Microcontroller based design of Power Meter

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Abstract: This paper presents a design of an affordable and convenient means for consumers to accurately measure the power consumption of the electrical devices. If a consumer is able to measure the AC power drawn from a particular household circuit, then they would be able to calculate the cost of operating that piece of equipment. Comparisons could then be made between similar machines, to see which consumes the most energy. In addition, the meter could facilitate troubleshooting a device that may be causing problems (i.e. frequently tripping a breaker). Therefore, the design must be flexible enough to accommodate measurements over a range of devices found in the average home. In addition, the power factor must be known in order to accurately calculate the average or real power. The meter should be able to sense values up to 15 A, to accommodate a range of typical household devices. An 8-bit C programmable microcontroller will calculate the power from the voltage and current measurements and act as the control device for the meter. A 9 V alkaline battery will be used as the power source. The output will be a 4-digit LCD to provide the minimum display accuracy needed for the required maximum power measurement and energy measurements. Finally, the meter should be an inexpensive and lightweight package, that is portable and easy to set up. The two sensing circuits will take the voltage off the terminals of the plugged-in device. These signals are divided down, sampled at 1 kHz by a CMOS A/D converter, and then manipulated by software in the microcontroller for power calculation. The microcontroller will use the first zero-point of the current signal as a reference to calculate the phase angle, and then subsequently, the power factor and the average or instantaneous power depending upon the function chosen. The average consumer has little practical knowledge concerning their own power usage or a means to safely determine it. Microcontroller-based embedded systems allow for accurate and stable measurements in an affordable and flexible design. The meter’s flexibility could be expanded to include devices with high start-up power requirements (e.g. motors) or large harmonic distortion or even some industrial applications. Also, adding a standard serial computer interface could allow integration of the measurements with software or modification of the design in circuit with little or no additional costs. If needed, the meter design could also be altered to accommodate other standards.

KEYWORDS: power meter, microcontroller, embedded systems, sensing circuits, A/D converter.
I. INTRODUCTION

Power consumption is a major concern for both the private citizen and industry alike. Nearly all appliances and machinery are powered by electricity supplied at a kilowatt per hour rate from an electric utility company. It then follows that the time over which power is consumed when operating a device equals money. Due to this unavoidable cost, there is a need for an accurate and affordable means of determining the amount of energy consumed by a particular device. The power meter provides an independent and tangible means of estimating energy costs per device basis. The ability to calculate energy consumption and its associated costs, perceivably, has numerous applications of both technical and economic importance to consumers. This work converts a power meter into a useful aid for the consumer. The objective of the power meter is to perform quick and cost effective measurements and provide meaningful results that the layman can understand. This will be done by basing the design on a microcontroller that can make the necessary calculations and provide excellent functionality. The meter should aid in lowering the average household’s electric bill. Also, the meter should aid in troubleshooting problem circuits, in making decisions about which piece of equipment to use and for how long, or even in making decisions about whether or not to upgrade an older device. As technology advances, digital power meters networked to the utility company are becoming more favorable because they allow instantaneous and remote monitoring; or in other words, they eliminate the need to travel to a location to physically read the meter. In addition, digital power meters allow measurements not only of a location but also of particular devices within a location.

II. SYSTEM LAYOUT AND COMPONENTS

The overall design is shown in Figure (1) below. The design is broken into four phases. The first phase consists of designing the voltage sensing and the current-sensing circuits. The second phase will be the A/D conversion of the sensed signals. The A/D converter converts the AC coupled voltage and current into DC voltage and current in order for the third stage, the microcontroller, to calculate, update, and store energy consumption over a specified time period. The leads to the fourth and final phase where the microcontroller sends its results to a 4-digit, low-power consumption, one-line LCD display. The display will toggle through different modes to show one-word messages, elapsed time, and measurements and their units.
The hardware system components implemented in the design are:

Liquid Crystal Displays (LCD):

LCD (Liquid Crystal Display) screen is an electronic display module. A 16x2 LCD display is used. The data register stores the data to be displayed on the LCD. The data is the ASCII value of the character to be displayed on the LCD.

Microcontroller:

A microcontroller (sometimes abbreviated µC, uC or MCU) is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Atmega 16 microcontrollers is used in the circuit design.

Voltage sensing circuit:
The voltage-sensing circuit cannot withstand the Vrms input signal. The input voltage is stepped down by a voltage divider as shown at the front end of the circuit in Figure (2).
The differential amplifier (DA):
The DA is designed so that the only scaling factor involved will be 36 from the voltage divider. To ensure unity gain the equation (1) is used:

\[ V_0 = \alpha \left(1 + \frac{2}{R_2} \right) (V_2 - V_1) \]

Where: \( \alpha = \frac{R_2}{R_1} \)

The scaling factor involved to get a decimal number that corresponds to the input voltage should be divided by \( \sqrt{2} \) in order to arrive at the proper value for calculation which corresponds to the input into the voltage-sensing circuit.

