Development and Application of an Energy Harvesting Power Factor and Apparent Power Sensor

Takaya Yoshitake
Department of Communication Engineering and Informatics
The University of Electro-Communications
Chofu, Japan
Email: y2131168@edu.cc.uec.ac.jp

Shunkichi Takamatsu, Shinichiro Mito
Department of electronic engineering
National Institute of Technology, Tokyo College
Hachioji, Japan
Email: mito@tokyo-ct.ac.jp

***Abstract*— A contactless, wireless and battery-free alternating current (AC) apparent power and power factor sensor was developed. A current sensing transformer was not only used as a noncontact current sensor but also acted as a power supply for the sensor. The AC voltage waveform was measured without metal contacts using a piezoelectric film. A low-power circuit was designed to measure the power factor from the current and voltage waveforms. The data obtained from the developed sensor showed good agreement with the results from a commercially available power meter. The sensor developed in this work is expected to enable energy savings and carbon dioxide reduction in industrial applications.**

Keywords; electrical power; electric field; noncontact measurement; energy harvesting; SDG

I. INTRODUCTION

Reduction of electrical power consumption remains a constant issue in factories because it will not only reduce manufacturing costs but will also reduce CO2 emissions [1][2] and thus enable compliance with the International Organization for Standardization (ISO) 14001 standard [3]. To achieve the required reduction, it is important to measure the power consumption of each item of equipment precisely [4]. For this purpose, compact, easy-to-install, and inexpensive wireless power consumption sensors are required, but at present, there is no sensor available that can achieve all these demands [5]-[10]. Several nonmetallic contact methods for voltage waveform measurement have been proposed [11]-[14] that offer the advantages of ease of installation and non-invasive techniques. However, these proposed methods are expensive or require multiple probes that make them difficult to implement.

In this study, we propose a non-metal-contact voltage measurement method based on a single probe using a piezoelectric film. In addition, we have fabricated and evaluated an energy-harvesting, non-invasive, and retrofittable wireless power consumption sensor for factory use that consists of the proposed voltage sensor, a current transformer, an energy-harvesting circuit, a power-factor (PF) measurement circuit and a wireless communication module. The device does not require complex electrical work, and it will cost approximately $20 because of its simple design.

In Section 2, the block diagram of our sensor is presented. Section 3 describes the non-metal-contact voltage measurement process using the piezoelectric film. Section 4 presents the PF measurement circuit. Section 5 shows the results from field tests. Section 6 presents the conclusions drawn from this study.

II. CONFIGURATION OF THE SENSOR

The configuration of the developed sensor is shown in Figure 1. We used a current transformer to measure the current in a contact-free manner. The operating power of the wireless module can also be obtained from the current transformer. The sensor can be powered by energy harvesting. The apparent power was calculated by multiplying the assumed-to-be-constant voltage by the measured current. The PF was calculated using the phase difference between the voltage waveform acquired by the proposed voltage sensor and the current waveform. The apparent power and PF obtained were transmitted using the wireless module (TWE-Lite, Mono Wireless Inc., Kanagawa, Japan).

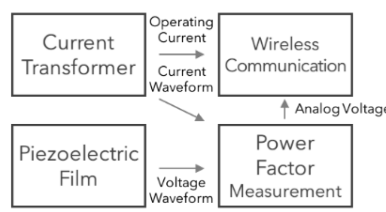


Figure 1. Block diagram of the PF and apparent power sensor

Installation of the developed sensor is easy because noncontact single probes are used for both the current and voltage measurements. Furthermore, our sensor requires much less maintenance than conventional sensors because of its energy harvesting-based operation.

III. NON-METAL-CONTACT VOLTAGE MEASUREMENT USING PIEZOELECTRIC FILM

A voltage can be measured non-invasively using a single probe by measuring the electric field strength around a wire when the voltage is applied to the wire [11][12]. We have focused on use of a piezoelectric film to provide a low-cost method to measure electric fields. The piezoelectric film comprises a piezoelectric material sandwiched between metal electrodes. The piezoelectric material is polarized by the electric field around the wire, and a potential difference is then generated between the two electrodes. The electric field around the wire can thus be detected using a single piezoelectric probe.

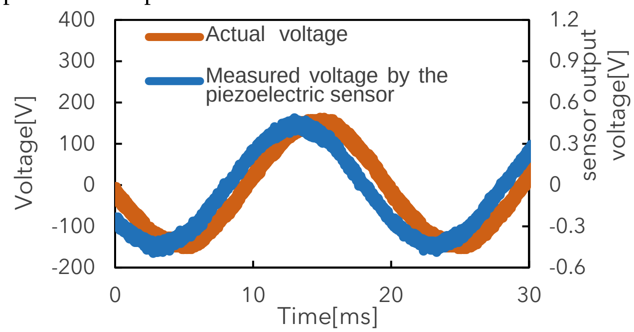


Figure 2. Results of noncontact voltage measurements using the piezoelectric film

A commercially-available piezoelectric film (LDT0-028K, TE Connectivity, Schaffhausen, Switzerland) was bent and was placed at a uniform distance from the center of the wire. The observed voltage waveform is shown in Figure 2. Although the output voltage and phase varied depending on the distance between the piezoelectric film and the wire, the correlation coefficient obtained for the actual and measured waveforms was 0.99. The proposed method can measure the relative change in the voltage, which is sufficient to enable calculation of the PF. The piezoelectric sensor output was related in advance to the actual voltage and was consistent with the calculation results from the equivalent circuit.

