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ACCURATE MEASUREMENT OF THE MAINS FREQUENCY

D. Ibrahim

Biomedical Engineering Department, Near East University, Lefkosa (Nicosia), Northern Cyprus
dogan@neu.edu.tr

Abstract- Mains frequency varies around the world. Some countries have adopted 50 Hz as the standard, while some other countries use 60 Hz. The accuracy of the mains frequency is very important in many industrial and commercial applications. This paper describes the design of a microcontroller based system for measuring the mains frequency accurately.

Keywords: Mains Frequency, Frequency Measurement, Microcontroller Application.

I. INTRODUCTION

There are several mains power systems in use around the world [1]. These different systems are characterized by their:

- Voltage
- Frequency
- Type of plugs and sockets used

In general, the type of plugs and sockets used is not a problem and passive adapters are available to convert between different varieties as long as the voltage and frequency are correct for the electrical device to be used. In general, we can divide the mains voltage and frequency usage in the world into four groups:

- 100-127 V, 50 Hz
- 100-127 V, 60 Hz
- 220-240 V, 50 Hz
- 220-240 V, 60 Hz

The voltage quoted is the root mean square, and the peak voltage can be calculated by multiplying the voltage with $\sqrt{2}$ or the peak-to-peak voltage is found by multiplying with $2\sqrt{2}$. The frequency used in mains electricity is either 50 Hz (20 ms period) sinusoidal or 60 Hz (16.66 ms period) sinusoidal. Table 1 gives a short list of some of the mains voltages and frequencies used around the world.

Some of the appliances we use at home may be affected if the mains voltage is not correct. For example, the motor speed of some CD players may be affected even though the motor supply voltage is regulated. The result of this is that the music can play slightly slower or faster. Also, some more sensitive appliances such as televisions may not operate correctly if the mains voltage is lowered.

Table 1. Mains voltages and frequencies around the world

Country	Voltage	Frequency
Argentina	220 V	50 Hz
Australia	230 V	50 Hz
Belgium	230 V	50 Hz
Canada	120 V	60 Hz
Denmark	230 V	50 Hz
Egypt	220 V	50 Hz
France	230 V	50 Hz
Germany	230 V	50 Hz
India	230 V	50 Hz
Israel	230 V	50 Hz
Libya	127 V	50 Hz
Portugal	220 V	50 Hz
Turkey	230 V	50 Hz
UK	240 V	50 Hz
USA	120 V	60 Hz
Venezuela	120 V	60 Hz

As the demand on the electricity supply increases the frequency usually drops. The electricity suppliers monitor the mains frequency constantly and aim to keep it within the allowed tolerances. A change in the mains frequency has negative effects in some of the appliances. For example, the speed of AC synchronous motors depend upon the supply frequency, and any appliance such as a turntable using such a motor will run slower or faster depending upon the changes. Also, some home or industrial clocks operate by counting the mains pulses, and such clocks will run slower or faster depending upon the changes in the supply frequency.

II. MONITORING THE MAINS FREQUENCY

In many applications it is important to know the quality of a power generating system [2], and be able to control the load frequency [3]. The mains frequency can in practice be measured using a simple frequency counter. But here the problem is that we need to measure very small changes, in the order of less than 0.01% and the cost of frequency counters to measure such small changes are rather high. In addition, we usually want to log the variations of the mains frequency over long periods of time and then to analyze these changes by for example plotting the results. Most low cost frequency counters are not capable of logging the frequency changes.

In this paper, the design of a microcontroller based accurate mains frequency measuring and logging device is given. The device has an LCD display that shows the changes in real-time. In addition, the frequency data is sent to a PC over the RS232 serial port and stored in a file on the PC. The stored data can easily be analyzed for example by plotting it or by using a statistical analysis package such as Excel.

III. THE HARDWARE

There are basically two methods used in the literature for frequency measurement [4]. The first method, which is not accurate, involves setting up a time window and calculating the number of cycles within this window. The second method which is more accurate and is the one used in this paper, involves calculating the period of the waveform. Here, basically an accurate timer is used to measure the period and hence calculate the frequency of the waveform.