Current sensing circuit:

The current-sensing must also be non-intrusive. Ideally, this means that the sensing circuit can draw no current itself, otherwise, the sensing circuits would then add to the load being tested and cause an inaccurate reading by reading the power being consumed by both the equipment being measured and the sensing circuit. To meet this requirement op-amps will be used with high input
impedances that are ideally infinite and therefore allow virtually no current to pass through the sensing circuit. A precision resistor will take the current being drawn by the load. Again this is due to the need to make a non-loading measurement. Due to the range of measurement a fuse will be implemented at the input. These are all factors that had to be satisfied when designing the current-sensing circuit. The circuit had to be non-intrusive and therefore not cause a loading effect on the circuit or device being tested. Therefore, this circuit is also based on the Instrumental Differential Amplifier (IDA) because of its high input impedance. This high input impedance allows a negligible effect on the load to be measured because it results in virtually no current flowing into the op-amps. The current-sensing circuit is placed in series with load being tested in order to make its current measurement.

![Image](image_url)

Figure (3) The current-sensing circuit.

The voltage across the Rsense resistor is input into the IDA, which has unity gain. This effectively makes the voltage sensed equivalent to the current drawn by the load as shown by Ohm’s Law, \( V = IR \), where \( R \), in this case, is equal to \( R_{\text{sense}} = 1 \ \Omega \). Thus, the relationship is essentially \( V = I \).

To achieve unity gain equation(1) will be used: The values for all the resistances are also shown in figure (2). The current sensing circuit is actually designed to output a one to one ratio to the input signal. An input of 5 Vp-p into the A/D converter corresponds to a 11111111 binary output.

. Analog to digital converter (A/D):
The A/D converter transforms the analog signal into a digital value.
III. Power Factor and energy measurement

The average or real power is given by equation (2).

\[ P = (V_{\text{rms}} \times I_{\text{rms}}) \times pf \]  

Where: the power factor \( pf = \cos(\Phi_V - \Phi_I) \).

In order to calculate power factor, the phase angle must be known. The following equations (3,4,5) may be used to calculate the power factor (pf):

\[ \alpha = \omega \times \text{disp} \text{ (in rad/s)} \]  
\[ \cos(\alpha) = 1 - \frac{\alpha^2}{2!} + \frac{\alpha^4}{4!} - \frac{\alpha^6}{6!} + \ldots + (-1)^k \frac{\alpha^{2k}}{2k!} + \ldots \]  
\[ pf = \cos(\alpha) \]

Now that the basis for calculation has been defined, a software program may be written to implement it. The microcontrollers code segment results in the following code segment:

```c
// This segment calculates power factor
alpha = 2*Pi*Freq*disp;
pf = cos(alpha)
```

Energy measurement is primarily what the power meter is made for. The calculation of the average power over a specified time period, the energy consumption of a device, will be carried out by continuously updating the power calculation as new inputs of voltage, current, and displacement are obtained.

IV. ALGORITHM

Bascom programming language is used in programming the microcontroller. Pony Prog program is used to download the (.hex) file into the microcontroller. The algorithm for the energy measurement is:

Start
Initialization:
..... Initialize timer (for T minute).
..... Initialize average = 0.
Data acquisition:
..... Acquire the voltage value.
..... Acquire the current value.
..... Calculate the power factor (pf).
..... Apply the formula to calculate the real power \( P = (V_{\text{rms}} \times I_{\text{rms}}) \times pf \).
V. RESULTS

The electronic circuit function is to display the energy consumption of the electrical appliances. Table (1) below shows the results when operating the circuit.

Table (1) The results when operating the circuit

<table>
<thead>
<tr>
<th>Sampled Voltage (Vp-p)</th>
<th>Scaled Voltage (Vp-p)</th>
<th>Sampled Current (A)</th>
<th>Scaled Current (A)</th>
<th>Power (W) (Assuming constant pf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>89</td>
<td>62.933</td>
<td>94</td>
<td>11.059</td>
<td>695.96</td>
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<tr>
<td>166</td>
<td>117.380</td>
<td>175</td>
<td>20.568</td>
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<tr>
<td>219</td>
<td>154.856</td>
<td>231</td>
<td>27.176</td>
<td>4208.37</td>
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<td>171.120</td>
<td>255</td>
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<tr>
<td>130</td>
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<td>243</td>
<td>28.568</td>
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</tr>
<tr>
<td>187</td>
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<td>117</td>
<td>82.731</td>
<td>123</td>
<td>14.171</td>
<td>1197.20</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

The power meter, at a consumer level, could prove to be a boon for the electrical energy knowledge of the layman. A consumer is not going to keep an appliance if the consumer knows that he can upgrade the appliance to one that does not consume as much energy. This upgrade results in a lower utility bill for the consumer as well as energy conservation in an indirect way. The average consumer may not understand exactly how much a piece of equipment costs to run. Indeed, it seems that most consumers only realize how much it costs to power their household for a month, and this monthly cost is provided by the power company. Yet, by providing a means of measuring power on an individual appliance level, the consumer can cut their costs by making more educated decisions about equipment operation. The design is an inexpensive product to cut utility bills down and help the world conserve energy.
REFERENCES:


