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A Single Phase Microcontroller Based Energy Meter

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Abstract ***- This paper presents a single phase electrical energy meter based on a microcontroller from Microchip Technology Inc. PIC family. This electronic meter does not possess any rotating parts, and the energy consumption can be easily read from a four digits display. Besides that, energy consumption is stored in the microcontroller's EEPROM memory. This action is necessary to ensure a correct measurement even in the event of an electrical outage or brown out. As soon as the supply is restored, the meter restart with the stored value. As this meter is compatible with the electromechanical ones, no additional costs will be incurred by the utility companies in their replacement. A single-phase energy meter prototype has been implemented in the lab to provide measurement up 10A load current from a 127V line voltage. The observed accuracy was better than 97%.***

I. INTRODUCTION

The electrical energy meter manufactures have focused their research effort towards the development of modern and more precise energy meters for large customer, where the added precision justifies the necessary investment. As a result, electromechanical energy meters remain pervasive for residential application [1,2,3].

However, the advent of low cost microcontrollers enables the development of a cost effective electronic electrical energy meter for residential use as well. As the electronic version does not possess rotating parts, it helps in avoiding tampering by unscrupulous persons. Furthermore, for large scale manufacturing, the costs can become lower than those of the electromechanical meters currently in production.

This paper presents a totally electronic single phase energy meter for residential use, based on Microchip Technology Inc. PIC family of microcontrollers [4][5]. The design takes into consideration the correct operation in the event of an outage or brown out, by recording the energy consumption in EEPROM memories internally available in the microcontroller. When the supply is restored, the energy consumption computation is properly initialized. Also, a four digit display is used to show the energy consumption.

A prototype has been implemented to adequate measurement up to 10A load current from a 127V (phase to neutral) voltage. Higher current capacity can be easily obtained by simply replacing the shunt resistor. Also, by changing the transformer tap and the voltage divider ratio, it can be easily modified for use in a 220 V supply.

II. ELECTRICAL ENERGY COMPUTATION

Equation (1) is the basis for the computation of the energy consumption (E) of any given load during a time interval Δt (= t2 - t1):

$$E = \int_{t1}^{t2} v(t)i(t)dt \qquad (1)$$

where v(t) is the supply voltage and i(t) is the load current.

In actuality, a discrete version of Equation (1) is used, where the voltage and current signals, after proper conditioning, are sampled and converted to digital form by an 8 bits A/D converter [6], operating at a sampling frequency of 1,082 kHz. The voltage and current sampled values are transferred serially to the microcontroller.

The microcontroller processes and stores the energy consumption. The energy is compared to a reference value (Eref) set during the calibration process, where, for a 1kW load, the consumed energy is calculated and accumulated (integrated) for 100 periods of 924μs (a program cycle). The following equation shows the computation of the Eref value:

$$E_{ref} = \frac{100 \cdot 924\mu s \cdot 1000W}{3600s} = 0{,}00002567\,\text{kWh} \qquad (2)$$

When the Eref value is reached, a counter is incremented and the comparison restarts. When this counter reaches the limit value of 38961, the value of energy consumption, expressed in kilowatts, is incremented by one, and the counter is reset.

The energy consumption is indicated by a four digits display. This display works on a time sharing operation, where each digit is individually turned on for five program cycles (4,62ms), that is sufficiently fast for the human eye to perceive, hence no flickering is detected.

III. MICROCONTROLLED ENERGY METER DESCRIPTION

A. General Overview

A general overview of the microcontrolled energy meter can be seen in the block diagram shown in Fig. 1 below:

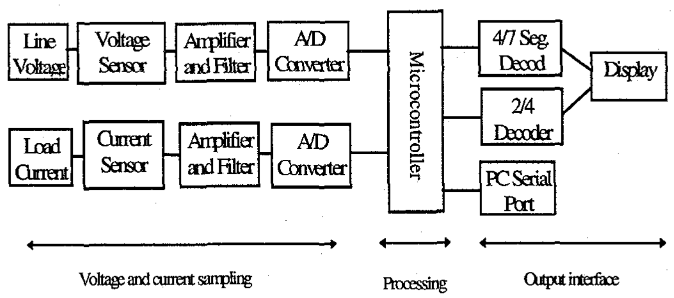

Fig. 1. Microcontrolled energy meter block diagram.

A description of individual blocks will be provided next.

