Proceedings of the 5th WSEAS Int. Conf. on Power Systems and Electromagnetic Compatibility, Corfu, Greece, August 23-25, 2005 (pp130-133)

A New Optically Isolated Wideband High Voltage Measurement System

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Abstract: - A high performance non-contact high voltage measurement system, based on the capacitive probe principle, is developed and extended to incorporate a novel analogue optical link to provide electrical isolation between the high and low voltage circuits. The system uses high-speed light emitting diodes and associated electronics. A buffer amplifier is used for better signal conditioning. Tests on a prototype with a range of voltage shapes and magnitudes have shown that the system has a bandwidth ranging from 11 Hz to 14 MHz and a stable voltage ratio with frequency.

Key-Words: - High voltage measurement system, Capacitive probe, Analogue optical link, Light emitting diode

1 Introduction

The requirement for optical isolation between the high voltage test area and the measurement and control area so that operators can work safely is now becoming compulsory because of the more stringent safety work regulations [1]. In addition, transmitting small signals over long distances in noisy environments such as those in high voltage substations imposes limitations on existing measurement systems. Generally, high voltage measurement devices in substations are very large in size, and are exclusively used for measuring power-frequency voltages.

In this paper, we describe a new voltage measurement system that has the advantage of having no contact with the high voltage terminal and offering a cheap optically-isolated transmission of the low-voltage signal over long distances. The optical link is analogue, hence, offering significant advantages over the more common digital and frequency converter systems. Laboratory calibration tests were conducted on a prototype designed and constructed at Cardiff University, and have demonstrated that the system exhibits a good frequency response ranging from 11 Hz to 14 MHz and stable voltage ratio over the frequency range.

2 Voltage Measurement System

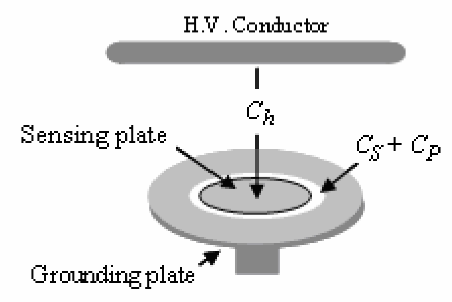
2.1 Principle of Capacitive Probe

The main voltage transducer uses the principle of the capacitive probe in which a charge, Q, is collected by a suitably dimensioned plate subjected to the electric field generated by the voltage, V, applied to the HV conductor placed some distance away. Figure 1(a) shows a diagram depicting the principle of voltage measurement by a planar-type capacitive voltage probe located under a high voltage conductor. A ring guard electrode, at earth potential, is used to minimize field fringing effects at the circumference of the sensing plate.

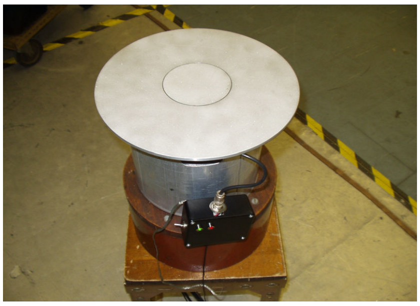
With this probe configuration, a capacitance, C_h , is formed between the high voltage conductor and the sensing plate of the voltage probe, and a stray capacitance, C_S, between the sensing plate and the guard grounding plate is also present.

This stray capacitance, C_S, is very small and can change in value due to minor variations in set up and penetration of small dust particles between the ring earth electrode and the sensing plate. In order to stabilize and control the voltage ratio, a capacitor, C_P, ($C_S << C_P$) is connected between the sensing plate and earth. Since C_P is in parallel with C_S, the effect of stray components on the measured voltage is thus minimized.

The voltage probe used in this work has a 100 mm diameter and was fabricated from an aluminum sheet of 6 mm in thickness. The earth ring electrode has an outer diameter of 300 mm. A gap of 1 mm was left between the two plates. Figure 1(b) shows the laboratory probe with its stand and housing for the low-voltage circuits.



