Design and Construction of a High-Precision Electrical Parameters Monitoring System

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Abstract—**Due to the increasing demand for monitoring electrical parameters in real time, many efforts have been recently made to develop different efficient data monitoring systems. This paper elucidates the design and construction of a low-cost Universal Serial Bus (USB) based electrical parameters monitoring system (EPMS) to measure various types of electrical parameters with visualization. In industry, it is essential to measure, acquire, and analyze generated or supplied AC RMS, peak or instantaneous voltage and frequency for different load conditions. In this research, a high-precision, cost-effective EPMS system is designed with a PIC18F4550 microcontroller, which is capable of performing these measurements. The designed EPMS has been tested with an application program developed in Microsoft Visual Studio 2010, which allows real-time monitoring and display of the parameters.**

Keywords-data acquisition device; electrical parameters acquisition; instantaneous value; PIC 18F4550 microcontroller; signal conditioning circuit; USB

I. INTRODUCTION

Electric parameter measurement, visualization, and processing as the input of an automated system has been a major concern for researchers in the last few decades. In order to realize a data acquisition system, a high-precision and cost-effective monitoring system is essential for monitoring electrical parameters in real time. As a result, an electrical parameters monitoring system (EPMS), which is a hardware or/and software based system typically used to monitor the performance of electrical parameters for a certain system or environment is required. In other words, the system refers to a process of collecting information to document or analyze some observable facts. The EPMS's data acquisition board can plug directly into a computer bus. The features supplied by the EPMS can include the quantity and nature of inputs (voltage, thermocouple, on/off), the outputs or the speed. Each board of EPMS, installed in the computer, is addressed at a unique input/output map location. The computer provides an I/O map for addressing locations of the processor used to get entry to the specific device required by its program. The connection of PCs to peripheral devices such as printers, monitors, modems and data acquisition devices is accomplished by the Universal Serial Bus (USB) interface [1]. There are some salient advantages of USB over conventional serial and parallel connections including higher bandwidth (up to 12 Mbits/s) and the ability to afford power to the peripheral device [2-3]. USB connections supply power and only one cable is necessary to link the data acquisition device to the computer, hence, in EPMS applications, USB is the best. Previously, many researches were concentrated on designing and constructing low-cost data acquisition systems directly related to monitoring and measuring electrical parameters (peak value, RMS value, frequency etc.) [4-6]. However, our research focused on a Low-Cost Data Acquisition and Control System Based on a Single Chip [6]. Although this system measures some physical parameters (temperature, pressure, vibration) smoothly, it was not consistent with real-time monitoring and display because of applications software and hardware incompatibility. Other research in [7] was done on a microcontroller-based data acquisition system for electrical motor vibrations using VB software. However, our main focus is on designing and constructing a high-precision, low-cost EPMS for measuring electrical parameters which are not like the research mentioned above because of the hardware and application software and accuracy of measurements.

II. SYSTEM DESCRIPTION

The proposed low-cost data acquisition system is constructed using a PIC18F4550 microcontroller with USB interfacing that measures the AC parameters, e.g. root mean square (RMS) value, average value, frequency, in a very reliable and accurate way. The entire block diagram is shown in Figure 1. To measure the AC parameters (peak value, RMS value, average value, frequency), a transformer is used to convert higher voltage levels to lower voltage levels (220V-12 V). The low-voltage output from the secondary side of the transformer is fed to the signal-conditioning circuit. The signal-conditioning circuit consists of two sections: (1) Inverting & scaling section: an inverting amplifier has been used to produce the inverse of the AC input voltage. By varying the value of the feedback resistor, a wide range of AC parameters (voltage, frequency) can be measured [8]. (2) voltage level shift section: a Summing amplifier which is constructed with negative scaled analog voltage input and a negative DC input voltage (-5 V dc) to shift the negative half portion of the peak-to-peak signal (negative and positive) above 0 V or ground level, because the microcontroller can't accept negative signals [9].