B. Voltage Sensing Circuit

The supply voltage is first attenuated by a voltage divider (R1 and R2), and next processed by a second order low-pass filter (R3, R4, C9, and C10). A high-pass ,first order filter (R5 and C11) is next used to eliminate any DC component eventually present in the signal due to offsets.

The selected A/D converter (ADC0831) requires an input voltage in the [0, +5V] range, and therefore a level shift op-amp (TL084) is used to introduce an 2.5 V DC offset in the filtered voltage signal, (due to R6/R7). A gain of 1.212 (1 + R6/R7) is also introduced, since a non-inverting configuration is used here.

The voltage divider was designed to produce a peak voltage of 2.0 V at the high pass filter output, for an $127\sqrt{2}$ V input peak voltage. After the 2.5 V level shift and the 1.212 gain are introduced, the final value of 5.0 V is obtained for the positive peak voltage. The corresponding circuit diagram is shown in Fig. 2.

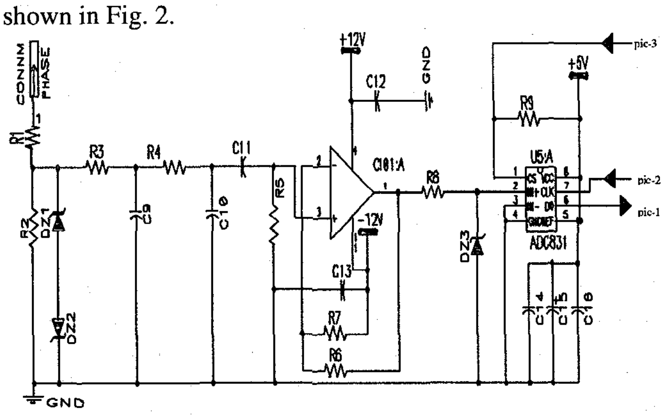

Fig. 2: Voltage sensing circuit.

C. Current Sensing.

Fig. 3 shows the current measurement circuit, where the current signal is obtained from a 10 mΩ shunt resistor due to cost considerations, when a maximum current of 10 A rms has been assumed. To prevent noise problems, a non-inverting, unity gain differential op-amp has been selected. Its output is passed through a second order low-pass filter and fed to a two-stage amplifier. The first one introduces a gain of 14.6, whereas the second one is responsible for the introduction of the 2.5 V offset and the additional gain of 1.212, similar to the voltage sensing circuit. The overall gain was selected to produce an output voltage of 5.0 V for a peak load current of $10\sqrt{2}$ A, that is fed to the ADC0831 converter input.

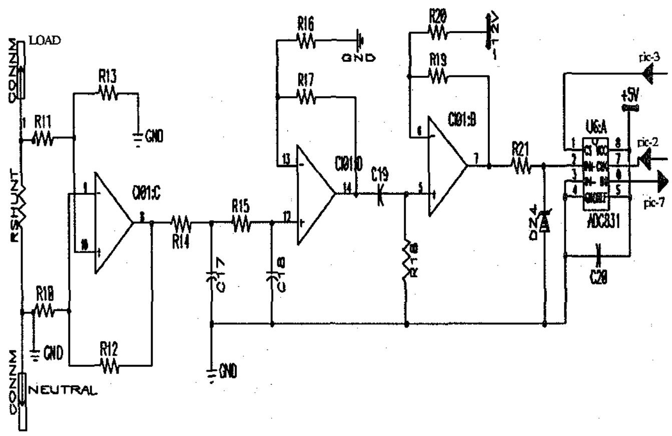

Fig. 3: Current sensing circuit diagram.

D. The microcontroller

The selected microcontroller was the PIC16C84 from Microchip Inc. [4] [5], that possesses relevant characteristics for the current application, such as low cost, EEPROM memory, that stores the measured energy value even in the presence of a power outage. It is a high performance microcontroller, that utilizes CMOS technology and have a RISC type architecture. Internal 1024 x 14 EEPROM program memory and 64 x 8 bytes EEPROM data memory are standard. It can be programmed in C language, by utilizing a C compiler developed for this family of microcontrollers by Paralax Inc. [7]. A maximum clock frequency of 10 MHz is possible, but in this circuit a 4.43 MHz clock was selected due to design considerations.

An 8 bit timer/counter with an 8 bit pre-scaling register (that effectively results in a 16 bit counter) is present, as well as 13 bi-directional I/O ports. Its I/O ports are capable of handling up to 25mA current (input) and 20 mA (output), what significantly reduces the need for extra interface circuits, such as buffers.

