the same as that of the switched mode power supply circuit from which it is derived. While the light is 'on' current flows from the photodiode to the inductor where energy is stored. When the light is turned 'off' the current is diverted to the load. For efficient power transfer the converter must be operated in continuous current mode, with the inductor current almost constant [3].

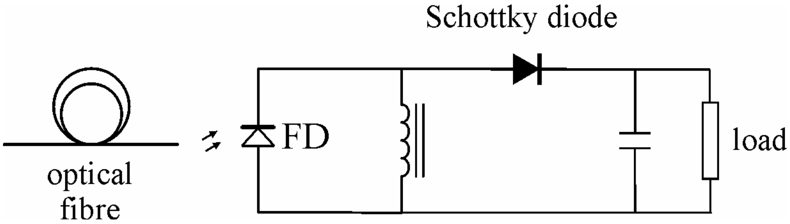

Figure 4. Flyback converter (FD - photodiode)

The required value of the inductance *L* is determined by *ton* and the photodiode voltage and current at optimum power transfer. If the ripple current is not to exceed 10% of the photodiode short circuit current then

$$L > \frac{V_P t_{on}}{0.1 R P_0} \qquad (1)$$

where R is the responsivity of the photodiode (in A/W) and Po the optical power. Substituting reasonable values of 1 mW for the optical power, 0.5 V for Vp, 0.5 A/ W for R and 0.2 ms for ton gives a minimum value of 2H for the inductance, a large but not impractical value.
The most appropriate choice of optical source is a GaAlAs laser operating at a wavelength of around 800 nm, since these devices are efficient, can couple optical power of order 1 rnW to 1 W into an optical fibre. The price of these lasers rises almost linearly with power, so that there is a considerable incentive to minimize the optical power required.
The silicon photodiode has been most widely employed for power conversion, because of its easy availability and low cost. It does however suffer from two major disadvantages: it is relatively inefficient (typically < 15%) and its terminal voltage is only 0.4 - 0.5 V. Photocells using GaAs have significantly higher efficiency of order 20 - 25%, but are less readily available in a suitable form.

FUNCIONAL DESCRIPTION

The optically powered current transformer is based on optically powered data link , which , when combined with a shunt replaces a conventional current transformer .

The system, which is shown schematically in figure 5, is divided in two modules , one located at high voltage called remote unit and the other at the controller or data acquisition at ground potential called the local unit.

The local module houses a laser driver and data handling circuitry. It is built into a modular enclosure and is to be powered from an external source, typically in the range of 12-36 V DC. The laser driver includes a semiconductor laser, which is operated in constant current mode. Power is set through a

computer interface and will be adjusted during operation using a feedback signal. If the fiber optic link is broken, the laser power will be reduced to a minimum safe level.
The remote module is PC-board mounted in a shielding enclosure together with the sensor.

