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A Low Cost Web-based Supply Voltage Quality Monitoring System

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Abstract: In this research, a web-based supply voltage monitoring system based on a compact microprocessor module is presented. It provides a low-cost and flexible solution for monitoring the power quality of electricity supply. The hardware consists of the module and a few extra electronic components. This shortens the development time and lowers the manufacturing cost. Also, the power quality data can be presented via a web page. Any user in the Internet can access the data from the new monitoring system. Moreover, the size of the system is very small presenting no difficulties for installation. All these features make it very competitive to be used as a supply voltage quality monitor. The prototype of this system has been built. It has been applied in our laboratory to continuously monitor the power quality so as to demonstrate its beauty.

Key words: Internet, microprocessor, power quality, web pages

Introduction

Electronic equipment is widely used in various areas nowadays. Such equipment has power electronic components, its load characteristic is usually highly non-linear. A large amount of harmonic current is created in a power system leading to poor electricity supply. Unfortunately, most of the electronic equipment is very delicate in nature and their operations can be easily disturbed by poor supply. This problem has been identified by previous research works (IEEE, 1983; Emanuel, 1993 and Mansoor, 1994). A computer is a kind of this equipment, which is very common in both commercial and industrial areas. A manager requires a computer to send or receive several electronic mails in his daily work while an engineer relies on it to generate the assembly drawing of his developed product. One disturbance in supply network will likely cause loss of million important data and has a serious impact to an organization. According to Supply Rules of CLP Power Hong Kong Limited in Hong Kong, the supply voltage rms value variation should not be greater than 6%. The total THD limit is 5% from IEEE Std 519-1992. Therefore, a low cost voltage monitoring system is essential to measure the real-time power quality data at various locations in a power network.

There are many kinds of power quality analyzer in the market. They are able to evaluate the quality of power supply by continuously monitoring supply voltage and current. Usually, they work with their proprietary software to retrieve the power quality data. Conversion of their data to standard format is possible but is very inconvenient. Much modification work is required to make the conversion automatic. Also, their sizes are very large. It is impossible to install them in a location where space is limited. Moreover, they are expensive and the simplest version of them costs about one thousands US dollars. It is hardly justified to employ this kind of analyzers for only monitoring purpose.

In recent years, microprocesssor-based modules have been involved in a great evolution. They have strong computation power and sufficient resources to suit for a particular application. Their prices are relatively low. Because of these features, they are very competitive to be adopted as the core modules in many industrial applications. Rabbit Core RCM2200 module is one of them manufactured by the company Z-WORLD. It has a 8-bit microprocessor running at 22 MHZ clock speed and has a great computation power. Inside the module, there are several peripheral devices connected making it a powerful core component. They include 10Base-T Ethernet chip, 26 parallel I/O ports, 256k flash memory and 128k static RAM. With the built-in Ethernet chip, communication with other computers in local area network (LAN) is ready for use. A complicated application program is allowed as there is a sufficient flash memory for program codes. To program it for a particular task, many I/O lines are available to serve this purpose. Also, there is a set of standard library for developers to utilize it's hardware directly. This would shorten the development time. With the web-related library, a web site broadcasting real-time power quality data can be developed without requiring to know much technical detail in TCP/IP networks. It is very small just occupying half the size of a business card. Therefore, the module provides a very good foundation for our low cost web-based voltage monitoring system.

In this research, a low cost web-based supply voltage quality monitoring system based on a compact microprocessor module is presented. The system has several features including simple construction, low manufacturing cost, compatible communication with other computers, user friendly interface and easy installation. With this system, users can simply view the power quality data in the Internet using their web browsers.

Hardware design of the new voltage monitoring system

The hardware design consists of three functional parts, namely incoming signal conditioning, noise suppression and analog-to-digital (A/D) conversion. For the former one, it provides an electrical isolation for the monitoring system. In this way, the system can be protected from disturbances in supply network. It is also used to lower the magnitude of the incoming signal for later processing. A noise suppression circuit is to remove noises to improve the accuracy. The latter part is to convert the analog signal into digital format for the RCM2200 module to carry out power quality analysis.

Incoming signal conditioning

Figure 1 shows that a step-down transformer is adopted for conditioning the incoming signal. A transformer provides a good electrical isolation due to its magnetic circuit and is able to step down the voltage to an appropriate level based on its turn ratio. The secondary side of the transformer is required to be shifted to 2.5 V by using a voltage reference diode. Together with a 100 kS rheostat for further adjustment, the magnitude of the analog signal can be kept within the operating range of a typical A/D chip (0 – 5V). In this case, we adjust the gain of signal conditioning circuit such that when the supply voltage is at its peak value (311 V), the corresponding step-down output signal will be 4.5 V. In this way, a factor of 69 (311 / 4.5) is required for scaling the output signal to its actual voltage magnitude and 10% margin is used to cater for any overvoltage incident.