E. Microcontroller Auxiliary Circuits.

Fig. 4 shows the circuit diagram of some additional circuits, required for the proper operation of the meter.

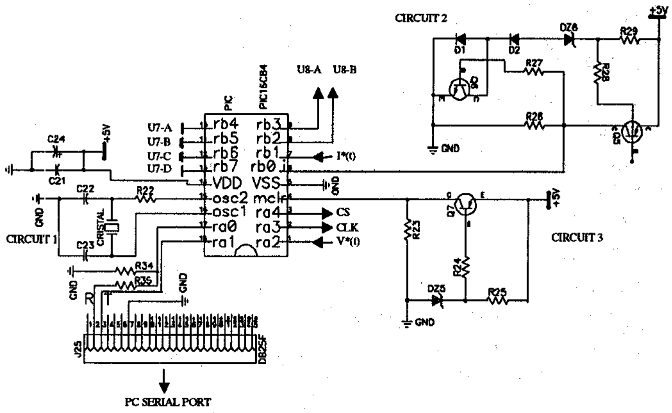

Fig. 4: Microcontroller and auxiliary circuit diagram.

1) Oscillator Circuit (circuit 1)

This circuit determines the PIC16C84 clock frequency. The capacitor and resistor values are those recommended by the manufacturer for the desired clock frequency.

2) Supply Voltage Level Detector (circuit 2)

This circuit is extremely important for the proper operation of the energy meter. If the PIC supply voltage becomes less than 4.2 V (probably due to an outage or line voltage sag), this circuit changes the external interrupt port RB0/INT (pin 6 of PIC) input from 5V to 0. This forces a program interrupt to occur, that activates the sub-routine that stores the energy consumption value into the microcontroller EEPROM, and next causes the program to go to a background loop, until the normal line voltage is reestablished. This is recognized by a voltage greater than 4.8 V at the external interrupt port, that makes the program to leave the background loop and resume the normal processing. In the event that the microcontroller supply voltage becomes less than 3.9 V, the disabling circuit is activated, what is explained next.

3) Disabling Circuit (circuit 3)

This circuit has been suggested by the PIC 16C84 manual, and termed Brown Out Protection. It works by rapidly disabling the PIC in the event the supply voltage becomes less than a pre-defined level (in this case, 3.9 V). This circuit prevents the PIC to work with low voltages levels, close to the minimum allowable value.

4) Microcomputer-energy meter serial interface circuit

In order to execute the calibration subroutine, the keyboard and visual interfaces are required. This is accomplished by using a RS232 serial communication with the microcomputer that runs the Windows Terminal program. This program is responsible for the control of the computer serial port with the PIC.

The meter calibration is a two-step process.: the first one is the acquisition by the converters, of the sample voltage and current signals corresponding to a zero input condition. This value will be next used to eliminate offset from the actual measurements. The second one consists in the calibration per se, when a 1 kW standard load of unity power factor is employed to derive the correct scaling factors.

F. Energy Consumption Display Circuit

This circuit makes use of standard 7-segments digital displays. This configuration, besides its low cost, makes it easy to read the current energy consumption. This circuit makes use of a 4/7 bits decoder, that defines which number will be displayed in the particular display. Besides this one, another 2/4 bits decoder is also required, in order to make the time sharing display, such that the each display is active during five program cycles. This latter decoder was required due to the limited number of output ports available in the PIC. The circuit diagram of the display circuit is shown in Fig. 5.

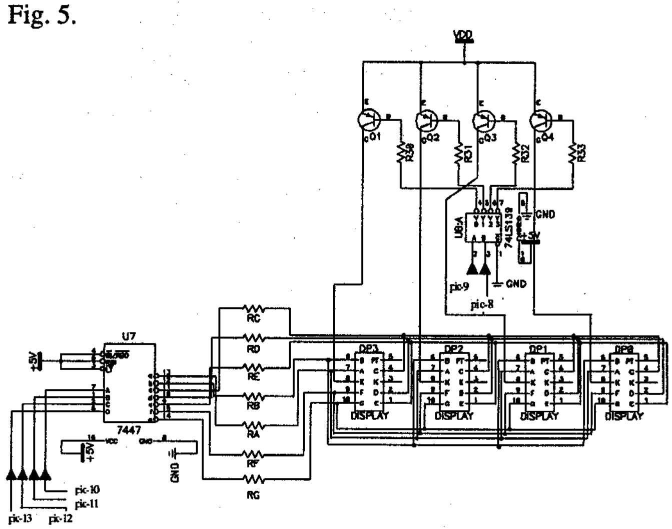

Fig. 5: Energy consumption display circuit diagram.

