Dušan Medveď, Patrik Šťastný

Electric power quality analyzer design using of open-source platform Arduino

Abstract: This paper deals with the electric power quality analyzer design according to standard IEC 61000–4–30 category B. This analyzer is intended especially to control of electric power delivering and it should measure the basic electric parameters of one-phase low-voltage level supply grid. As for the analyzer concept there was used open-source platform Arduino.

Keywords: power quality analyzer, voltage measurement, current measurement, frequency measurement, Arduino, power quality, open-source platform

I. INTRODUCTION

Electricity is nowadays one of the most important “raw material” that is used in industry, institutions or households. Electricity is through the transmission and distribution grids supplied to the end user. During transmission of this energy there are many external factors that can impair the quality of energy supplied. It is very important to identify the source of problems with the quality of electricity and in the case of an internal source of low-quality supply, it is necessary to take corrective action. On the other hand, the electricity should be seen as an energy commodity trading with contractual parameters laid down in the standard EN 50160. Non-delivery of quality goods could leads to complaint. The basis for the solution of problems connected with the power quality analysis is utilizing the instrument called the network quality analyzer that serves a lot of measuring and determining of electric parameters according to standard EN 50160.

II. ELECTROMAGNETIC PHENOMENA IN POWER SYSTEM

Nowadays there is an effort in the area of power quality to introduce it into the uniform categories. A leading role in this area has the Standards Coordinating Committee on Power Quality (IEEE SCC22) that is responsible for coordinating IEEE activities related to the quality of electric power as it affects equipment, users, utilities, power and communications systems. This committee divides the electromagnetic phenomena as follows [3]:

- Transients
  - Impulsive
  - Oscillatory
- Short-duration variations
  - Instantaneous
  - Momentary
  - Temporary
- Long-duration variations
  - Interruption, sustained >1 min 0.0 pu
  - Undervoltages >1 min 0.8–0.9 pu
  - Overvoltages >1 min 1.1–1.2 pu
- Voltage unbalance Steady state 0.5–2%
- Waveform distortion
  - DC offset Steady state 0–0.1%
  - Harmonics 0–100th harmonic Steady state 0–20%
  - Interharmonics 0–6 kHz Steady state 0–2%
  - Notching Steady state
  - Noise Broadband Steady state 0–1%
- Voltage fluctuations <25 Hz Intermittent 0.1–7%
- Power frequency fluctuations

These categories of electromagnetic phenomena we can describe by different attributes than the typical voltage level, specific frequency spectrum or time duration of electromagnetic phenomena.

A very important task is to determine the problem to the appropriate category of electromagnetic phenomenon, because only through it we can properly resolve the problems connected with the quality of electricity.

III. MEASUREMENT OF QUALITY INDICATORS OF ELECTRICITY

The power quality is assessed on the basis of measured data and their subsequent evaluation. The standard IEC 61000-4-30 (Part 4: Testing and measurement techniques – Power quality measurement methods) defines the measurement of power quality in the distribution system. The results of measurements allow to determine the origin of quality deterioration and to analyze the faults and identify if the problem was created by the customer or on the supplier side. The analysis results indicate the possible measures available to minimize the consequences of failures and make efficient use of electricity supply and consequently to reduce losses [5].

A. Classes of measurement performance

Class A performance

This class of performance is used where precise measurements are necessary, for example, for contractual applications, verifying compliance with standards, resolving disputes, etc. Any measurements of a parameter carried out with two different instruments complying with the requirements of class A, when measuring the same signals, will produce matching results within the specified uncertainty.

To ensure that matching results are produced, class A performance instrument requires a bandwidth characteristic and a sampling rate sufficient for the specified uncertainty of each parameter.

Class B performance

This class is due to the fact that many existing instruments were not obsolete. According to the above standards to evaluate the quality parameters we find a very vague definition of the requirements of evaluation parameters for class B. The standard IEC 61000-4-30 provides to instrument manufacturers the flexibility in the method of evaluating power quality parameters, and therefore instruments were degraded to the level of so-called indicators. These measured results are unreliable. This freedom provides a simplified algorithms and construction equipment. These changes have positive impact on the price of the devices but the negative sign on the accuracy of the results.