Noise suppression

In a real situation, noises are present everywhere. They degrades the accuracy of the system by means of anti-aliasing effect (Jack, 1993). A low-pass filter is required to filter them out. The cut-off frequency of the filter is set to the frequency of the highest order harmonic. In our case, 13th order harmonic is selected as the highest-frequency component. This harmonic is common as there are many electronic-based motor drives with 12-pulse output in the supply network creating harmonics of the order of 12n±1 where n is an integer (Sen, 1988). Thus, the designed cut-off frequency is set to be 650 Hz. An active filter of second order using an operational amplifier is adopted, Fig. 2. The filter has several advantages over passive filters. It provides adjustable gain to compensate for signal attenuation. Its high internal impedance prevents excessive loading of the driving source while its low output impedance prevents it from being affected by the load. Also, it can maintain a very steady response within the pass band while giving a very sharp attenuation in the stop band. Equation (1) determines the cut-off frequency (Clayton, 1985).

$$f_c \,'\, \frac{1}{2\sqrt{2BRC}} \tag{1}$$

By choosing the resistance, R to be 7.5 kS and the capacitance, C to be 22 nF, the actual cut-off frequency is calculated to be 682 Hz which is close to the designed value.

Analog-to-digital conversion

There are many ICs available for A/D conversion in the market. They offer different degrees of resolution and different sampling rates. Usually, a better resolution will have the sampling rate lower. MCP 3201 A/D chip is selected, which is manufactured by Microchip. It offers 12-bit resolution with the sampling rate of 100 kHz. In fact, our required sampling frequency is only 1.3 kHz (2 x 650 Hz) and the fast sampling rate of the chip is not fully utilized. However, it employs serial peripheral interface (SPI) for data transfer. This feature is a favorite attribute to the new system as the RCM2200 module has built-in SPI library. Also, little hardware work is required as only three signal wires are connected between the chip and the module Fig. 3. The digital output (D_o) of the A/D chip is governed by Equation 2.

$$D_0 \;'\; \frac{4096\,(V_{IN\%} \,\&\, V_{IN\&})}{V_{REF}} \tag{2}$$

where V_{IN+} is the input analog signal, V_{IN-} is set to 0 V and V_{REF} is set to 5 V for full usage of the operating range.

Finally, the hardware design has been completed. A prototype of the web-based voltage monitoring system has been built (Fig. 4). The total cost of this prototype is about 65 US dollar. In case of mass production, a much lower manufacturing cost is expected.

Software design of the new voltage monitoring system

The software is to program the RCM2200 module to carry out three tasks concurrently. They are data acquisition, power quality calculation and data presentation. The computer language used for software development is Dynamic C (Z-World, 2001) which is offered by Z-WORLD. It slightly differs from a traditional C. It is aimed to assist developers to write reliable embedded control software by providing various useful features. One of them is to create an environment for concurrent parallel processes to be executed in a single program. Because of this feature, we can concentrate our efforts on the three tasks so as to reduce the development time.

Data acquisition

The built-in SPI library is adopted to facilitate data transfer from the A/D chip to the RCM2200 module. In this case, two procedures are used from the SPI library, which are "SPIInit" and "SPIRead". The former one is to initialize the hardware settings of the module for SPI communication. In this case, the pin PB0 is configured to provide clock signal while the pin PD5 is used to receive data signal. The latter procedure is to read the signal from the A/D chip.

As the highest-frequency component in the signal is at 650 Hz, the sampling frequency is required to be at least 1.3 kHz by Sampling Theorem. A timer in the module is thus programmed to provide this sampling frequency. For the sake of simplicity, the time interval of 741 £gs is employed to provide a little bit faster sampling frequency (1.35 kHz). The procedure "SetVectIntern" offered by the standard library is used to assign the new interrupt service routine for the timer. In this service routine, data sampling is carried out by calling the procedure "SPIRead". Once obtaining the sampled data, harmonic calculation will be carried out for analysis, which will be mentioned in the next section.

