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Electricity Monitoring and Interference Reduction of Two-Wire Household Appliances Using Current and Voltage Sensor Tag

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Abstract- This paper demonstrates a nonintrusive current and voltage sensor tag with an interference reduction scheme for accurate electricity monitoring of the household appliances using typical SWG 30 zip-cord power lines with analysis using autotransformer 3P1 with ATmega16 microcontroller and CRO. Both current and voltage sensors are design with a inductive coil of 100 turns and 80 turns of copper coil, respectively, in an small area. The tag exhibits a sensitivity of 28.52 mV/mA and 0.13 mV/V via active low-pass filter circuits for the current and voltage detection. A compensation circuit inputted with the signals of the voltage sensor is applied for the interference reduction of the current sensor electrically coupled with the power cord for measuring the loaded current of 1 A, 50 Hz on the power line.

Keywords: Household electricity monitoring, current and voltage sensor tag, CRO, ATmega16, autotransformer

I. INTRODUCTION

New techniques for current detection have been developed to meet the increasing demands for electricity efficiency which can be used in nonresidential and residential applications. To improve the individual sensor performance by taking the advantage of good proximity provided by the sensor tag, a spiral inductive coil is fabricated and copper antenna are devised on the Standard Wave Gauge (SWG) 30 of household appliance to sense the current and voltage in the two-wire power line respectively. Current sensing is based on the detection of magnetic flux change in the two-wire power line of household appliances. And voltage sensor senses the voltage in neutral line [5].

Active filter readout circuit designed for the current and voltage sensor. Voltage sensor detect voltage and also reduce the electrical interference in current sensor which is resulted from the electric-field coupling of the load on the power cord. Compared analysis is takes place via signal processing using microcontroller AT mega 16, using autotransformer and CRO. The proposed current and voltage sensor tag gives reliable, accurate, and ubiquitous current and voltage detection with interference reduction scheme.

II. RELATED WORK

There are many techniques developed for electricity monitoring in industrial and household appliances some of these are:

A flexible nonintrusive current and voltage sensor tag is demonstrates with an interference reduction scheme for accurate electricity monitoring of the household appliances using typical SPT-2 18 AWG zip-cord power lines. Both current and voltage sensors with the design of a 50-turn inductive coil and two capacitive electrodes, respectively, in an area of 1.3 × 1 cm2 are fabricated on a 100-μm-thick flexible polyethylene terephthalate substrate as a sensor tag . The tag exhibits a sensitivity of 271.6 mV/A and 0.38 mV/V [1]. Other presents new results in the testing and characterization of a MEMS sensor for AC electric current. Sensor response is linear with sensitivity in the range of 0.1-1.1 mV/A[3]. Another study presents measurements of the actual worst-case short circuit currents encountered in artificial interlamination shorts. A procedure uses an adapted miniaturized Rogowski coil [7]. Proof-of-principle experimental demonstration with theoretical modeling is presented for resonantly enhanced Faraday rotation in a microcoil current sensor. This new type of current sensor has the potential to be ultrafast, compact, and low-cost [8]. The giant magneto resistance (GMR) effect has revolutionized the fields of data storage and magnetic measurement. In this work, a design of a GMR current sensor based on a commercial analog GMR chip for applications in a smart grid is presented and discussed. Static, dynamic and thermal properties of the sensor were characterized. The characterizations showed that in the operation range from 0 to ±5 A, the sensor had a sensitivity of 28 mV/A[9].

III. SYSTEM DESCRIPTIONS

The project is divided into two subsections: A) Sensor Building and B) Compared Analysis

A) Sensor Building

The sensor tag is divided into two subcomponents: One is current sensor for current sensing, and the other is voltage sensor for voltage detection. Typical two- wire power cord with current and voltage sensor tag is shown in Figure 1. Current sensor is made up of the inductive coil structure with 2 primary windings and 100 secondary windings, with a core of low-loss magnetic material [5]. The electromagnetic field is developed across two wire line as a result of current flowing in fire line. It is designed with the detection of magnetic field generated by the electric current flowing through power cords. It detects the current by encircling the source conductor with the sensor coils. Voltage sensor tag is made up of 80 turns of copper coil. The voltage sensor detects voltage in neutral line which is a interference voltage induced by fire line. Since the magnetic and electric fields generated by the power source have r^{-1} and r^{-2} dependence, respectively, where r is the distance from the sensor to the source, we require high sensitivity of the nonintrusive sensors [1].