IV. Power Factor Measurement Circuit

The developed sensor was operated using the power obtained from the current transformer; it is thus necessary to measure the PF with low power consumption. In this research, we used an analog circuit to perform PF measurements with low power consumption.

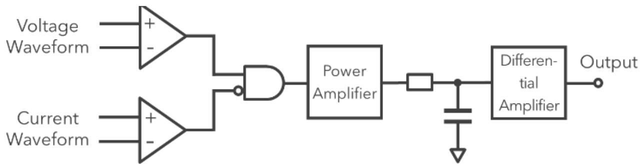
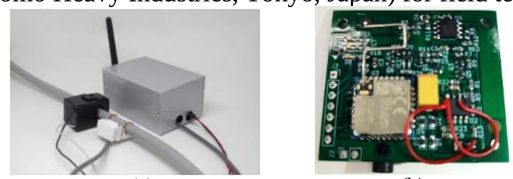


Figure 3. Block diagram of PF measurement circuit.

Figure 3 shows the block diagram of the fabricated PF measurement circuit. The current and voltage waveforms are converted into square waves, and the phase difference is then obtained as the pulse width by taking the logical product of these waves. Subsequently, the phase difference is output as an analog voltage through power amplification, smoothing, and differential amplification processes. The output is connected to the analog-to-digital converter of the wireless module and the data are transmitted. This circuit can be applied to both single- and three-phase electrical loads.

V. Fabrication and Field Test

The noncontact wireless apparent power and PF sensor was fabricated as shown in Figure 4. The fabricated sensor was then attached to an injection molding machine (SH100C, Sumitomo Heavy Industries, Tokyo, Japan) for field testing.



(a) (b)

Figure 4. Fabricated sensor. (a) Appearance of the fabricated sensor. The black probe is the current transformer, and the white probe is the voltage probe developed in this work. The silver box contains the processing circuit. (b) Appearance of the fabricated sensor board.

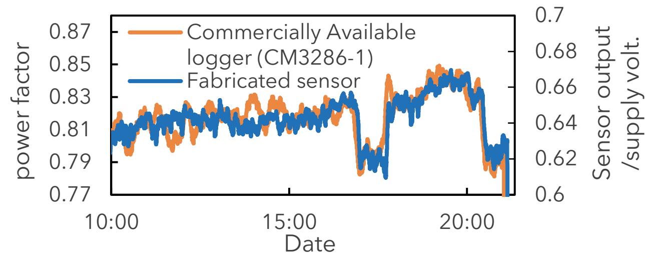


Figure 5. Comparison of the PFs obtained from a commercially available logger and the fabricated sensor.

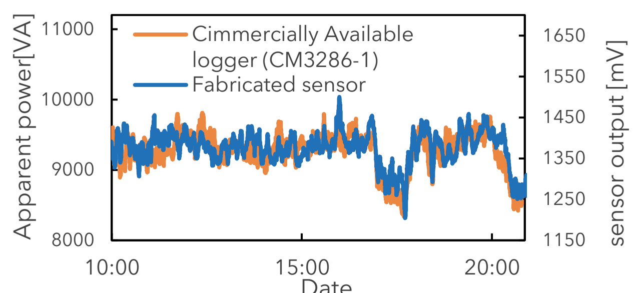


Figure 6. Comparison of the apparent power results obtained from a commercially available logger and the fabricated sensor.

Figures 5 and 6 show comparisons of the PFs and the apparent power values, respectively, that were measured using the developed sensor with those measured using a commercially-available power logger (CM3286-01, HIOKI E.E., Tokyo, Japan). The PF obtained by the developed sensor has a correlation coefficient of 0.80 with that measured using the commercial logger. The apparent power showed a correlation coefficient of 0.73. These results indicate that our sensor was able to measure the power consumption sufficiently accurately. The accuracy is suitable for rough logging of the PF and could be improved by calibration and grounding processes.

VI. Conclusion

Voltage waveforms have been measured using a single piezoelectric probe without metal contacts. An energy-harvesting wireless apparent power and PF sensor was prototyped using this piezoelectric probe. The data acquired using the developed sensor showed good agreement with the data acquired using a commercially-available power meter.

ACKNOWLEDGMENT

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