Class S (Survey) performance

The S-class is used only for statistical applications such as survey or estimate of the quality of electrical energy, but with a limited subset of the measured parameters. The apparatus of S-class uses the equivalent sampling intervals as class A. The difference between them is that the devices of class S are less costly to produce, because of the lower processing requirements.

IV. POWER QUALITY ANALYZER DESIGN

The power quality analyzer (Figure 1) is an apparatus for assessing the parameters of a single phase LV network (Table I). The device was used for the collecting and processing of the analog signals while providing three voltage inputs, three current inputs and one ground input. The measured results are displayed on the 3.2” color display and by SD card module the measurement data can also be recorded. The analyzer works on the basis of open-source platform Arduino MEGA2560 [1], [2], [4].

Figure 1. Power quality analyzer – a view from the right

TABLE I
Measured parameters by designed power quality analyzer

Measured quantity	Range	Unit	Phase	Evaluation interval	Tolerance
RMS – voltage	0-250	V	L1, L2, L3	200 ms	± 1 %
RMS – current	0-14	A	L1, L2, L3	200 ms	± 1 %
frequency	50	Hz	L1	10 periods	± 0,5 %
active power	–	W	L1, L2, L3	200 ms	± 2 %
appar. power	–	VA	L1, L2, L3	200 ms	± 2 %
power factor	–	–	L1, L2, L3	200 ms	± 2 %
voltage curve	–	–	L1	50 ms	–
current curve	–	–	L1	50 ms	–

To determine all parameters of the power supply, which is given in Table I, it is suitable to sample the voltage and current in each phase, and from the obtained samples calculate the particular parameters of network.

Block diagram of the designed analyzer is in Figure 2. The measured values are the first supplied to the block in which their voltage amplitudes are decreased and measured quantities are transferred into voltage. There is also overvoltage protection (thermal fuse) in the case of voltage measurement. Subsequently, these voltage is transferred through the low-pass filter for analog inputs A/D (Analog to Digital) of microcontroller ATmega2560.

Those parameters can be displayed on the LCD color display or sent via the USB port or wireless Bluetooth to a PC or other portable devices (tablet, mobile phone) for further processing, eventually the analyzer could be used as a data recorder machine and measured data could store on the SD card.

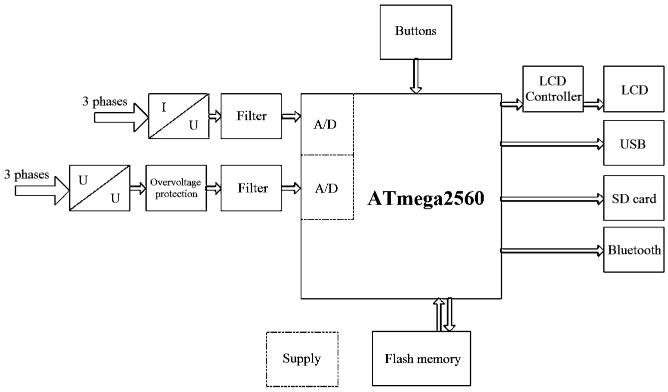

Figure 2. Block diagram of the power quality analyzer

A. Measurement of electric parameters of network

It is important to say a few details about the actual design of the analyzer. The power analyzer consists of two printed circuit boards. On the first board there are placed input-output terminals and measuring circuits (Figure 3). On the second board (Arduino Mega2560) there is a microprocessor and supporting circuitry, it is connected to the communication interface, graphical display and control buttons of analyzer. Wiring diagram of power analyzer is shown in Figure 4.

Analyzer should measure the parameters of LV network. The measuring circuits of analyzer are designed to measure the maximum value of voltage up to 1000 V and current up to 20 A (AC).

