An Investigation of Parasitic Capacitance Determination Using High Frequency Injection Technique for Non-Contact Voltage Measurement System

Noppawit Longseng †1 Kittikhun Thongpull †2

Abstract: The growing demand for smart energy and smart metering concepts increase the development of advanced measurement devices and systems. However, conventional voltage measurement systems in power lines require physical contact with the conductor inside the power line. This method is still common nowadays whereas inconvenient installation and unsafe for the operators. This paper proposes a method of non-contact voltage measurement exploiting the parasitic capacitive coupling with online capacitance determination. The parasitic capacitive coupling occurred by covering metal plates around an insulated power line cable. The capacitance determination employs a high-frequency signal injection technique that transmits a reference signal to calculate the established parasitic capacitance value. The proposed method has been experimented with to determine the capacitor value generated by the capacitive coupling which then is used to calculate the actual voltage of the power line. From the experimental results, the proposed voltage measurement system can measure the actual voltage of the power line with the capability to eliminate noise errors and impact uncertainty under various conditions.

Keywords: Capacitive Coupling, Non-contact voltage measurement, High-Frequency Injection

1. Introduction

Conductor contact voltage measurement has been used for a long time. To measure the voltage in the wires it is necessary to cut and connect the circuit to make direct contact with the conductors. But in some systems, the installation of measuring devices is a risk to the user. The development of a method for measuring voltage without touching the conductor occurred to solve this problem. The vast majority of current research on non-conductor voltage measurements is based on the measurement of capacitance formed according to the principle of capacitive coupling. The effect of a nearby voltage signal [1]. Study the effect of capacitor forming on the surface and of the sensor and within the conductors of the wires [2]. Errors due to harmonics of various order [3]. Effects of impedance changes occurring in the ground system during non-contact voltage measurement circuits and power system [4]. This paper presents an investigation of parasitic capacitance determination using high frequency injection technique for non-contact voltage measurement system

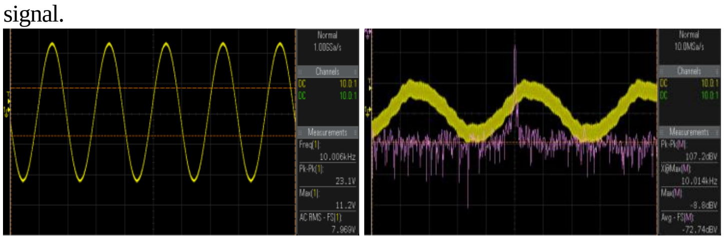
2. An Investigation of Parasitic Capacitance for Non-Contact Voltage Measurement

2.1 Theories and Principles

The characteristic of the sensor is created by wrapping a cylindrical copper sheet around the wires. Capacitors form the principle of capacitive coupling, with copper plates outside the wires and inside the wires being plates on both sides of the capacitor. A signal can flow through both capacitors as shown in Fig. 2 with displacement current. Displacement current occurs when the electric field flux changes between the capacitor plates. The high-frequency signal infuses into the system to be integrated into the fundamental signal. These signals can be measured on the $C_{sensor1}$ side of the sensor. Capacitance can be calculated by analyzing the circuit at two frequencies: high frequency and fundamental frequency. Wherewith the capacitors formed in the same environment can be assumed to be the same capacitor.

2.2 Filter circuit design

The signal from the sensor can be analyzed through a high-pass filter and a low-pass filter. The circuit for filtering high-frequency signals is designed as a passive 3rd order. The high pass filter is used to filter the signal add into the power cable through $C_{sensor2}$. To ensure that the filtered signal is a high-frequency signal injected into the system by adding the signal to the system at different frequencies and comparing the signal. The filtered high-frequency signal corresponds to the signal injected by the signal generator as shown in Fig. 1. The signal measured from $C_{sensor1}$, when considered in the fast fourier transform mode, can be seen that the signal with the peak magnitude has the equal frequency as the test signal.



(a) (b)

Fig. 1. Sensor testing with high-frequency signal injection.
(a) High-frequency signal for injection to the sensor.
(b) Output from the sensor when infusing the test signal.

A low-pass filter is used to filter signals at fundamental frequencies. The filter circuit is designed as a passive filter. Fundamental frequency signals are used to determine the magnitude of gain compared to the voltage signal in the transmission line and the signal coupling from the sensor.

2.3 High Frequency Injection Technique

The non-contact voltage sensor model is shown in figure 2. The measured signal from the sensor is attenuated as it passes through a capacitor coupling with a plate. Capacitor C_d is used to divide the voltage so that the voltage received from the sensor does not exceed the voltage measurement circuit obtains. The following equations are calculated regardless of C_d as the circuit can tolerate voltage from the sensor. The equivalent circuit of the sensor when separated into two frequencies of each source is shown in figure 2. The attenuation constant is separated into two frequency bands: the high-frequency range G_1 and the fundamental frequency range G_2. Connecting signals from two sources through attenuation can be written as a relation equation as follows:

$$V_o = V_{o\_HF} + V_{o\_FF} \tag{1}$$

$$V_o = G_1 V_R + G_2 V_S \tag{2}$$

†1 Prince of Songkla University
†2 Prince of Songkla University

V_o is the magnitude of the signal measured from the sensor through an op-amp that acts as a buffer to maintain the signal. By separating the computational range into two, the attenuation constant G_1 can be calculated according to equation (3).