Power quality calculation

This process involves a set of mathematical algorithms to calculate the power quality data based on the measured data. There are two types of the power quality data required to be presented, namely supply voltage root-mean-square (rms) value (V_{rms}) and supply voltage total harmonic distortion (THD). For rms value at any instant n, it can be calculated by Equation 3.

$$v_{rms,n} = \sqrt{\frac{1}{N}\sum_{i=n-N+1}^{n} v_i^2} = \sqrt{\frac{S_n}{N}} \qquad (3)$$

where v_i is the instantaneous value of supply voltage, N is the total number of sampling points and S_n is the sum of square of N sampled data. To minimize the overall error, a large number of sampled data is required to calculate the rms value. In our case, data of five cycles are sampled for each rms calculation. In order to speed up the calculation, a first-in-last-out queue is set up. It can store 135 sampled data which is equal to the total number of data in five cycles. When there is a new data, the value S_{n+1} can be quickly obtained from Equation (4) eliminating much mathematical manipulation.

$$S_{n+1} = S_n + v^2_{n+1} - v^2_{n-N+1} \tag{4}$$

With S_{n+1}, the updated rms value ($V_{rms,n+1}$) can be determined using Equation 3. The new data (v_{n+1}) should replace the oldest one (v_{n-N+1}) in the queue. In this way, the rms value calculation can be carried out more effectively. For the total harmonic distortion (THD), it can be found by Equation (5).

$$THD_n = \frac{\sqrt{V^2_{rms,n} - |V_{1,n}|^2}}{|V_{1,n}|^2} \tag{5}$$

where $|V_{1,n}|$ is the rms value of the fundamental component of supply voltage. $V_{1,n}$ is the fundamental value in complex form, which can be calculated by Equation (6).

$$V_{i,n} = \frac{2}{N} \sum_{i=0}^{N-1} v_{n-N+1+i} e^{-j\frac{2\pi i}{N}} \tag{6}$$

By using the same queue to store v_i, the next $V_{1,n+1}$ can be easily obtained by Equation (7). The value $e^{j2\pi/N}$ is pre-calculated and stored as a constant in the program to further speed up the whole calculation.