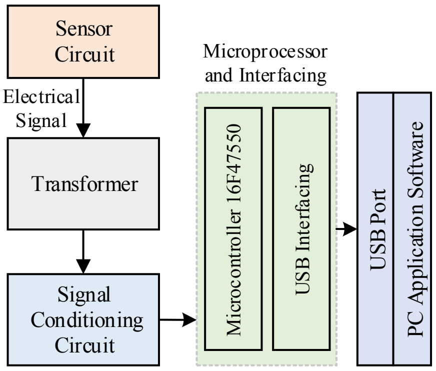


Figure 1. Block Diagram representation of the EPMS.

The microcontroller receives the conditioned signal and converts it to binary data through its built-in analog-to-digital (A/D) converter module [10-13]. The microcontroller processes the data according to its program. A USB connector is used to interface between the microcontroller and the PC application software (Microsoft visual studio 10), which measures and displays data or value as per the program.

III. CIRCUIT DIAGRAM AND OPERATION

The circuit diagram of the designed EPMS system is shown in Figure 2.

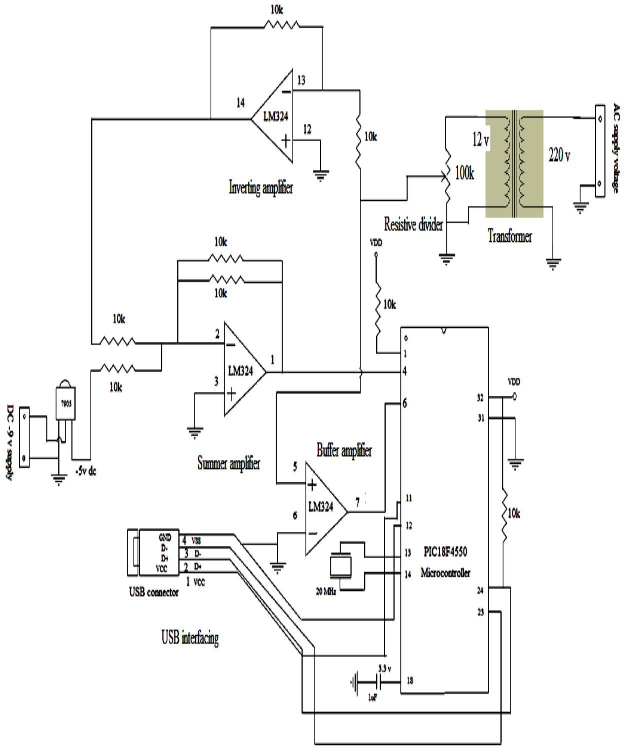


Figure 2. Circuit diagram designed in Proteus.

The primary winding of the transformer (220 V/10V) is directly connected to the main AC supply (220 V) and it lowers the voltage level to a 12 V AC RMS at its secondary terminal. The proposed EPMS data system measures the input voltages only within a range of 5 to 10 V. Voltages higher than that limit must be attenuated. In this scenario, a voltage-divider bias is used to lower the AC RMS from 12 V to 1. A unity-gain buffer amplifier on the divider output has been used to overcome the low impedance loading effect. The inverting Amplifier (LM 324) scales a signal to any voltage level depending on the setting of the feedback resistor and the input resistor values and produces a negative AC signal voltage (negative feedback) which is the input of the summing amplifier [10-11, 14-15]. To shift the voltage above ground level, a summing amplifier, having two inputs, one from the inverting amplifier (LM 324) and another from DC (– 5V) supplied by an LM7905 (three-terminal negative-voltage IC regulator) has been used [14-16]. The built-in A/D converter module of the microcontroller changes an analog signal into a digital signal and manipulates the USB interfacing as per the program written for it [12-13, 17]. The USB connector interfaces between the microcontroller (PIC18F4550) and the personal computer [18]. The PC application software, Microsoft Visual Studio 2010, C#, has been used to monitor AC parameters.

IV. SIGNAL CONDITIONING CIRCUIT

The transformer output signal has been conditioned before going to the EPMS board. The signal-conditioning circuit performs the main functions: amplifies or modifies the transformer output to measure a wide range of the signal, provides an opposite output which is easy to handle with an analog input signal. The signal conditioner frequently performs additional functions such as Isolation, Linearization, conversion, Filtering and Impedance matching [19].