IV. ELECTRICAL ENERGY MEASUREMENT PROGRAM

The electrical energy measurement program was developed on a dedicated C Language compiler from Parallax Inc.[7]. Assembly language [5] was also used for time critical routines. The Electrical Energy Measurement Program flowchart is showed in Fig. 6.

V. EXPERIMENTAL RESULTS

To validate the proposed energy meter, several experimental tests were carried out. The single-phase prototype was initially calibrated using a 1kW standard load of unity power factor. Some experimental results were obtained to verify the meter precision, as shown in table I .

Table I - Experimental precision assessment

Load	Actual Time	Measured Time	Error (%)
1kW	3600s	3643s	1,19
0,75kW	4800s	4769s	0,65
0,5kW	7200s	7304s	1,44
0,33kW	10800s	10855s	0,5
0,25W	14400s	14635s	1,63
0W *	36s	36,01	0,03

*The meter was calibrated at no-load (0W), but emulating a 1kW load, since it is a faster way to verify the measurement program stored on microcontroller. The meter should increment the total energy consumption by 1kW every 36s.

VI. CONCLUSION

This paper has demonstrated the possibility of measuring the electrical energy consumption with a microcontroller based meter, as an alternative to the conventional electromechanical meters.

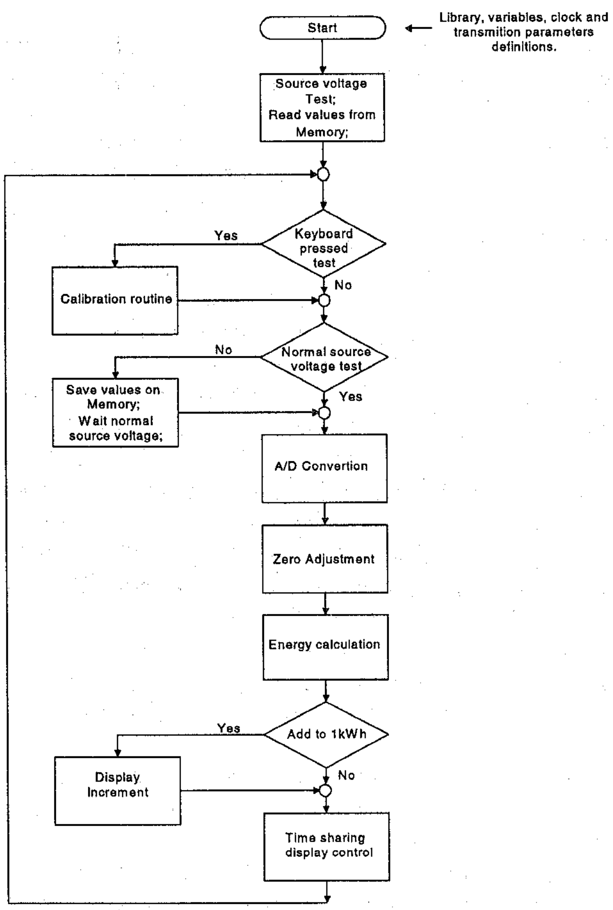

Fig. 6 - Electrical energy measurement flowchart.

The microcontrolled meter does not posses rotating parts, what helps in the prevention of frauds due to tempering, that is per se an attractive feature for the utilities. Furthermore, it is estimated that this new meter might have a production cost lower than that of an electromechanical meter. The estimated costs is around U$ 15,00 when mass produced.

The precision experimentally obtained for this new meter better than 97%. This value is compatible with the electromechanical meters in the market. In addition, the process of reading the energy consumption is facilitated by the four-digit display, that is simpler than that for the analog meters. The calibration process is implemented by using a RS232 interface from any microcomputer that runs the Windows Terminal program. This communication form is simple, since it makes use of the basic configuration available in the microcomputers.

It is worth saying that, in order to increase the meter current capacity, it is only required to reduce the shunt resistor value, in the current sensing circuit, whereas in order to utilize it in a 220 line, it is sufficient to change the voltage divider circuit. Of course, the basic principles used here can be easily extended to the case of three-phase meters as well.

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