The block diagram of the designed mains frequency monitoring device is shown in Figure 1. The operation of the device is based on a near-zero-cross-detector circuit [5]. Mains supply is reduced to 9 V using a wall mains adapter. As shown in Figure 2, the near-zero-cross-detector circuit is made up of a bridge rectifier and a transistor. Full-wave rectified mains signal is applied to the base of the transistor. The transistor is normally on and its output is low when the signal is high. As the signal drops to 0.7 V, the transistor turns off and the collector voltage rises to the supply voltage (+5 V), generating a pulse. Figure 3 shows the rectifier output and the transistor output. As shown in the figure, three such pulses are obtained during a full period of the mains frequency. These pulses are then fed to one of the inputs of a PIC microcontroller [6]. The microcontroller starts an accurate timer when a pulse arrives. The timer is stopped at the arrival of the third pulse. Thus, the timer count is proportional to the period and hence to the frequency of the waveform. This timer count is converted into real frequency and is displayed on an LCD display. In addition, the data is sent to a PC using the serial RS232 port. A Visual Basic program [7] on the PC receives the frequency data, time stamps the data and then stores it in a file. The frequency data can be displayed and analyzed by importing it into Excel.

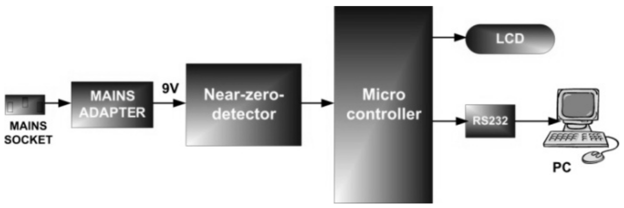

Figure 1. Block diagram of the frequency monitoring device

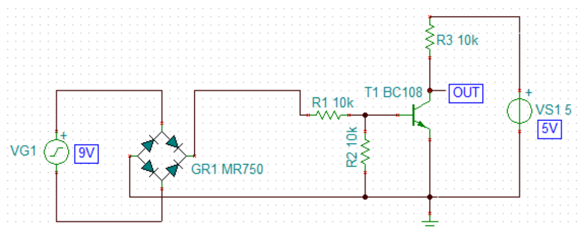

Figure 2. The near-zero-cross-detector circuit

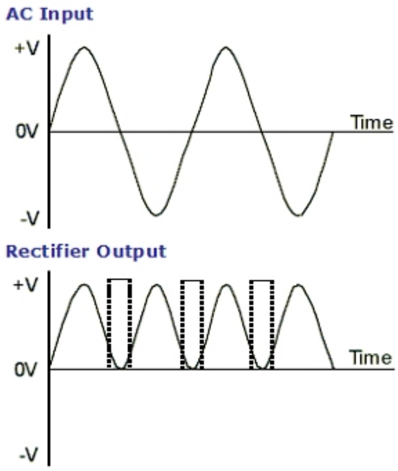

Figure 3. Pulses are obtained in one cycle of the mains waveform

The near-zero-cross-detector circuit generates pulses at the same near zero points of the waveform, thus making it possible to accurately measure the signal period. Figure 4 shows simulation of the near-zero-cross detection circuit. The circuit was simulated using the popular TINA circuit simulation suite [8], developed by DesignSoft. Figure 4 shows the rectified full-wave mains waveform together with the output pulses of the near-zero-detector circuit on a virtual oscilloscope of TINA.

Figure 5 shows full circuit diagram of the device. A PIC18F4520 microcontroller is used in the design with the timing provided with an 8MHz crystal. PORT B of the microcontroller is connected to a 2x16 LCD display. UART output pin (RC6) is connected to a MAX232 type RS232-TTL converter chip and then to the PC serial port via a 9-pin D-type connector. Output pulses of the near-zero-detector circuit are fed to port pin RC2 of the microcontroller.

The project was built and tested using the EasyPIC6 microcontroller development board [9]. EasyPIC6 (see Figure 6) is a low-cost highly powerful microcontroller development board. The board has the following basic features:

- Support for most types of PIC microcontrollers
- On-board programmer
- In-circuit debugger (mikroICD)
- 2x16 text LCD
- 2x16 COG LCD
- 128x64 graphics LCD
- LCD touch controller
- 36 LEDs
- 36 push-button switches
- DS1820 temperature controller chip
- RS232 connector
- USB connector
- PS/2 connector
- Port expander module
- I/O edge connectors

A small breadboard was used to construct the near-zero-detector circuit.