A. Inverting & Scaling

The output signals from sensors are usually too small for applying directly to low-gain, multiplexed data acquisition system inputs, so some amplification is necessary [20]. The data acquisition system uses basic operational amplifiers, which are configured easily to amplify or buffer the signals. The operational amplifiers simply accept an input signal referenced to common, amplifies it, and inverts the polarity at the output terminals [11, 17]. Therefore, it acts as an inverting amplifier. The output voltage of the inverting amplifier is given below.

$$V_0 = -V_{in} (R_f/R_i) \quad (1)$$

Here, V_0 is the output voltage, V_{in} is the input voltage, R_f is the feedback resistor, R_i is the input resistance.

For this system, an LM324 IC is used for the inverting operation. The inverting operation is configured by inserting a 10 kΩ resistor between pin 13 (inverting input) and pin 14 (output pin) of the LM324 and a 10 k Ω resistor between the 1.0 V AC input supply and the inverting pin of the LM324. The simulation output is shown in Figure 3.

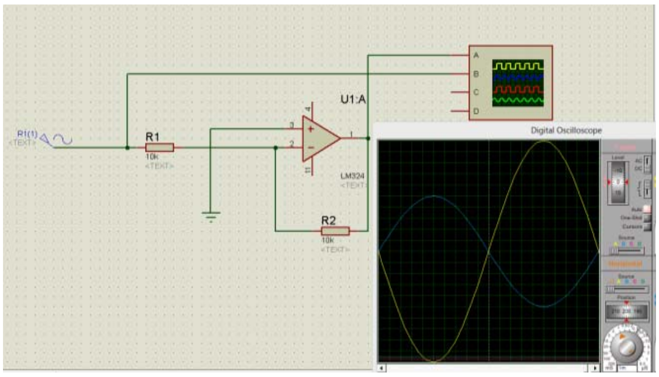


Figure 3. Simulation output of inverting amplifier.

On the other hand, a voltage scaler circuit is designed with four 10 kΩ resistors and an OP-AMP, LM324, for 5, 10, 15, and 35 V scaling. The Proteus schematic diagram 3 below shows that the voltage can be scaled by adjusting the gain.

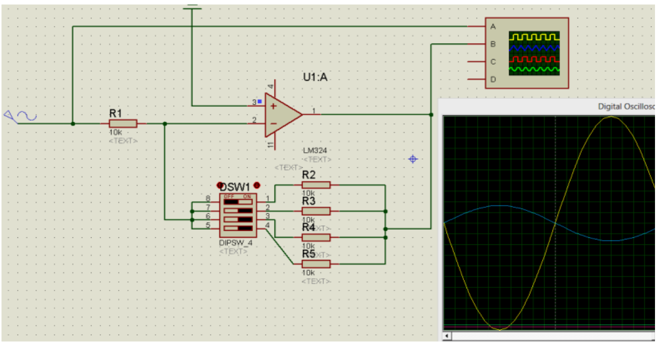


Figure 4. Op-amp scaling circuit output when different switches are on.

B. *Voltage Level Shifting*

A voltage level shifter circuit is used to convert a positive/negative peak-to-peak signal into a range suitable for a single-supply A/D converter [21]. This circuit converts an AC signal into a 0 to 5 V signal level so that it can be sampled by the A/D converter of the microprocessor [11-13]. In this research, a scaled inverted AC input and a DC (-) 5 V supplied by LM7905 can be applied to the inverting pin of the LM324. As a consequence, the voltage level has been shifted above the ground level. After that, it can be given as input to the analog port pin, AN2, of the microcontroller and converted into digital format by the A/D converter module [22].

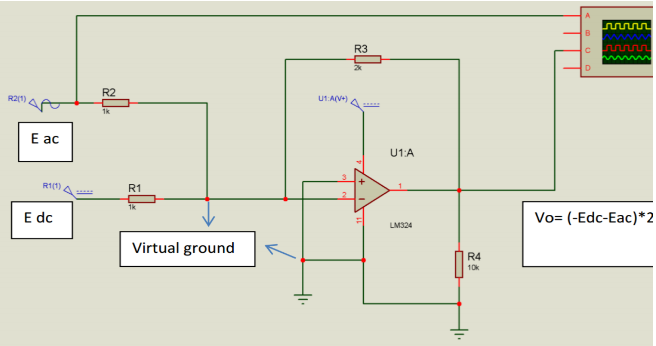


Figure 5. Voltage level shifting of AC voltage level for ADC input.