Operational Principle of Current Sensor

As the magnetic field generated around a standard SWG 30 power cord with a 1-A current input, the largest time-variant magnetic field will exist on the top or bottom sides of the central area of the two-wire cord. An inductive coil tag can be used as the current sensor with the largest output voltage signal generated by the electric current flowing through the power cord, while it is closely attached to the power cord on the designated location. The current sensor exploits Faraday's law of induction to measure currents.

According to the Biot-Savart law, the magnetic flux density generated from a single current-carrying power cord is derived as follows

$$\vec{B} = \frac{\mu 0 I \cos \omega t}{2\pi r} \hat{a}_{\phi} \qquad (1)$$

Where, B is the magnetic flux density, I is the current inside the cord, ω is the angular frequency of current, and r is the distance from the source to a point in space.

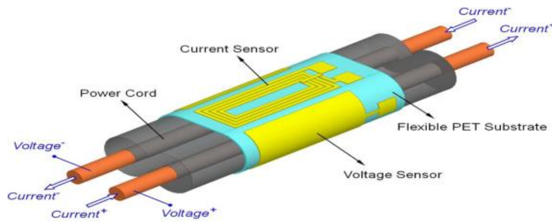


Figure 1. Two- wire power cord with current and voltage sensor

Thus, according to Faraday's law of induction, the open-loop current-sensing coil's induced voltage, which is proportional to the magnetic flux change resulting from the time-variant current flowing through the power cord, can be calculated as follows:

$$V_{in} = -\sum_{n=1}^{N} \frac{d\phi_n}{dt} = -\sum_{n=1}^{N} \frac{d}{dt} \oint \frac{\cos wt \mu_0}{\pi t} I \hat{a}_\phi . d\hat{A}_n \quad (2)$$

Where, V_{in} is the induced voltage of the coil, N is the total number of the coil, A_n is the area of the nth turn of the coil, and ϕ_n is the integral of the vertical component of magnetic flux passing through the nth turn area. This gives a current sensor that provides, simple working principle, low losses and isolation [5].

Operational Principle of Voltage Sensor:

In a two wire household power cord, distribution of the electric field with the neutral and fire lines applied with 0 and 230 V are located on the left and right sides of the cord, respectively. The electric field normal to the half circle interface on the right-hand side of the fire line is the best location with a sensing anteena that can exhibit the densest electrical flux, i.e., largest induced charge density, than that in any other location surrounding the power cord. Therefore, the proposed voltage sensor comprising 80 turns of copper coil winding in zigzag fashioned. This coil works as antenna which attracts and senses the electric field across neutral line. As the antenna pinches a power cord to sense a sinusoidal electric field in the power cord, an ac current i_c can be induced between the voltage sensor and the inner conductor of the fire line.
By introducing the current i_c to the readout circuit, the output voltage can be therefore estimated. The voltage sensor is used for two purposes first for measuring the electricity voltage of the power cord and second for eliminating the interference noise of the current sensor.

B) Compared Analysis

The Compared analysis is takes place with two processes. First process is electricity monitoring of two wire household appliance and second process is interference reduction for current measurement of loaded household appliances.

Electricity Monitoring of Two Wire Household Appliance

Electricity monitoring of two wire household appliance is takes place by the process as shown in Figure 2. The current sensor is used to sense the current in the fire line and is attached on fire line of two wire household appliance. Figure 3 shows the hardware setup of project with current and voltage sensor tag.