$$V_{1,n+1} = (V_{1,n} - V_{n-N+1} + V_{n+1}) e^{j\frac{2\pi}{N}} \tag{7}$$

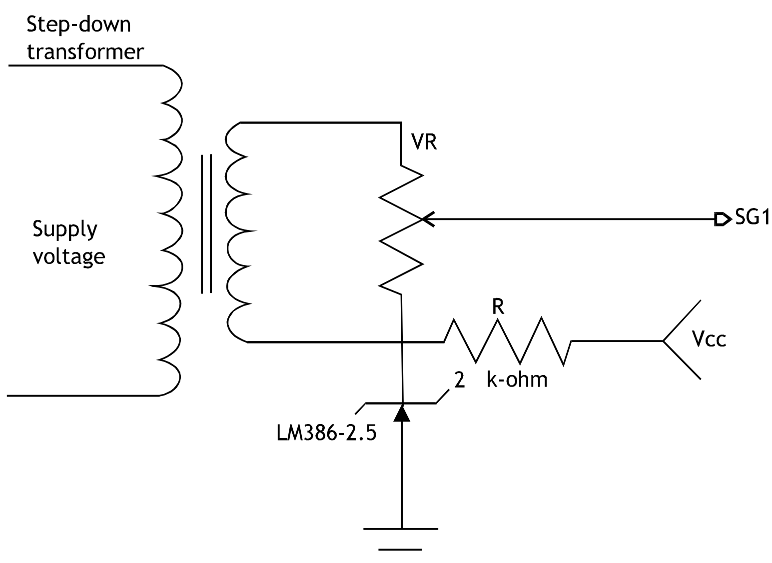

Fig. 1: A circuit for incoming signal conditioning

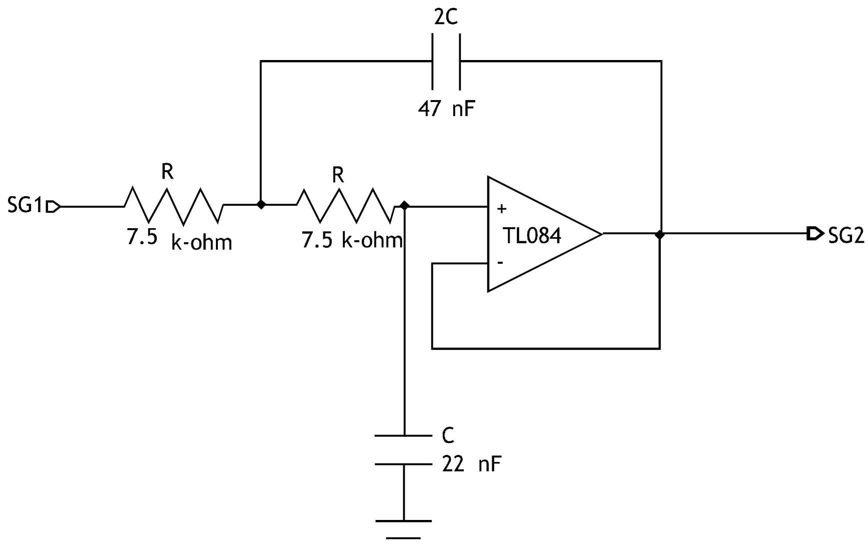

Fig. 2: A circuit for noise filtering

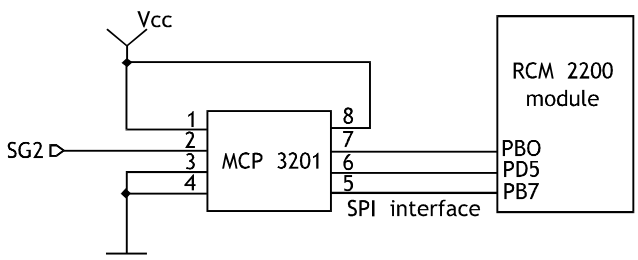

Fig. 3: A circuit for A/D conversion and interface with the RCM2200 module

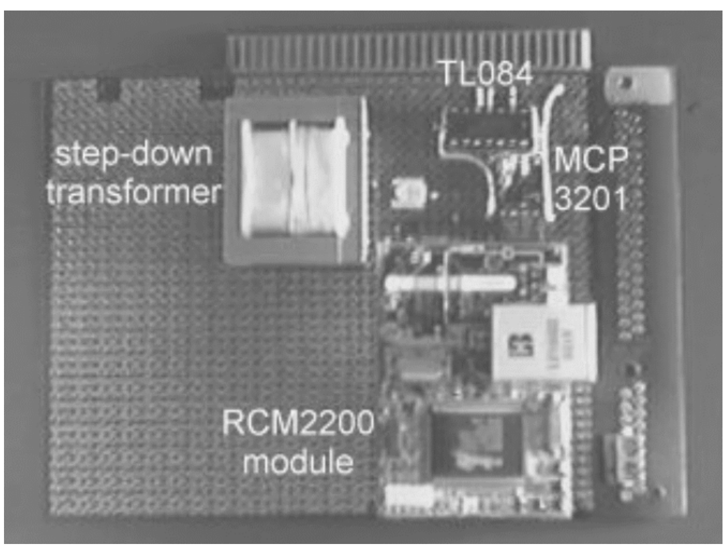

Fig. 4: The prototype of the low cost web-based supply voltage quality monitoring

Fig. 5: The outlook of the power quality web page retrieved from the RCM2200 module

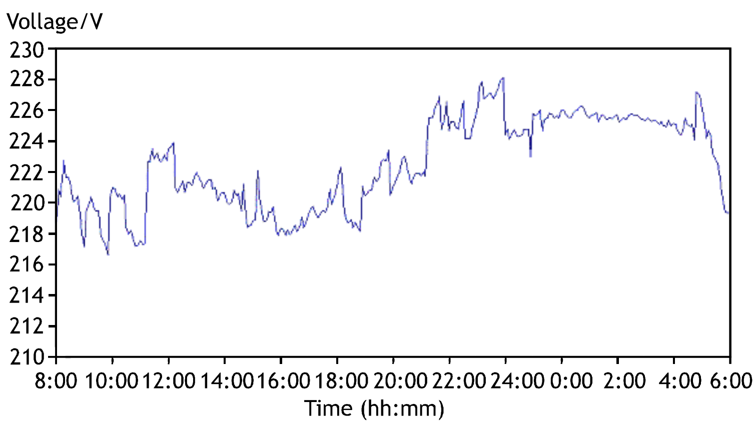

Fig. 6: The profile of supply voltage rms value measured by the new monitoring system