V. DATA-ACQUISITION HARDWARE INTERFACING

Data acquisition hardware interfaces between the EPMS and the computer include a module connected to the computer's ports (parallel, serial, USB etc.) or cards connected to slots in the motherboard such as s-100 bus, Apple bus, ISA, MCA, PCI, and PCI-E [23-24]. Therefore, the parallel port USB is the external hardware of the EPMS System. In this research, the EPMS hardware contains an inverting amplifier stage, voltage level shifting, A/D converter, USB interfacing. The circuit diagram of the USB interface with the microcontroller PIC18F4550 of the Data acquisition board is in Figure 6.

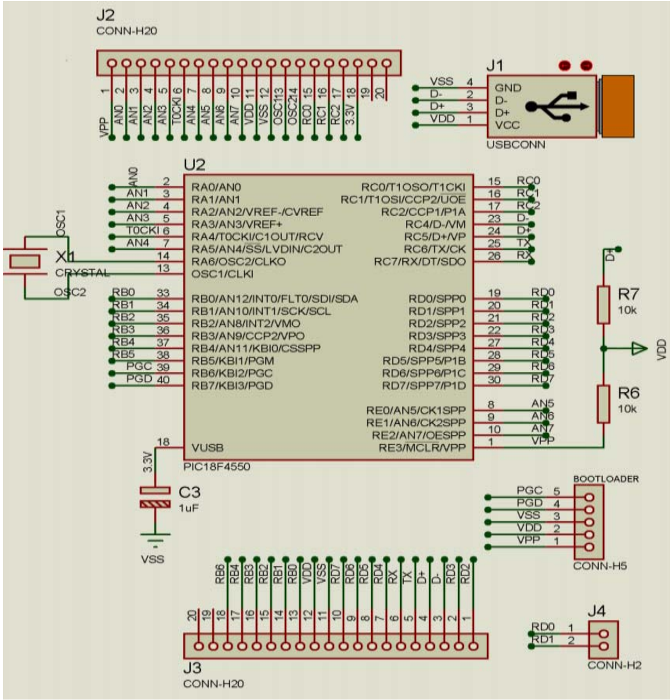


Figure 6. Interfacing of Microcontroller with USB Connector.

To deal with EPMS hardware communicating with the PC, EPMS software is important. Data-acquisition applications are executed, monitored, and controlled with the EPMS software. In the data-acquisition software, one need to perform many tasks such as maintaining the data rate, handling the device, memory management etc. The data acquisition software can be developed with the help of a general purpose programming language such as BASIC, C, Java, FORTRAN, C++, C#, PASCAL etc. [25-27].

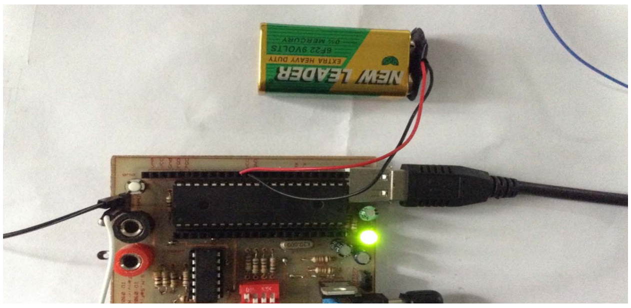


Figure 7. Visualization of Constructed EPMS system.

The EPICS language is also used for designing large-scale data acquisition systems [28]. In this project, Microsoft Visual Studio 2010, and C# application software is used for monitoring electrical parameters visually. The visualization of the constructed EPMS system is shown in Figure 7. Here the EPMS system provides an indication through LED if it gets a connection to PC via USB connector.

