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Electrooptic Methods for Measurement of Small DC Currents at High Voltage Level

Tønnesen, Ole; Beatty, Neville; Skilbreid (fratrådt), Asbjørn Ottar

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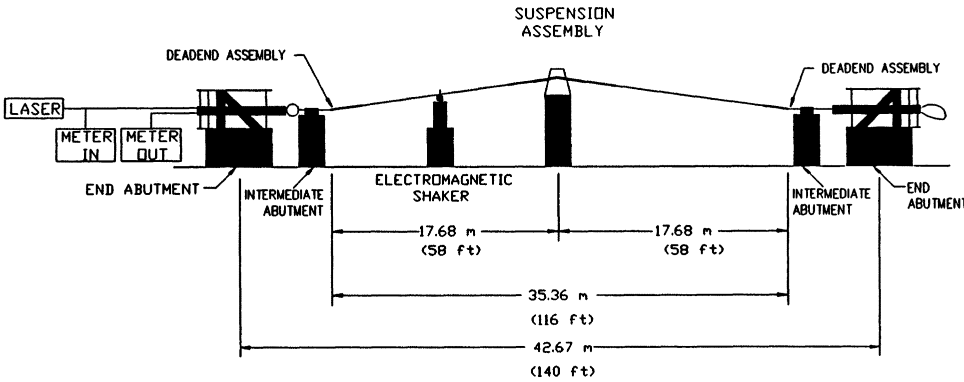
the outer strands near the suspension assembly and dead-end assembly. The OPGW was terminated beyond the dead-end assemblies. The optical fibres were fusion spliced together to form one continuous length. Light was injected into one end of the fibre by a laser source.

The maximum strains achieved during the aeolian vibration tests ranged from 160 to 240 $\times$ 10^{-6} in/in. The test frequency ranges from 79 to 92 cps and each cable was subjected to 100 million cycles. The maximum strains achieved during the galloping tests ranged from 125 to 485 $\times$ 10^{-6} in/in. The test frequency was about 1.2 cps and each cable was subjected to 100,000 cycles.

Based on the mechanical tests performed by Ontario Hydro the following general conclusions are made. All three cables met Ontario Hydro's requirements for aeolian vibration, galloping and fatigue tests on the aluminum core tube.



Arrangement for Aeolian Vibration Tests

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Electrooptic Methods for Measurement of Small DC Currents at High Voltage Level

Ole Tønnesen, Member IEEE, Neville Beatty and Ottar A. Skilbreid
Electric Power Engineering Department
Build 325, Tech. University of Denmark
DK-2800 Lyngby

Summary

Two electrooptic methods for measurement of DC currents at high voltage level, extending from the nA range and up to the milliampere range have been developed. First, by switching the polarity of a measured DC voltage into a Pockels cell, DC currents can be measured and transmitted along an optical fibre to an electrooptic converter. Second, by use of an electronic circuit the measured signal can be converted into a modulated frequency form for transmission along an optical fibre. These systems are described, measurement results are presented and improvements to be made in the future are outlined. The measuring methods can be used both for development and supervision of electrical insulating systems.

For DC measurements a system wherein the voltage is applied (across the Pockels cell) not directly but via an electrooptic circuit was developed. This circuit periodically inverts the polarity of the voltage across the cell, effectively applying a square wave voltage with amplitude equal to the DC voltage to be measured.

The switching circuit is based around two high voltage transistors T_A, T_B, with the Pockels cell electrodes being each connected to one of the transistor collectors. The transistor collectors are connected via resistors R_A and R_B to the protective side of the voltage to be measured and the emitters to the negative side. The currents flowing in to the bases of the transistors are independently controlled by the light levels following on the two photodiodes PD_A, PD_B.

Current to frequency transducer

An alternative current measuring device using an unijunction transistor has been developed and tested. An unijunction transistor, UJT, is a three terminal device, constructed as a n-type silicon resistor with ohmic contacts at both ends. An emitter rectifier contact E is inserted between the two ohmic contacts, which here are called B1 and B2. Under normal operation, V_{BB}, the voltage of B2 relative to B1, is positive. Now, when a voltage equal to $n \cdot V_{BB}$ relative to B1 is applied to the emitter E, a current will start to flow. The factor n will typically be in the range 0.50–0.75. Once the current starts to flow an avalanche process turns the E-B1 region into a highly conducting path with a negative resistance characteristic. Therefore, a current pulse train with a frequency dependent upon the applied voltage, is established. The UJT component has a very stable trigger voltage and good temperature stability.