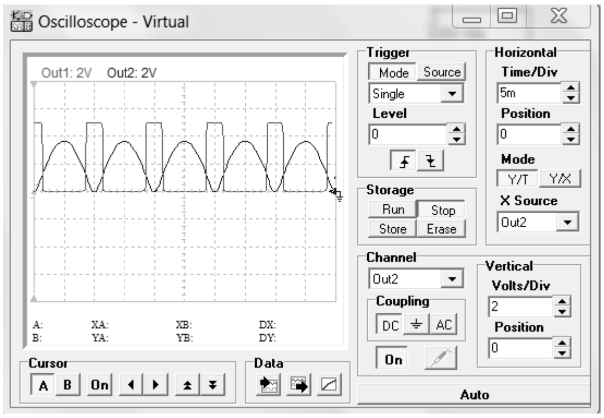

Figure 4. Simulation of the near-zero-detector circuit

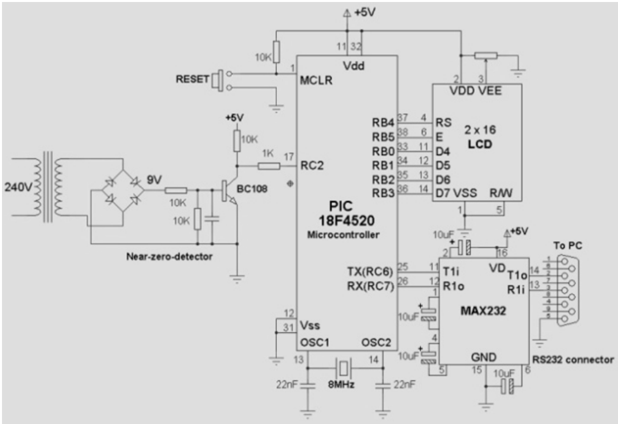

Figure 5. Circuit diagram of the monitoring device

IV. OPERATION IN DETAIL

The output pulses of the near-zero-detector circuit are counted using 16 bit timer/counter TMR1 of the microcontroller. With an 8 MHz crystal, the counting period is 0.5 μs and maximum count is 65535. In a perfect 50 Hz signal, with 20 ms period, the maximum count will be 40,000. Table 2 shows the counter values at different frequencies of the mains supply. The frequency (f) of the waveform is then given in Hz by:

$$f = \frac{2\times 10^6}{count} \tag{1}$$

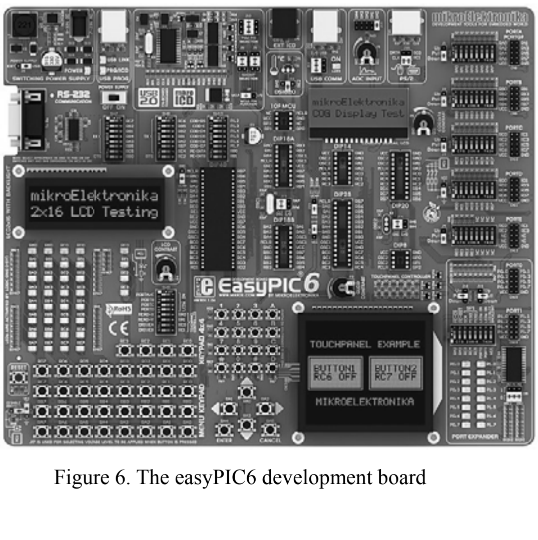

Figure 6. The easyPIC6 development board

By considering that a difference of one count can be measured, the accuracy of the frequency measurement is then given by approximately 0.001 Hz or 0.002%.

Table 2. Frequency and counter values

Frequency (Hz)	Counter value
49.0	40816
49.2	40650
49.4	40485
49.6	40322
49.8	40160
50.0	**40000**
50.2	39840
50.4	39682
50.6	39525
50.8	39370
51.0	39215

V. THE SOFTWARE

The software consists of the microcontroller software (or the measuring software), and the PC software (or the data logging software).