VI. DATA ACQUISITION HARDWARE INTERFACING

When the data acquisition card is connected to the USB-2.0 port of the computer through a USB-A connector, then new hardware appears in the control panel, device and printer folders of Windows operating machine. As soon as the device is connected, Windows installs the device driver of the connected EPMS system. Figure 8 shows the notification of the successful connection of the EPMS system in the computer.

Akib (akib-lappy)
State: Network Connected
Category: Digital media server
Manufacturer: Microsoft Corporation
Status: Offline
Model: Generic software device

Figure 8. Notification of reception of EPMS Connection in Computer.

The input signals of the EPMS are received from the function generator. From the function generator, three kinds of signals are taken as the input to the EPMS system. The waves are sinusoidal wave, square wave, and triangular wave. Their amplitude varies with ranges (up to 7.44 V AC), and frequency ranges (up to 200 Hz). The designed EPMS is also tested to measure the AC line supply of 220 V, 50 Hz AC from the laboratory. The lab setup of the EPMS system is shown in Figure 9.

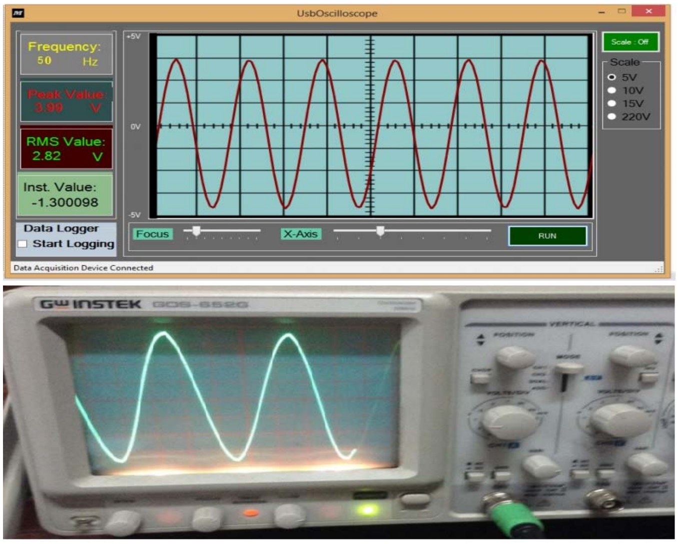
Figure 9. EPMS set-up implemented at the lab.

VII. RESULT ANALYSIS

A. AC Wave Measurement

For AC wave measurements, three types of wave (sinusoidal, square and triangular) are fed to the EPMS system from the function generator with a 50 Hz frequency. The comparison between the oscilloscope and the EPMS system in terms of peak voltage, RMS voltage are shown in Figures 10, 11, and 12.

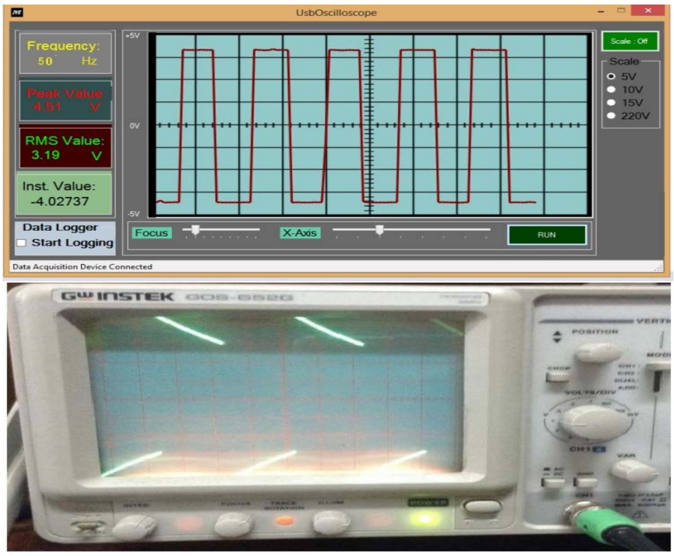
From Figure 10, the peak voltage for the sinusoidal wave in the EPMS system is 3.99V, whereas on the oscilloscope it is 4 V. The percentage error between the two measurements of RMS value is 1.4%.



