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AC POWER MONITORING DEVICE BASED ON MC9S08GB60 MICROCONTROLLER

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Abstract: *Paper proposes hardware and software design of alternate current power monitoring device based on 8-bit general purpose MC9S08GB60 microcontroller by Freescale Semiconductor. It is fully adapted to achieve measurements of true RMS values of voltage and current, real power and power factor by utilization of integral evaluation which is fully independent on the course of measured voltage and current. Developed evaluation software is able to visualize all measured quantities in user friendly graphical user interface. It communicates with meter via RS232 serial interface.*
Key words: *Microcontroller, MC9S08GB60, true power, apparent power, power factor*

1. INTRODUCTION

Electric equipment connected to the electrical power system can be divided into two basic categories. Devices that have the apparent power equal to the real power, thus voltage and current are in the phase, belong to the first one. This requirement is satisfied only by appliances with pure resistive character, light bulbs and heating elements, for instance. All others behave as a complex load consisting of a real and reactive part of power. The majority of the reactive part is represented by inductance of coil windings in transformers, inductors and motors, where alternating magnetic field is generated and it shifts the phase up to +90 degrees. On the other hand, devices with capacitive load characteristic occur less frequently. There is an electric part called capacitor, which has opposite function than coil – it shifts the phase up to -90 degrees. This reactive power causes great problems with power distributing because it overloads distribution nets and, in addition, electrometers do not record it, so the energy consumer will pay only the real part of the power that was transformed to light, heat, torque, etc. Due to this fact, wholesale customers must maintain the power factor in the range of 0.95 – 1.00. Energetic suppliers monitor this value and in most cases its violation is penalized by introducing extra pay. Due to this fact it is very important to monitor power factor in AC circuits and in case of need to correct it to acceptable range.

This contribution proposes design of measurement device which can evaluate all basic electrical quantities in AC circuits – true RMS voltage, true RMS current, real power, apparent power, reactive power and finally power factor with ability to transfer them via serial communication interface for further processing, visualization and archiving.

2. HARDWARE OVERVIEW

Power monitoring device is based on Freescale MC9S08GB60 microcontroller (MCU). It is a member of low-cost, general purpose, high-performance Freescale 8-bit flash-based microcontrollers with Von-Neumann architecture. Central processor unit with enhanced HCS08 core is fully upward compatible with Freescale 68HC05 family. On the chip are integrated following peripherals: 3-channel and one 5-channel 16-bit timer/pulse width modulator modules, two serial communication interfaces, serial peripheral interface, inter-integrated circuit bus module, internal clock generator module, 10-bit analog-to-digital converter with 8-channel analog multiplexer, on-chip 64 KiB FLASH memory with in-circuit programming capability, 4 KiB RAM, 56 general-purpose input / output pins (16 high-current pins), 8-pin keyboard interrupt module, on-chip debug module (DBG) (***, 2008).

Correct program function is monitored by integrated watchdog system and illegal operational code and address detection. Internal program loading and debugging is provided by on-chip debug module (DBG). Internal bus frequency can be 20 MHz at 2.08 to 3 V supply voltage range or 8 MHz at 1.8 to 3 V supply voltage range (***, 2006).

2.1 Circuits design

Hardware of measurement device can be divided into several main functional blocks: power supply, voltage and current sensing circuits, MCU evaluation unit, communication interface and analog output (Fig.1).

Voltage and current sensing circuits perform signal adaptation to range acceptable by analog-to-digital converter. The shunt in current subcircuit is able to continuously handle currents of 10 A RMS, voltage divider is designed for voltages up to 250V RMS. Inputs of A/D converter are protected against over voltage by Schottky diodes. Analog-to-digital conversion is performed by external successive approximation 12-bit A/D converter MCP3202 with on-board sample and hold circuitry. It is equipped by 3-wire synchronous serial interface to communicate with microcontrollers (***, 1994).

Communication interface and analog output circuits are optically isolated from measured circuit by five single channel optocouplers 6N137. They have integrated very high speed photo-detector logic gate allowing transfer rates up to 10Mb/s. A minimum common mode rejection (CMR) value is 5 kV/μs (***, 2001). Communication interface uses two optocouplers for receive data and transmit data signals, analog output three optocouplers for serial peripheral interface (SPI) signals.

Analog output utilizes 12-bit digital-to-analog converter MCP4921 with SPI interface and rail-to-rail output amplifier (***, 2010). It is followed by amplifier stage adapting its output to unified voltage range 0 – 10 V.