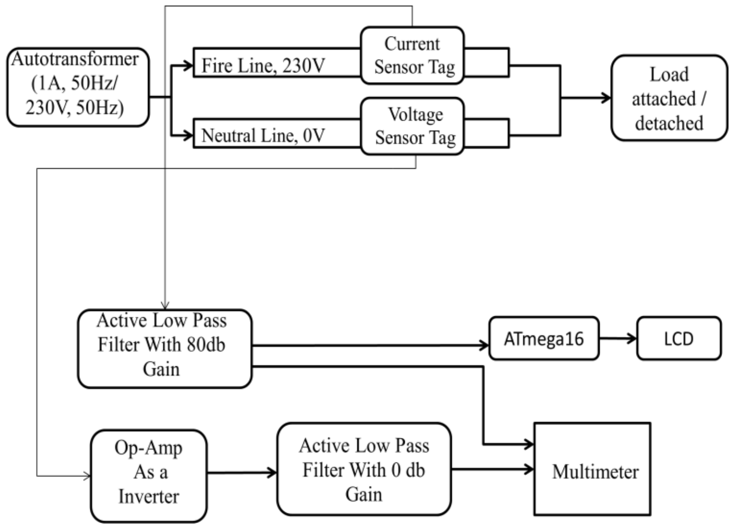


Figure 2. System model for electricity monitoring of two-wire household appliance.

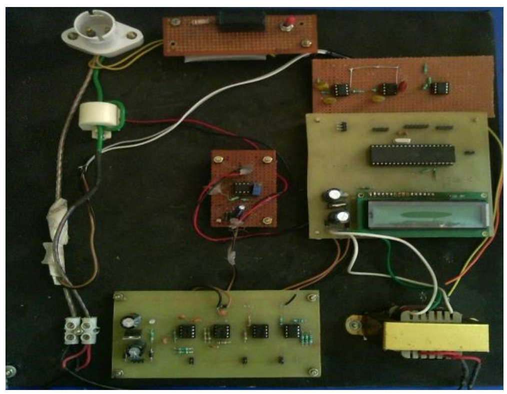


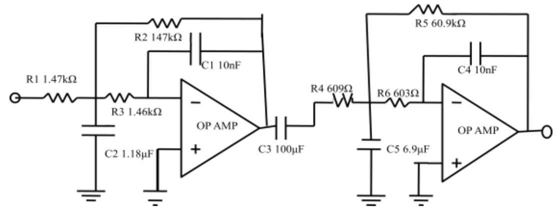
Figure 3. Hardware setup including a current sensor and a voltage sensor with there readout circuitries.

And voltage sensor is attached on neutral line is used to detect voltage in neutral line which is induce by fire line as an interference voltage. The sensor output is connected to the readout circuit. . Prior to the filter, the voltage sensor is connected to an inverter to provide a current path directly to the virtual ground.

To the end of the power cord the autotransformer is connected to provide variable supply. For current sensor, the 40W bulb as a load is attached to the power cord (short loaded state) and for variable current input to the cord from the autotransformer the respective outputs are measured at the end of the current sensor read out circuit by using multimeter. For voltage sensor in open loaded state, for variable input voltage to the cord is applied by the autotransformer and the respective outputs are measured at the end of the voltage sensor read out circuit using multimeter. The respective readout circuits characterization required for sensor tag is explained below.

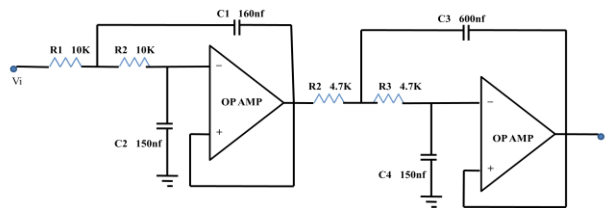
Device Characterization

The current sensor and voltage sensor only sences the current and voltage in the power cord respectively. As the voltage in the power cord is very small i.e.in the milivolt range it is necessary to amplify it and also need to select the frequency range for better performance. Hence different readout circuits with operational amplifier are designed for sensors.The readout circuits characterize the induced voltage from the coil and from the voltage sensor respectively. This read out circuit is a fourth order Butterworth low-pass filter functioning as a low-pass active filter. Butterworth filter provides very flat response and does not present ripples in the pass band. The current and voltage sensors are connected to a fourth order Butterworth low-pass filter. The active low-pass filters as read out circuits are shown below.



(Gain= 79.5db in measurement)

Figure 4 Active low pass filter circuit designed with an 80-dB gain (79.5 dB in measurement) and a 100-Hz cutoff frequency for the current sensor.