Frequency: 50 Hz
Peak Value: 3.99 V
RMS Value: 2.82 V
Inst. Value: -1.300098
Data Logger
☐ Start Logging
Data Acquisition Device Connected

Figure 10. Comparison of sinusoidal wave for both oscilloscope and EPMS.

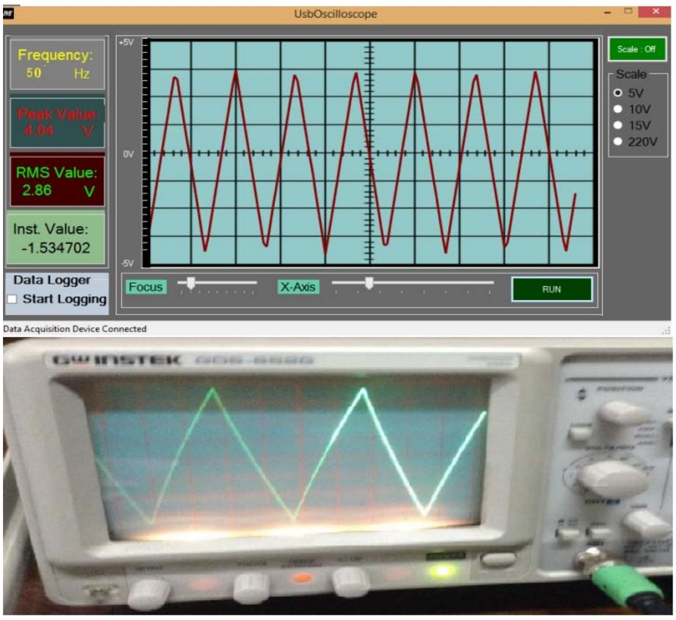
For the square wave, the percentage error in peak voltage for the EPMS system in comparison to the oscilloscope is 0.67%. The decay of the square wave in the oscilloscope is due to some parasitic capacitance as well as the high value of time constant.



Frequency: 50 Hz
Peak Value: 4.51 V
RMS Value: 3.19 V
Inst. Value: -4.02737
Data Logger
☐ Start Logging
Data Acquisition Device Connected

Figure 11. Comparison of the square wave for both oscilloscope and EPMS.

On the other side, the peak voltage of the sawtooth wave in the EPMS is 4.04 V, and in the oscilloscope near to 4 V for 1 V per division scaling.



Frequency: 50 Hz

Peak Value: 4.04 V

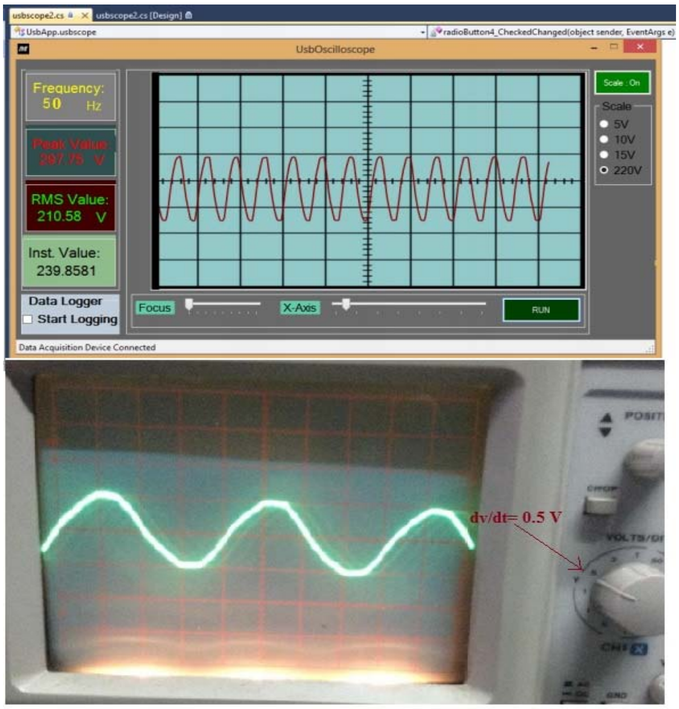
RMS Value: 2.86 V

Inst. Value: -1.534702

Figure 12. Comparison of the triangular wave for both oscilloscope and EPMS.