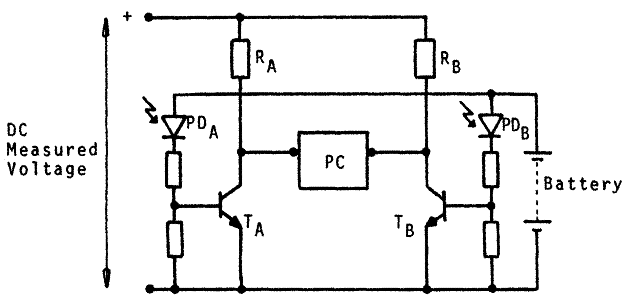
Conclusion

In conclusion we can say that two alternative transducer systems for measuring small DC currents at high voltage levels have been developed.

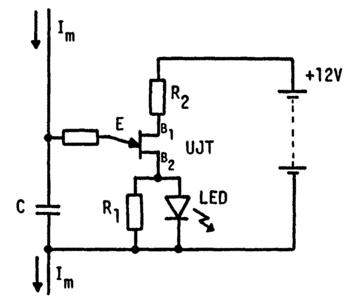
The transducer using the Pockels effect can measure DC currents with a lower limit around 0.5 μA. The upper limit is given by the choice of the measuring resistance. The current to frequency transducer can measure currents in the range 1 nA–1 mA.

The development of the transducer systems is still in progress.

Discussers: H. Kirkham and Alan Johnston.



Switching circuit. The voltage across the Pockels cell PC is periodically inverted.



Current to frequency transducer. UJT: Unit junction transistor, C: Discharging capacitor, I_m: Current to be measured.

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Off-Nominal Frequency Measurements in Electric Power Systems

M. M. Giray and M. S. Sachdev
Power Systems Research Group
University of Saskatchewan
Saskatoon, Canada

Summary

Some power system protection applications require accurate estimates of voltage magnitude and frequency over a wide measurement range. Most digital techniques for measuring frequency have acceptable accuracy over a small range in the neighborhood of the nominal value. This paper presents a method for extending the measurement range of the Least Error Squares (LES) technique. The paper also examines the effectiveness of the technique and presents some results from simulated studies and laboratory experiments.

It is essential to maintain the frequency of a power system close to its nominal value. Usually, frequency deviations in the range of two to three percent only are allowed for short durations of time. In this range, the Least Error Squares algorithm (LES) provides accurate estimates and is, therefore, suitable for implementing in most frequency relays. However, the measurement errors increase as the frequency deviation from the nominal value increases.

During start-up and shut-down of a generator, its frequency varies over a wide range. If the generator is connected to a transformer, both the generator and the transformer can experience overexcitation. Excessive volts-per-hertz (V/Hz) indicates that overexcitation has occurred. One method of estimating this parameter is to measure the voltage magnitude and frequency and then calculate volts-per-hertz. Volts-per-hertz relays that provide accurate measurements over 10 to 70 Hz range would be desirable for use on steam turbine driven generators.

The frequency of the voltage of a thermal generator is low during start-up and shut-down procedures. If a fault occurs during this period, the frequency of the fault currents and voltages will be less than the nominal value. Most voltage and current relays operate incorrectly at these frequencies. It would, therefore, be desirable to have relays that provide good estimates of voltages and currents over a wide range of system frequency.

Considering these applications, the LES technique that simultaneously measures the amplitude and frequency of a voltage or current was investigated [1]. The frequency estimation technique uses nonrecursive digital filters for estimating each component. One of the options for calculating frequency is to use sampled values of a voltage and coefficients of two filters.

The frequency deviation from the nominal value estimated by the LES technique is the ratio of the magnitudes of the frequency responses of the two filters. The magnitudes of the frequency responses are nearly equal in the 58 to 62 Hz range. The difference between the two frequency responses increases as the frequency deviates farther from 60 Hz. The mismatch between the two frequency responses is the cause of the errors in the estimated frequency at off-nominal values.

The Proposed Technique

The mismatch between the frequency responses of the two filters used to estimate frequency is a major source of errors in estimating the frequency deviations. The proposed technique that corrects for the errors at off-nominal frequencies is developed in this paper. In this technique, the errors expected to be present in the estimated values of the frequency are predetermined and correct values of the frequency are stored in a look-up table. When a frequency deviation is estimated, the corresponding value of the frequency is obtained from the look-up table. This approach increases the useful measurement range of the technique substantially.

The effectiveness of the technique was checked for frequencies in the 40 to 70 Hz range. Since the frequency deviation estimates are accurate in the 58 to 62 Hz range, the correction procedure was applied in the 40-58 Hz and 62-70 Hz ranges only. The values of the frequency corresponding to the frequency deviations from -20 to $+10$ Hz range were calculated.

The technique was used to estimate frequency of signals that were generated in computer programs and other signals that were recorded in the laboratory. The results show that the proposed technique successfully extends the frequency measuring range of the LES technique.