(Gain= 0.9db in measurement)

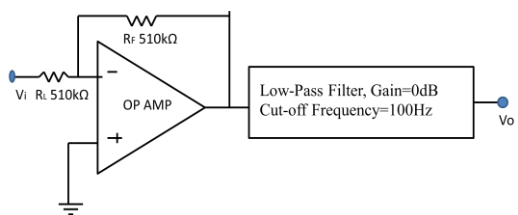


Figure 5 (a) Active low pass filter circuit designed with a 0-dB gain (0.9 dB in measurement) and a 100-Hz cutoff frequency is used for the voltage sensor, (b) an inverter is connected to the filter to provide a current path directly to the virtual ground

For the current sensor readout circuit is designed with an 80-dB gain (79.5 dB in measurement) and a 100-Hz cutoff frequency as shown in Figure 4 [1]. For the voltage sensor active filter circuit is designed with a 0-dB gain (0.9 dB in measurement) and a 100-Hz cutoff frequency is used as shown in Figure 5 (a) [11]. These read out circuits reads the output voltages of sensors and amplify it over the 50Hz range of frequency. And there amplified outputs of sensors are then used to monitor electricity. Prior to the filter, the voltage sensor is connected to an inverter with $R_F = R_L = 500k$ as shown in figure 5(b) to provide a current path directly to the virtual ground that makes the measured sensing output solely depend on the resistive load.

Interference Reduction for Current Measurement of Loaded Household Appliances

In household appliances monitoring using the sensor tag, the interference is observed during the current measurement of the power cord loaded with the input of 230 Vrms 50 Hz. Figure 9 (a) shows the output waveforms of the current sensor attached to a household appliance where the power cord is plugged into the receptacle but not loaded with any current. At this OFF stage the observed signal of the appliance mainly comes from the electric interference resulting from the time-variant electric field surrounding the fire line [1]. Similarly voltage sensor will also induce an ac current in the current sensor coil. Therefore, coupled signals will be induced simultaneously in the sensor coil with the same frequency.

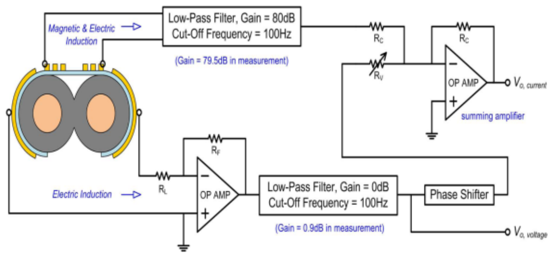


Figure 6. Circuit diagram for interference reduction method.

There are several research works have proposed for suppressing the electric interference employing a physical grounded metal shield [4], [6]. As the addition of shielding structure increases the process complexity this project proposed another interference reduction method combined with the voltage sensor to solve this problem as follows: Figure 6 shows the full diagram for interference reduction scheme in current sensor. When the bulb is off, voltage sensor's output signal after amplification and filtering is connected to a phase shifter to make the signal with 180^0 phase shift with respect to the current sensor's initial output signal and then both sensors output which are 180^0 out of phase with respect to each other gives to a summing amplifier's input for the interference reduction of the current sensor.

IV. RESULTS

The electricity of SWG-30 poer cord is monitored with current and voltage sensor by using autotransformer 3P1. For the current sensor the cord is loaded with a 1-A 50Hz with variable electric current supplied by the autotransformer with 40W bulb is loaded to the power cord. As the current input to the power cord increases the corresponding output voltage of the current sensor increases. Figure 7 shows the current sensor output signal versus different input current flowing through the power cord at 50Hz, and the correlation is linear as predicted in [10].

Voltage sensor is characterized by connecting the power cord with the household 230V 50-Hz power outlet in an open-loaded state. The input voltage to cord is varied by autotransformer and we get respective output voltage at voltage sensor. This voltage in the neutral line sense by voltage sensor is the induce voltage from fire line which is very small. Hence for voltage sensor we will get very small change in output voltage with respect to large change in input voltage. Figure 8 shows the output signal of the voltage sensor versus the different input voltage applied on the power cord at 50 Hz.