$$G_1 = \frac{(V_{HPF}/G_{HPF})}{V_R} = \frac{V_{o\_HF}}{V_R} \tag{3}$$

The high-frequency signal used in the sensor experiment is a sine signal at a frequency of 10 kHz. V_{HPF} is the voltage measured from the high pass filter. V_R is the voltage applied to the sensor of the signal generator. G_{HPF} is the voltage divider attenuation constant in the high pass filter. By design, the filter has a high-frequency signal pass attenuation constant of 0.1949. When the impedance of the filter circuit is determined (Z_{Filter_HF}), the sensor impedance (Z_{sensor_HF}) can be calculated by considering the attenuation constant and the voltage divider between the sensor impedance and the impedance of the filter circuit. The relationship equation can be written as follows.

$$G_1 = \frac{Z_{Filter\_HF}}{Z_{Filter\_HF} + Z_{sensor\_HF}} \tag{4}$$

Comparing equations (3) and (4), the relationship of the impedance in the system to the high-frequency signal can be written as follows:

$$\frac{Z_{Filter\_HF}}{Z_{Filter\_HF} + Z_{sensor\_HF}} = \frac{V_{o\_HF}}{V_R} \tag{5}$$

Equation (5) can be substituted to find the Z_{sensor} because Z_{Filter_HF}, Z_{sensor_HF}, and V_R are known. And the value of Z_{sensor_HF} can be calculated for the capacitor in the sensor according to equation (6).

$$C_{sensor} = \frac{1}{j2\pi(10k)(Z_{sensor\_HF})} \tag{6}$$

In the fundamental frequency range of 50 Hz, the equation for the attenuation G_2 can be written according to equation (7).

$$G_2 = \frac{V_{LPF}/G_{LPF}}{V_S} = \frac{V_{o\_FF}}{V_S} \tag{7}$$

V_{LPF} is the magnitude of the voltage measured from the low pass filter. V_S is the magnitude of the voltage in the wire to be measured. G_{LPF} is the attenuation constant of the voltage divider in the low pass filter. From the filter circuit design to filter the fundamental 50 Hz signals, the cut of frequency is designed to have an attenuation constant of approximately 1. The impedance of the filter circuit is determined, the sensor impedance can be calculated in consideration of the voltage divider attenuation constant between the sensor impedance and the impedance of the filter circuit. The relation equation can be written as follows.

$$G_2 = \frac{Z_{Filter\_FF}}{Z_{Filter\_FF} + Z_{sensor\_FF}} \tag{8}$$

Z_{sensor_FF} can be calculated in the same way as equation (6), using the C_{sensor} value in the fundamental 50 Hz frequency range. From the equations (2), (3), and (7), the variables obtained can be substituted to calculate the voltage in the wire according to equations (9) or (10).

$$V_S = \frac{V_o - G_1 V_R}{G_2} \tag{9}$$

$$V_S = \frac{V_{o\_FF}}{G_2} \tag{10}$$

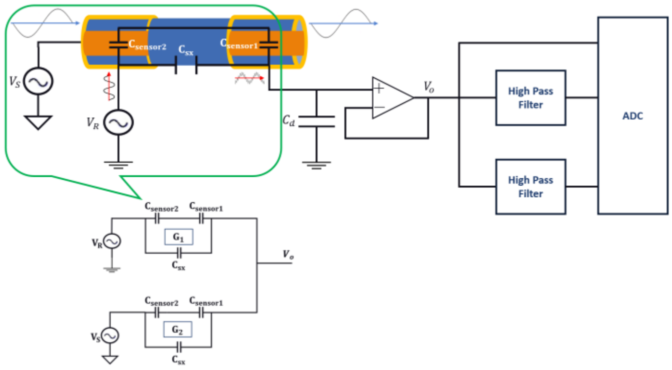


Fig. 2. Non-contact voltage sensor model and equivalent circuit for calculating bi-frequency separate sensors

3. Experiment Setup and Results

A method of injecting a high frequency to the sensor is used to observe the behavior of the output sensor signal. In the experiment, a sine-wave high-frequency signal from 10 kHz to 400 kHz injected to the sensor. When measuring the signal on the sensor output (Vo), the high-frequency signal was found at the same frequency as the frequency inject to the sensor compound the fundamental signal. The signal passing through the high-pass filter was analyzed in the fast fourier transform mode to observe the highest signal frequencies and system noise. The frequency of the signal with the maximum magnitude (X@Max(M)) is the frequency of the signal being inject to the sensor. The magnitude of the signal (Max(M)) from measurements at different frequencies has the same magnitude. The results ensure that the signal passing through the capacitor from the capacitive coupling principle.

4. Conclusions

The capacitors that form can be altered by the effects of the environment such as temperature and humidity changes, electric and magnetic fields around wires, deterioration of the material in the wire. Utility of investigation of parasitic capacitance determination using high-frequency injection technique for non-contact voltage measurement system. A key advantage is that the investigation of capacitors within the formed sensors allows the system to calibrate the computed variables in real-time. For future work, the analyzed equations will be tested further. Testing in a variety of sensor situations and applications at higher voltage levels, including data errors, compared to conductive contact voltage measurement methods to assess sensor performance.

Reference

[1] Lawrence, David, et al. "Non-contact measurement of line voltage." IEEE Sensors Journal 16.24 (2016): 8990-8997.

[2] Shenil, P. S., R. Arjun, and Boby George. "Feasibility study of a non-contact AC voltage measurement system." 2015 IEEE International Instrumentation and Measurement Technology Conference (I2MTC) Proceedings. IEEE, 2015.

[3] Shenil, P. S., and Boby George. "Evaluation of a Digitizer Designed to Interface a Non-Intrusive AC Voltage Measurement Probe." IEEE Sensors Journal 20.10 (2020): 5606-5614.

[4] Shenil, P. S., and Boby George. "Non-Intrusive AC Voltage Measurement Unit Utilizing the Capacitive Coupling to the Power System Ground." IEEE Transactions on Instrumentation and Measurement (2020).