Measurement of periodic voltage waveforms on secondary side of high voltage measuring device using Arduino

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Abstract. Data acquisition on the secondary side is an important part of high voltage signal measurement. Based on Arduino microcontroller, a data acquisition (DAQ) system is developed. The frequency, root-mean-square value and DC component of periodic voltage waveforms can be measured by the system. The relative errors of the DAQ system are tested by comparing with standard voltage waveforms. The measurement range of the DAQ system is further discussed. The DAQ system in this paper is helpful to measure the periodic voltage waveforms on secondary side of high voltage measuring device.

1. Introduction
The measurement of periodic parameters includes analog circuit measurement and digital sampling measurement. With the development of computer technology, microelectronics technology and semiconductor manufacturing technology, digital sampling measurement method has become an important method in the field of electrical measurement [1,2]. The secondary voltage of high voltage measurement device has rich characteristic parameters: total effective value, basic effective value, total harmonic distortion rate and total harmonic distortion rate, DC component (non-sinusoidal component), frequency, peak value (including positive peak, negative peak, peak value). The measurement of these parameters requires a large number of special instruments, and the accuracy is generally low [3].

Arduino is a convenient, flexible and easy to use open source electronic prototype platform, which has the advantages of cross platform, simple, clear, open and rapid development. Arduino includes hardware (Arduino boards of various models) and software (Arduino IDE) [4,5]. Arduino is built on the open source simple I/O interface and has a processing and wiring development environment similar to Java and C. It mainly consists of two parts: the hardware part is the Arduino circuit board which can be used for circuit connection; the other part is the Arduino IDE [6]. As long as the program code is written in the IDE and uploaded to the Arduino circuit board, the Arduino circuit board can be controlled by the program [7,8].

In order to solve the practical difficulties of the measurement of periodic voltage waveforms on secondary side of high voltage measuring device, this paper develops a data acquisition (DAQ) system based on Arduino microcontroller. The system is able to measure the frequency, root-mean-square (RMS) and DC components of periodic voltage waveform. By comparing with the standard voltage waveform, the relative error of the data acquisition system is tested. The measurement range of the data acquisition system is further discussed.
2. Measurement Principle

Figure 1 illustrates the measurement circuit. $R_1, R_2, R_2', R_3$ and $R_4$ are resistances, $n_1, n_2$ and $n_3$ are nodes in the circuit, $v_{in}$ is the input waveform, $S$ is a single pole double throw (SPDT) switch. A DC bias voltage, which is provided by 3.3 V power port, is superimposed on the waveform. $R_2$ and $R_2'$ provide different voltage dividing ratios. In the report, the branch of $R_2$ is conducting. Compared with diodes, the resistors have little influence on the shape of the measured waveforms. Therefore, this circuit is more suitable to meet the demand of recording and display the original waveforms.

The relationship between measured voltage and actual input voltage is

$$v_{in} = k(v_1 - v_2)$$  

(1)

where $v_1$ and $v_2$ are the voltages on node $n_1$ and $n_2$, respectively. The voltage dividing factor $k$ is

$$k = \frac{R_1 + R_2'}{R_2}$$  

(2)

3. Data processing

The flow chart of Arduino program is presented in figure 2. Five sub-functions are included in the program. These sub-functions are explained in the following.
3.1 Function 1 – Checking the sampling time interval
Because of the time cost when executing “for loop”, the actual sampling rate is not equal to the theoretical baud rate. In the program, the moments before and after executing the “for loop” sampling are recorded. The time interval between two sampled values $\Delta t$ is

$$
\Delta t = \frac{t_{S2} - 2t_{S1}}{N_0}
$$

(3)

where $t_{S1}$ and $t_{S2}$ are the times obtained by the command “micros()”. $N_0$ is the total sampling amount in the sub-function. The relationship of these variables is shown in figure 3.

3.2 Function 2 - Calculating DC component of the waveform
During each measurement process, $N_1$ numbers of sampled voltages are recorded. $v_{DC}$, which means the DC component on $n_1$, is defined as

$$
v_{DC} = \frac{v_{1\text{max}} + v_{1\text{min}}}{2}
$$

(4)

where $v_{1\text{max}}$ and $v_{1\text{min}}$ are the maximum and minimum input voltage on node $n_1$, $v_2$ is the bias voltage on the node $n_2$. $v_{in-DC}$ is the DC component of input voltage

$$
v_{in-DC} = k\left(v_{DC} - v_2\right)
$$

(5)
3.3 Function 3 - Calculating the frequency

The starting time of a period of waveform, marked as $t$, is judged by the following equation

$$
\begin{cases}
 v_i^{n+1} - v_{DC}^{n+1} < 0 \\
 v_i^{n} - v_{DC}^{n} > 0
\end{cases}
$$

(6)

where $N$ is the $N$-th sampling voltage. The frequency of waveform $f$ is

$$
f = \frac{1}{T} = \frac{1}{N_2 \Delta t}
$$

(7)

where $N_2$ is the amount of sampling in one period. $T$ is the time of a period.