(a) Capacitive Probe Principle



(b) Photograph of the capacitive probe

Fig.1 Details of the capacitive probe

2.2 Improved Low-Voltage Arm

In order to improve safety and isolation of the high voltage test circuit from the measurement/control area and because the signal generated by the above capacitive probe is small, we propose to use an intermediate stage between the probe output and the recording device. This intermediate stage will include a buffer amplifier for signal conditioning and an analogue transmitter-receiver optical link to provide electrical isolation between the high and low voltage circuits [2, 3].

Here, a 50 Ω coaxial cable is used to transmit the voltage signal from the probe to the transmitter, and a 50 Ω matching resistor R_m is used at the sending-end of the coaxial cable. For capacitive voltage dividers, it is well known that a matching resistor R_m is required for the coaxial cable that is used to transmit the signal to the recording device which is usually characterized by a high input impedance, Z_t.

In addition, a further tuning circuit which helps to reduce the effects of the cable on the signal is connected at the receiving-end of the cable. This circuit is composed of a resistance R_t of value equal to the characteristic impedance of the coaxial cable and a capacitance.

The resulting divider ratio for the system is frequency dependent. It can be shown that the voltage ratio, U_L , for input signals in the low frequency range, such as power-frequency voltages, is expressed as [3],

$$U_L = \frac{(C_h + C_p + C_s + C_c + C_t)}{C_h} \qquad (1)$$

At high frequencies, however, the divider ratio Uh is expressed as

$$U_h = \frac{(C_h + C_p + C_c)\cdot(R_m + R_t)}{(C_h \times R_t)} \qquad (2)$$

In practical applications, C_P is 5~10 nF ($C_h << C_P$), and ideally, U_h must be equal to U_L for all frequencies. From the circuit of Figure 2, it is clear that the overall ratio of such divider is also dependent of the input impedance of the terminating instrument. Therefore, a voltage follower (LH0033) of very high input impedance Z=50 MΩ and an out put impedance 50 Ω is used and the values of R_t and C_t are selected to ensure $U_L = U_h$

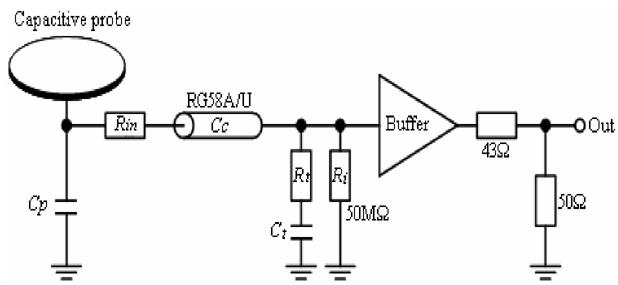


Fig.2 Details of matching of the low voltage arm

2.3 Optical Link System

A high-speed, wideband optical link is required to transmit the measured voltage signal to the recording instrument for signals ranging from power-frequency voltages to fast-impulse voltages without any distortion by circuit configuration and electromagnetic interference. To address this, an analogue optical link system using fast diodes is designed. The transmitter circuit, which converts the electrical signal into an optical signal (E/O converter), uses a GaAsP series light emitting diode of type HFBR1527 having a rise-time of 12 ns and a fast and linear response for the

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selected range of operation. The optical signal is transferred to the receiver via a glass fiber link of 30 m. The receiver, which converts the optical signal into an electrical signal (O/E converter), is designed with a PIN photo-diode of type HFBR 2526 with a built-in amplifier, and a rise-time of 3.3 ns. Figure 3 shows the circuit configuration of the optical link fabricated during this work.