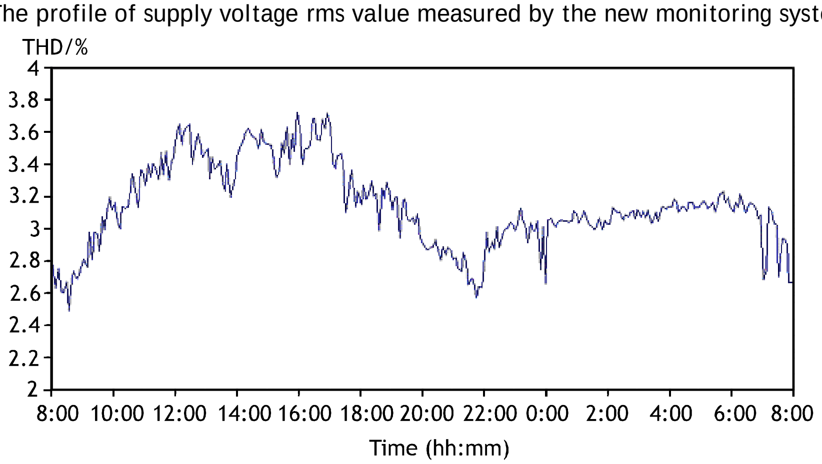

Fig. 7: The profile of supply voltage THD value measured by the new monitoring system

Data presentation

Using a web page to present the power quality data in a computer centre is the most convenient, economical and effective way. In fact, recent research work has demonstrated the advantages of applying the Internet in various areas (Roberto, 2001; Riko *et al*., 2001 and Chwan, 2001). As many users connect to the Internet, they can easily retrieve the web page to view the power quality data using their web browsers. No proprietary software is required. Also, the Internet has been used for several years without complaints. It is recognized that the Internet is a reliable and efficient internetwork. Because of these advantages, a web site is set up in the RCM2200 module for data presentation.

To implement a web site in the module, several procedures from two related libraries, “dcrtcp.lib” and “http.lib”, are employed. Firstly, a procedure “sock_init” is called to initialize the setting of TCP/IP working environment and enable the Ethernet chip for communication. The step is essential for all TCP/IP communication. “http_init” is then called to initialize HTTP daemons for a web server which runs on HTTP protocol. As the module has to handle three concurrent processes, a procedure “tcp_reserveport” is called so as to allow it to accept a TCP/IP connection request even when its processor is not available to handle the request. In this way, the other side of the connection will wait for the request to be processed. The input parameter to this procedure is set to 80 which is the default port number for HTTP protocol. To process HTTP request from web users, a procedure “http_handler” is called regularly to handle the request such as retrieving the web page for power quality data. It parses the request and passes control to the relevant handler for execution.

Figure 5 shows the outlook of the web page retrieved from the new monitoring system. Both voltage rms value and THD value are displayed. Their values are compared with their corresponding limits. A warning message “Poor power supply” will be displayed in the web page if any one limit is found to be violated. The web page is refreshed automatically every 30 seconds and thus provides users the updated power quality information.

Applications of the new voltage monitoring system

Firstly, the new monitoring system provides power quality data to users via a web page. In fact, it also serves as a useful tool for power quality investigation. As a web page is a text file, the information inside it can be easily extracted by a simple computer program. By retrieving the content of the web page regularly, both supply voltage rms value and THD value can be recorded continuously. Their profiles can be generated and provide very important information for the investigation. To demonstrate this capability, a computer program has been developed to capture power quality data at a 5-minute interval. The profiles of supply voltage rms value and THD value on a typical day in our laboratory are shown in Figure 6 and Figure 7 respectively.

For some workstations in the laboratory, an immediate action is required to reduce damage from poor power supply. Since the refresh rate of a web page is limited, the above approach cannot cater for this purpose. A modification on the original program of the new system is required. One way is to make use of TCP/IP communication, that is, a specific TCP/IP message is sent to the workstations whenever poor supply is detected. Another procedure “sock_write” from the library "dcrtcp.lib" is employed to achieve this. Of course, a program continuously receiving TCP/IP messages is required to be installed in the workstations. With a slight modification, the system can provide an alert signal for important workstations to take up remedial actions.

The development of a low cost web-based supply voltage quality monitoring system has been presented in this study. A web page has been developed for this system to present power quality data and is open to the public for visit. As the system is built on the platform of a microprocessor module, there are several advantages. They are simple construction, low manufacturing cost, compatible communication with other computers, user friendly interface and easy installation. As seen in Section 2, there are only two IC and a few electronic components required for the whole monitoring system. That is why it possesses simple-construction and low-cost features. As the module has a built-in Ethernet chip, presentation of power quality data via a web page has no difficulties. Users can view the power quality data using their web browsers easily. Continuous monitoring on the quality of power supply is also possible by retrieving the web page at a regular interval as seen in Figure 6. With slight modification and a simple add-in software installed in the client sides, the system can cater for the situation requiring immediate actions. There is no installation problem as the size of the system is very small. Therefore, it is a very good supply voltage quality monitoring system for various situations.

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