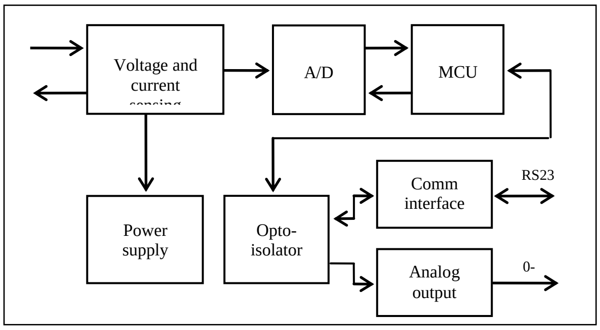

Fig. 1. Block schematics of the device

3. SOFTWARE IMPLEMENTATION

3.1 Device firmware

The main requirement on measurement device was the ability to evaluate true RMS values of voltage and current and true power independently on the shape of input signal waveforms. Due to this fact it is not possible to use equations derived for harmonic shape of voltage and current. Thus to obtain right values of measured quantities integral equations must be utilized. Because fully digital processing is used these equations must be converted from time-integrals to sums. The accuracy depends on sampling frequency after this modification.

RMS values of voltage and current are evaluated by equations (1) and (2), true power by equation (3).

$$V_{RMS} = \sqrt{\frac{1}{T_P} \cdot \int_0^{T_P} v^2(t)dt} \approx \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} v_i^2} \tag{1}$$

$$I_{RMS} = \sqrt{\frac{1}{T_P} \cdot \int_0^{T_P} i^2(t)dt} \approx \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} i_i^2} \tag{2}$$

$$P = \frac{1}{T_P} \cdot \int_0^{T_P} v(t) \cdot i(t)dt \approx \frac{1}{n} \cdot \sum_{i=1}^{n} v_i \cdot i_i \tag{3}$$

Where n is number of samples, v_i sampled voltage and i_i sampled current.

Apparent power is calculated from RMS voltage and current by equation (4). Power factor is evaluated as a ratio of true power to apparent power (5).

$$S = V_{RMS} \cdot I_{RMS} \tag{4}$$

$$\cos\varphi = \frac{P}{S} \tag{5}$$

Firmware of the device was created in C language using integrated development environment CodeWarrior IDE. Routines working on the foreground are called by timer subsystem with sampling period so the execution is very time-critical. The purpose of these routines is voltage and current sampling and computing sums of their squares. To achieve highest possible computing speed resulting in higher sampling rates, squares are not computed by standard routines but they are fetched from precalculated results table stored in FLASH memory. Routines working on the background perform the final computations of measured values in floating point and also the communication via serial interface RS232 with supervision system and set analog output voltage value.

3.2 Evaluation software

All measured values are visualised with “Power monitor” utility which was created in Microsoft Visual C++ 6.0. Main window of the program is depicted in Fig. 2. On the left part of the window is located group of the edit boxes displaying following measured quantities: RMS voltage and current, true power and power factor. The TP difference field shows difference between actually measured true power and previously saved value by user. Right part of the window contains device control related buttons and combo boxes. With “Aout mode” combo box can be selected which measured value will be transferred to analog output. There are available 3 options: true power, voltage and current. Analog output range can be selected by next control “Aout range”. Voltage and current ranges are fixed to values of 300 V RMS and 10 A RMS but true power ranges are scaled to 100, 250, 500, 1000, 2500 and 5000 W. This scaling enables better utilization of digital-to-analog converter resolution. Using “Zero TP” button can be set true power value for true power difference computations and finally “RESET” button set all program controls to default state.

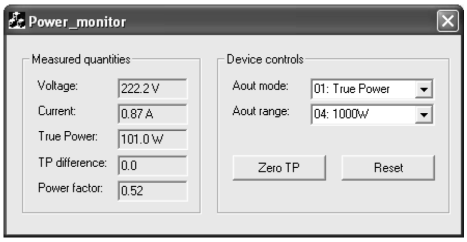

Fig. 2. Main window of the power monitoring software

Power monitoring device can transfer 512 samples length voltage and current waveforms acquired at 6000 Hz sampling frequency after receiving special command. For this purpose was created script in Matlab 6.5 environment. Example of acquired voltage and current waveforms is in Fig. 3.

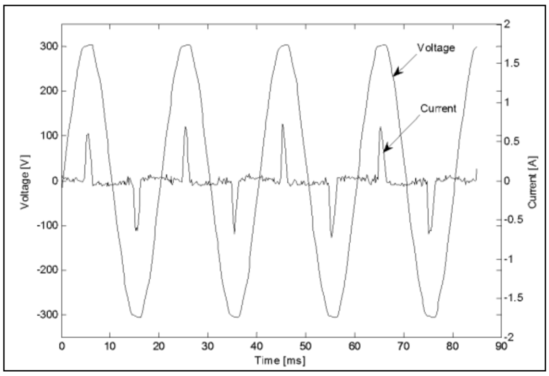

Fig. 3. Example of measured voltage and current waveforms

4. CONCLUSION

The contribution proposes design of measurement device which can evaluate all basic electrical quantities in alternating current circuits – true RMS voltage, true RMS current, real power, apparent power, reactive power and finally power factor with ability to transfer them via standard serial communication interface for further processing, visualization and archiving. Developed data visualization program can display all measured values. In case of need it is possible to display acquired voltage and current waveforms by script in Matlab environment.

5. ACKNOWLEDGEMENTS

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