A. Microcontroller Software

Figure 7 shows operation of the microcontroller software. Counter TMR1 is cleared and internal counting starts on the high-to-low transition of the input pulse on pin RC2. The counting continues until the third pulse is detected, and stops on the high-to-low transition of the third pulse.

The frequency is then calculated using the equation given above. Floating point calculations are used in the program for high accuracy. The calculated frequency is displayed on the LCD as well as it is sent to the PC over the serial link. This process is repeated forever with a 5 second delay between each measurement. Parts of the program are written in Assembly language so that the pulse edges can be captured accurately. Figure 8 shows a typical display of the measured frequency.

```
BEGIN
        Initialise global program variables
        Configure LCD
        Configure UART
        DO FOREVER
                Wait for first rising edge of the pulse
                Clear timer/counter TMR1
                Start timer/counter TMR1
                Wait for second rising edge of the pulse
                Wait for third rising edge of the pulse
                Get timer/counter value
                Calculate the frequency
                Display frequency on LCD
                Send frequency to RS232 port
                Wait 5 seconds
        ENDDO
END
```

Figure 7. Operation of the microcontroller software

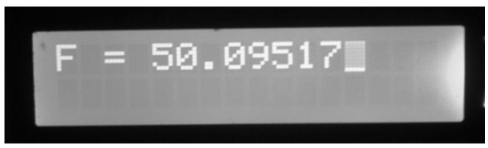

Figure 8. Typical display of the measured frequency

The microcontroller software is based on the mikroC language [9]. mikroC is a highly popular and powerful C programming language, developed for the PIC microcontrollers. The language includes an extensive set of library functions to enable the user interface various external devices to microcontrollers.

B. PC Software

The PC software reads measured frequencies from the microcontroller, inserts the current date and time, and then stores the time-stamped data in a file on the PC for offline processing. This program is based on Visual Basic 6. The user starts and stops data logging by clicking the appropriate buttons. Data is stored with the fields being separated with a comma so that it can easily be imported to other programs. Figure 9 shows a typical plot of the collected data after it is imported into Excel. This data was collected in the TRNC after a 24 hour collection period in March 2011.

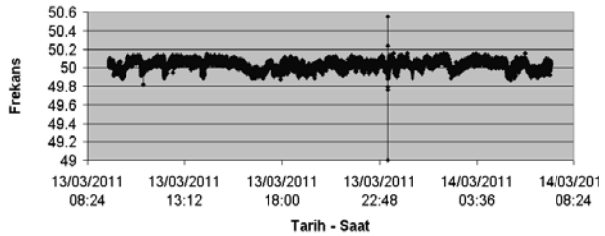

Figure 9. Plotting the collected data using Excel

VI. CONCUSSIONS

This paper has described the design of a highly accurate microcontroller based device for measuring the mains frequency. The frequency is displayed on an LCD every second and is also sent to a PC for logging and offline analysis. It is also possible to save the data locally on an SD card type storage by simple modifications to the circuit and the software, thus making the system independent of any external processing. The collected data can easily be displayed on a graphic LCD. The data is saved in such a format that it can be analyzed statistically, and also plotted using the standard statistical packages, such as Excel. The collected data should be useful in determining any problems within the power generating plant. The novelty of this paper is that a very low-cost and highly accurate technique is described for measuring the mains frequency.

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BIOGRAPHY

Dogan Ibrahim was born in Nicosia, Cyprus, 1954. He received the B.Sc. degree in Electronic Engineering from the University of Salford, the M.Sc. degree in Automatic Control Engineering from the University of Manchester, and the Ph.D. degree in Digital Signal Processing from the City University, all in UK. Currently, he is a Professor in the Department of Biomedical Engineering at the Near East University, Lefkosa, Northern Cyprus. He is the author of many technical books and several hundred technical papers and conference proceedings. His interests are in the field of digital signal processing, automatic control engineering, and biomedical sensors. He is on the advisory board of several technical journals. He is a Fellow of the Institution of Engineering and Technology (IET), and a chartered electrical engineer.