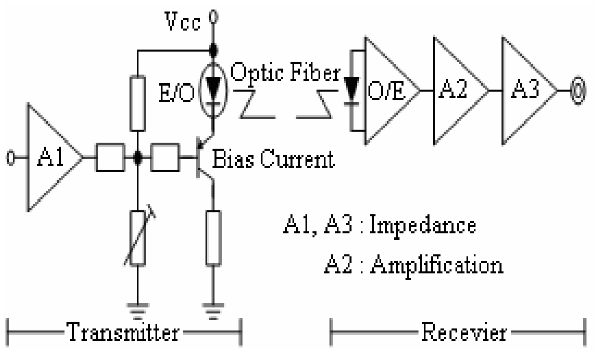


Fig.3 Details of the optical link circuit and assemblies

In contrast to existing optical systems used for measurement applications, the proposed optical link has two special features: a) transmit and receive analog signals which make real-time signal transmission possible without the process of voltage to frequency (V/F) conversion or analog to digital (A/D) conversion, and b) transmit bipolar voltage signals by using only one unipolar light emitting diode (LED).

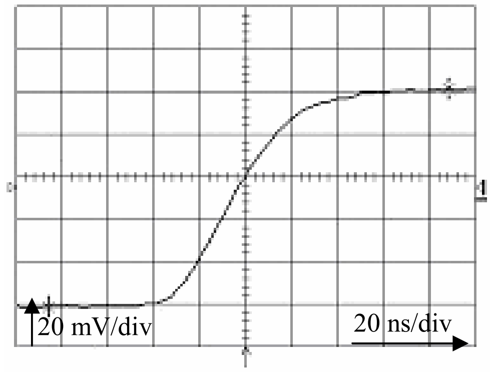
The latter is achieved by applying a bias current to the diodes and then operate them in linear region of their characteristic. In this investigation, the magnitude of the bias current was set to 50 % of the rated forward current of the LED. For this type of diode, the optical power increases by adding a positive signal to the bias current and decreases by subtracting a negative signal from the bias current.

3 Results and Discussion

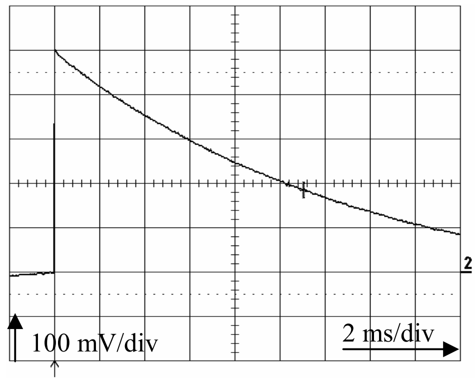
A step-like voltage with a rise-time of 44.2 ns was generated with a Thandar, TG501 function generator. Figure 4 shows the step response waveform of the measurement system. The true rise time of the measurement system being calibrated t_r is then calculated using the method of quadrature [4] which stipulates,

$$t_r = \sqrt{t_{r0}^2 - t_{ri}^2} \quad [\text{ns}] \quad (3)$$

With t_{ro}: total rise time of signal, tri: rise-time of the pulse generator. The intrinsic rise time of the oscilloscope (Lecroy 9354C) used in this experiment is less than 1 ns, and the measured rise time to the input signal is 51.1 ns as can be observed in Fig. 4(a). Using the data of Figure 4 and Equation (3), we obtain the true rise time for the voltage measurement system, t_r=25.6 ns. The frequency bandwidth is determined by the transfer function, and the high cut-off frequency of the frequency bandwidth, and is estimated to be 13.6 MHz. From Fig. 4(b), we can observe that the decay time of the system when using a unit step input is 13.3 ms, and the low cut-off frequency is estimated to 11.4 Hz.



(a) rise-time

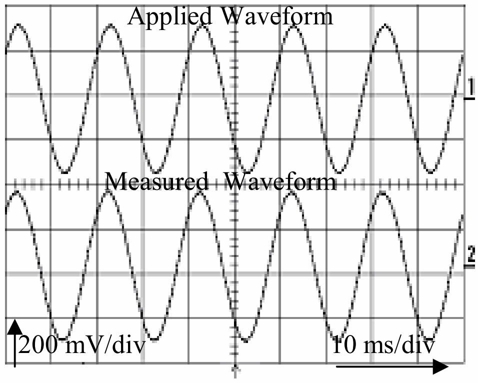


(b) decay time

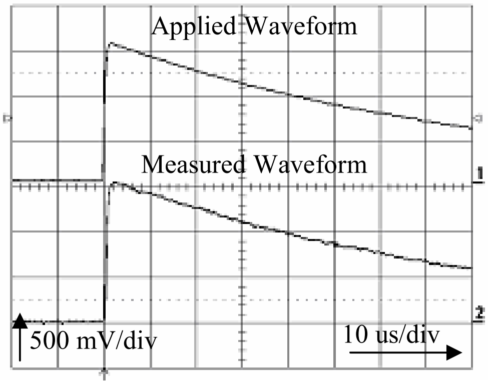
Fig.4 Step response waveforms of the proposed voltage measurement system