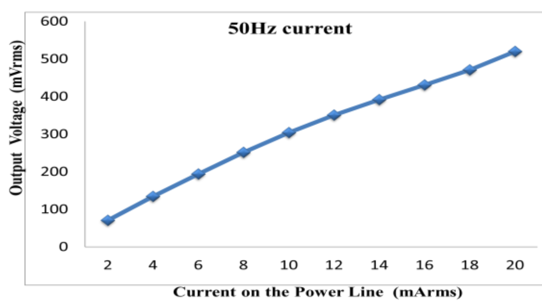


Figure 7. Measured output voltage of the current sensor versus different input current at 50 Hz in the tested power line.

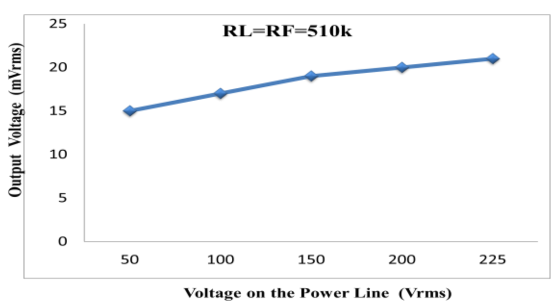
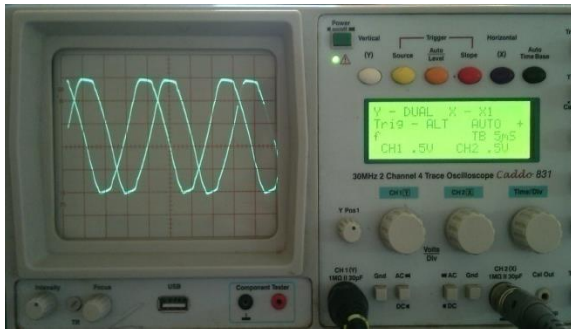


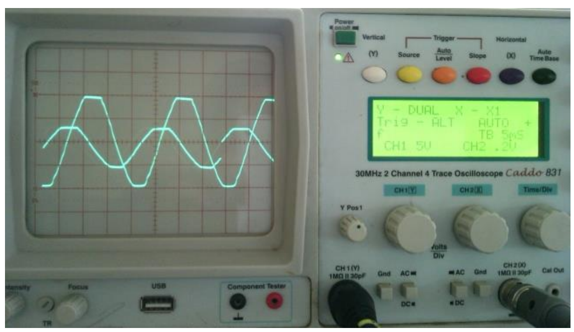
Figure 8. Measured output voltage of voltage sensor verses different input voltage at 50Hz in the tested power line.

The voltage in the power cord loaded with 40W bulb is also displayed on LCD display. For this the microcontroller ATmega16 is used. It is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega16 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed. After that we have to initialize the LCD which interface with the microcontroller through the port C. For 40W bulb the voltage in SWG-30 power cord is shown on LCD is 2.285mV.

The successful interference reduction in current measurement is carried out using scheme as shown in figure 5 and results shown on CRO. Figure 9 (a) shows the Waveforms of the current sensor by sensing the power cord loaded with household 230V 50-Hz supply with interefence and 9(b) shows the waveforms of current sensor by sensing the power loaded with 230V 50Hz supply after interference reduction.



(a)



(b)

Figure 9. (a) Waveforms of the current sensor by sensing the power cord loaded with household 230-V 50-Hz supply with interference. (b) Waveforms of the current sensor by sensing the power cord loaded with household 230-V 50-Hz supply after interference reduction.

With the design of a inductive coil and 80 turn copper coil antenna in an small area the sensor via the reading circuit exhibits a sensitivity of 28.52 mV/mA and 0.13 mV/V for detecting 50-Hz electric current and voltage, respectively. Also provides successive interference reduction in current measurement.

V. CONCLUSION

In this paper, the electricity monitoring of household appliances using a current and voltage sensor tag with an interference reduction scheme has been successfully demonstrated. The current and voltage sensors operated by Faraday’s induction law and sensing electromagnetic field principle, respectively. The characteristics of lower manufacturing cost, better reliability, and easier implementation shows the potential of the nonintrusive current and voltage sensor tag for widespread power detection of household appliances.

VI. FUTURE WORK

For future research EMI/EMC (Electromagnetic interference/ Electromagnetic compatability) related problems can be solved using the current and voltage sensors.

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