3.4 Function 4 - Calculating the RMS value

The RMS value is calculated by its definition

$$
V_{RMS} = \sqrt{\frac{1}{T} \int_0^T v_m^2(t) \, dt}
$$

$$
= \sqrt{\frac{1}{N_2 \Delta t} \sum_{n=1}^{N_2} v_{in,n}^2 \Delta t}
$$

(8)

where $n$ is the $n$-th sampling in a period.

3.5 Function 5 – Output the measured value

Judging whether the input is changed. If the variation of input RMS value or DC component of voltage is larger than 0.03 V, or the variation of frequency is larger than 1 Hz, put out a series of new measured results. If the input value is over the measurement range, put out “Over Range”.

4. Verification

The operation of the serial monitor is shown in figure 4. It can be seen that the measured voltages are always close to the standard value. However, when the measured frequency is 60 Hz, some 30 Hz values are put out occasionally. Referring (6), if there are some fluctuations on $v_1$ when $v_1$ close to $v_{DC}$, the misjudgment may happen, and the measured frequency may be half of the actual value.

Figure 4. Measured results on serial monitor.
The relative measurement errors are shown in figure 5. In figure 5, the waveforms are generated by waveform generator Agilent 33220A. $v_{AC}$ is the RMS value of sine waveforms without any DC component. The relative errors of measured voltages are less than 1%, but the relative errors of $f$ is increased with the increase of input frequency.

![Figure 5. Relative errors of measurement](image)

(a) Results of $v_{RMS}$, when $v_{DC}=0$ V, $f=60$ Hz  
(b) Results of $f$, when $v_{DC}=0$ V, $v_{AC}=4$ V

(c) Results of $v_{DC}$, when $v_{AC}=4$ V, $f=60$ Hz  
(d) Results of $v_{RMS}$, when $v_{AC}=4$ V, $f=60$ Hz

5. Discussion of the Measurement Ranges
The measurement range of voltage is determined by the voltage dividing resistances. In the practical circuit, $R_1=99.0$ kΩ, $R_2=22.3$ kΩ, $R_2'=2.18$ kΩ, $R_3=99.5$ Ω, $R_4=220.3$ Ω, and $v_2=2.27$ V. By referring (2), $k=5.44$. The instantaneous input voltage is

$$v_{in} = (v_1 - 2.27V) \times 5.44$$  \hspace{1cm} (9)

The range of Arduino analog input is 0~5V. Thus, the maximum and minimum voltages of $v_{in}$ are 14.85 V and -12.35 V, respectively. When measuring a sine waveform without any DC component, the recommended range of RMS value is $12.35/1.414=8.73$ V. If the switch $S$ was turned to $R_2'$ branch, there is $k=46.41$, and the measurement range is from -105.35 V to 126.90 V.

The maximum and minimum measurement frequencies are depended on the sampling rate and sampling amount. When the sampling rate is 9600 baud, the actual sampling time interval $\Delta t$ is 112 μs. In every measurement loop, the data is saved in an integer array. In case of overflow, the sampling number $N_1$ is set to 800. In order to measure a whole waveform, the sampling time should not be less than two times of the period. Therefore, the minimum frequency is

$$f = \frac{2 \times 10^6}{\Delta t \times N_1} = 22.32$$  \hspace{1cm} (10)

If the frequency of the waveform cannot be judged by (6), the waveform will be considered to be a DC signal.

With the increase of frequency, the sampling amount in a period is decreased, and the measurement error will be increased. This situation is also reflected in figure 5(b).
6. Conclusion
A DAQ system for measuring periodic waveforms is designed by using Arduino microcontroller. Five functions are used to process the sampling data. The measured results are verified by the waveform generator Agilent 33220A. The relative error of the measured voltage is less than 1%. As for the measured frequency, the relative error is increased with the increase of the actual frequency. The measuring range can be adjusted by changing the voltage dividing resistances. The frequency of measured waveform should not be less than 22.32 Hz.

Acknowledgements
This paper was supported by the Key R&D Program of Liaoning Province (2018220017, 2019JH8/10100062, 2019JH8/10100066).

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