B. *AC Line Voltage Measurement*

At the laboratory, a line voltage of 211 V (RMS), with a frequency of 50 Hz is applied to the EPMS system through a transformer and resistive divider circuit. Using a multimeter, the input of the EPMS system is 0.3516 Vrms with the conversion ratio 600.



Frequency: 50 Hz

Peak Value: 297.75 V

RMS Value: 210.58 V

Inst. Value: 239.8581

Figure 13. Comparison of the EPMS system and the oscilloscope.

From the oscilloscope, the peak voltage is 0.5 V, so that the RMS voltage is 0.3526; with conversion ratio 600, the line voltage would be 211.56 V. The error percentage is 0.26%. On the other hand, the proposed EPMS system measures the line voltage as 210.58 V. In this case, the error percentage is 0.20%, which is quite low.

The line voltage (RMS) measured by both the oscilloscope and the EPMS system for a certain duration is shown in Figure 13.

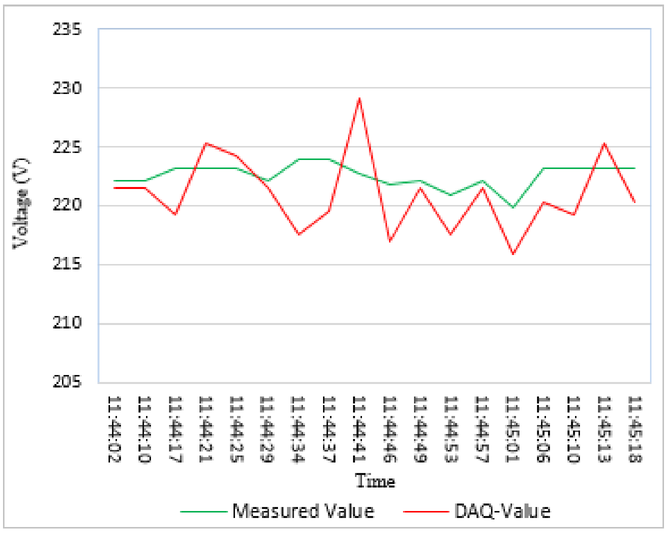


Figure 14. Line voltage measured by EPMS system and oscilloscope.

Figure 15 shows clearly the error percentage of both measurements. From the figure, it is clear that the error is less than 1%, which represents clearly the accuracy of the designed EPMS system.

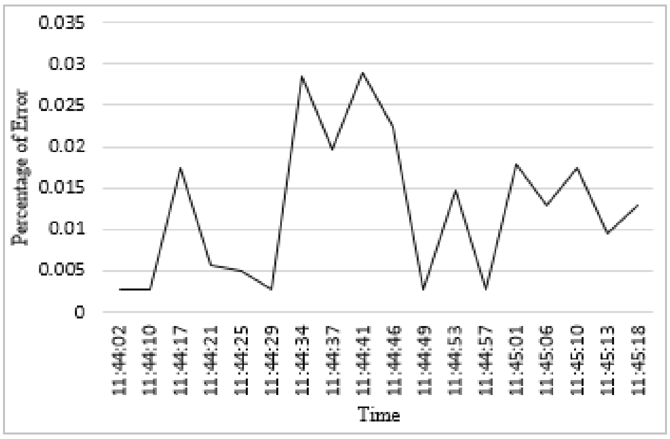


Figure 15. Error percentage vs time graph.

VIII. RESULT ANALYSIS

The low error percentage of the data monitoring system reveals a reliability to record and monitor data in real time in the industry. Besides, data can be stored in the computer hard drive for future analysis. The system is designed with a low-cost microcontroller, an operational amplifier, USB connector which represents the cost-effectiveness of the system. The proposed EPMS system can show better performance in lower frequencies up to 500 Hz frequency level. The high-frequency signal can be measured by using frequency to voltage converter IC (up to Giga hertz level) or, configuring PIC microcontroller timer module, which reflects the solution of an aforementioned challenge.

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