Calibration tests were also carried out with a fixed configuration between the capacitive probe and the high voltage conductor. Various types of voltages were applied to the conductor, and the dividing ratio was calculated by comparing the output of the measurement system with the direct measurement of the voltage applied to the conductor. Figure 5(a) to 5(d) show the measured waveforms during these tests.

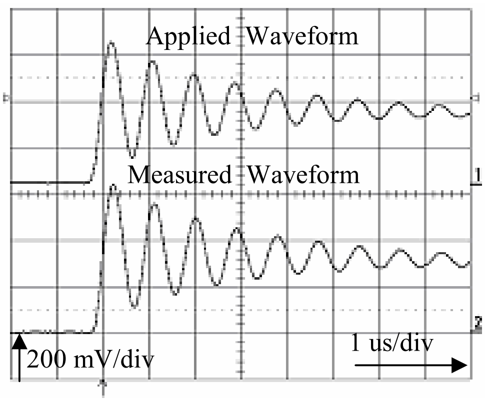
The 50 Hz waveforms were generated using a high voltage transformer while the impulse voltages were generated by a recurrent surge generator (type Haefely, SG481). The so-measured overall ratios range from 951 : 1 for chopped impulse voltages to 1021 : 1 at power frequency giving a change of 7.4 %.



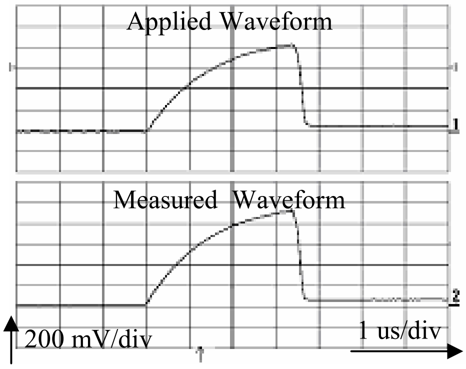
(a) Commercial frequency



(b) Non-oscillating impulse voltage



(c) Oscillating impulse voltage



(d) Chopped impulse voltage

Fig.5 Measured waveforms using the proposed voltage measurement system

4 Conclusion

A high performance, non-contact high voltage measurement system which is based on the capacitive probe principle, is developed. The system includes a novel analogue, optical link which uses high-speed light emitting diodes and associated electronics. A Laboratory prototype was constructed and tested with a wide range of voltages shapes and magnitudes.

Calibrations tests were carried out and have demonstrated that the proposed voltage measurement system has a bandwidth ranging from 11 Hz to 14 MHz and a stable voltage ratio with frequency.

A significant advantage of such measurement system is its immunity to electromagnetic interference in noisy environments such those encountered in high voltage installations.

References:

[1] Zhi Fang, Yuchang Qiu, E. Kuffel: "Development of an opto-electrical system for application to high voltage measurement", Proc. of the 13th International Symposium on High Voltage Engineering(ISH), Paper No. 527, 2003

[2] Spellman CA, Haddad A., German DM, Waters RT: "An improved three-phase voltage measurement using capacitive probes", Proc. of the 34th Universities Power Engineering Conference (UPEC), pp. 352-355, Leicester(UK), 1999.

[3] Moustos E: "Development of a low current optical transducer for high voltage applications", MSc thesis, Cardiff University, 1999.

[4] Liao Ruijin, Sun Caixin, Zhen Xiaoguang, "Development of a transient voltage measuring system", Proc. of the 8th ISH, Paper No. 54.16, 1993, pp. 141-144.