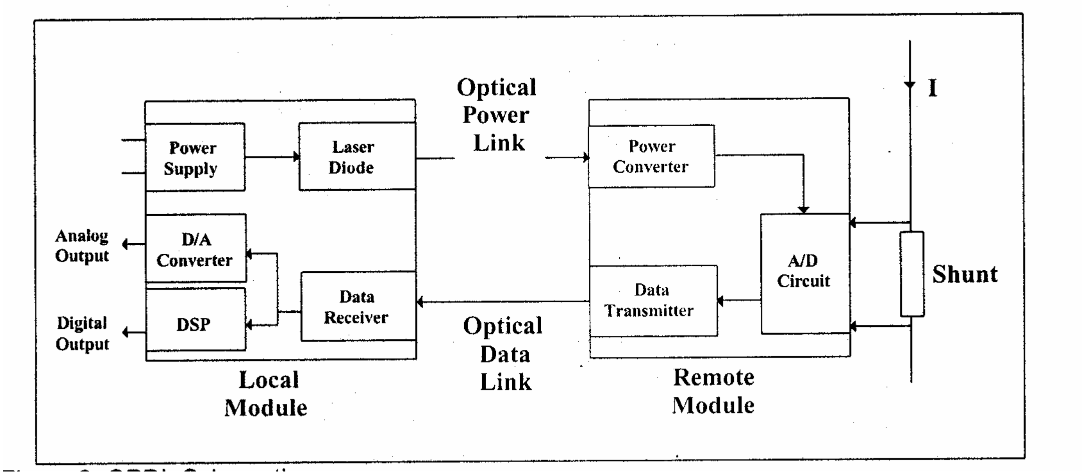

Figure 5 Optically powered data link block diagram

The optically transmitted power is converted to electrical power by the photovoltaic power converter, which is essentially a solar cell divided into sections. The analog input signal is fed into an analog to digital converter (ADC) . Its associated control logics commands the ADC to make a conversion of the signal. The result of a conversion is a serial data stream from the ADC output [4].

In the widespread concept of Digital optical current transducer, shown in Figure 6 ., the current is

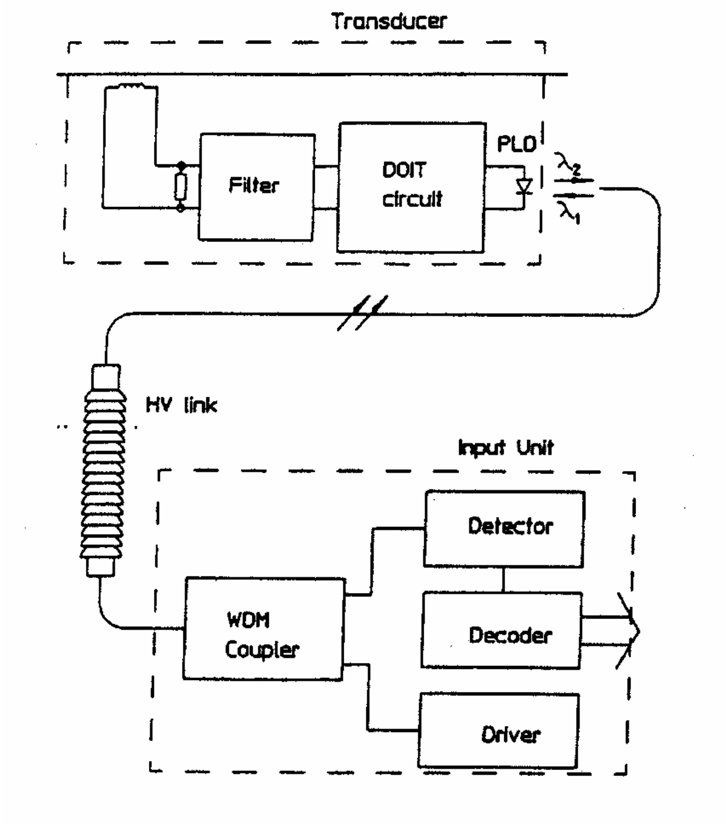

Figure 6 . Digital optical current transducer

measured using a low voltage current transformer with a burden resistor connected across the secondary terminals. The voltage is filtered and converted to digital form with an ADC. For isolation of digital optical current transducer on line potential, fibre optic high voltage suspension or support insulators are used. The links consist of a fibre reinforced epoxy member with a polymerouter insulation. The design has very high mechanical strength and low weight compared to ceramic insulators [5].

CONCLUSION

Described technology is convenient to modern equipment for metering and protection , based on microprocessors and digital technology. Optically powered current transformers bring the significant advantages that they are non-conductive and lightweight , which can allow for much simpler insulation and mounting designs. In addition, optical sensors do not exibit hysteresis and provide a much longer dynamic range and frequency then iron – core current transformers. Their small dimensions and the low weight allows them to be transported and mounted at lower cost. The possibility of integration on circuit breakers also gives considerable economical advantages, having in mind reduced civil works for foundation and cable trenches. The safety advantages of optically powered current transformers are well recognised: a signal transmission immune to electromagnetic interference and polluted environment , full galvanic insulation and designs without oil or pressurized gas [5].

Technology of optically powered sensors is applied for voltage instrument transformers as well as the other measurements in high voltage apparatus.

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