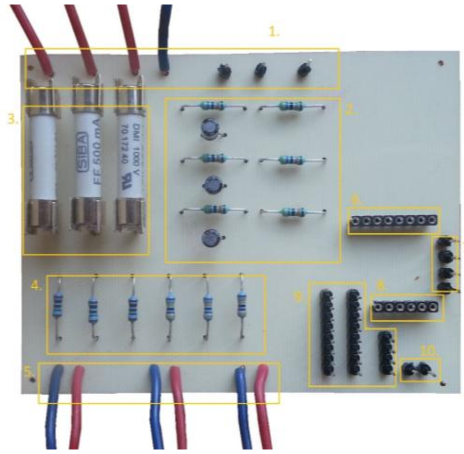

Figure 3. First PCB

Where: 1 – voltage and current inputs; 2 – filter and a circuit for current measuring; 3 – fuses; 4 – voltage divider; 5 – output to transformer; 6 – access to the SD card; 7 – output from the SD card to the Arduino; 8 – input to Bluetooth; 9 – energy supply (from left: + 5 V, GND, + 3.3 V); 10 – output from Bluetooth to Arduino.

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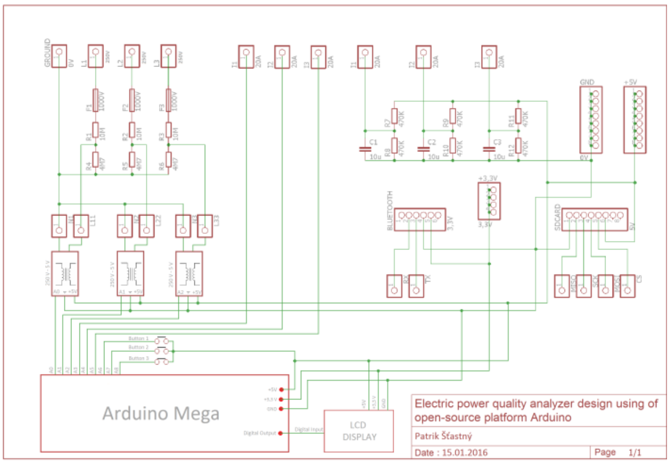


Figure 4. Wiring diagram of power quality analyzer

B. *Current measurement*

The current transformer YHDC SCT-013-020 (Figure 5) is a non-invasive current sensor, which is able to measure AC current up to 20 A. It is characterized by non-linearity of ± 3 %. Inside the sensor there is built the loading resistor of a value 33 Ω. Induced current flows through this resistor and generates a voltage drop in it. On the output by measuring current of 20 A, thus results in the voltage of 1 V. The measured current has alternating character, so the output voltage varies between –1 V to +1 V. Analog input of Arduino can measure only positive voltage. The voltage had to be adjusted by the addition of a reference DC voltage + 2.5 V (offset). This allows to obtain the final voltage in the range of + 1.5 V to + 3.5 V. The whole course is shown in Figure 6. The capacitor C1 serves as a low-pass filter.

Figure 5. Current clamp meter YHDC SCT 013-20 (current transformer)

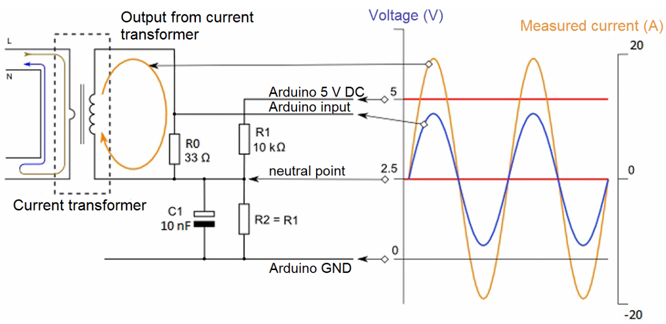


Figure 6. Current measurement

For measuring there was used Emonlib.h library. Procedure for calculation of rms current is as follows:

$$I_{RMS} = \frac{\sqrt{\sum_{n=1}^{n} I_n^2}}{n} \quad \text{A} \qquad (1)$$

where n – number of samples,
I – value of maximal current in particular sample.

In Figure 7 one can see the calculation algorithm, which is based on a command “for”. This command is used to repeat a certain part of the code that is placed in square brackets. In case of this analyzer it is a formula (1). The cycle is repeated until the time condition is fulfilled, e.g. the number of samples to be sampled.

For accurate measurement the device must be calibrated. It is impossible to produce a device with absolute precision. In general, the more accurately measures the device, the more expensive it is. To the accuracy of currents measuring impact three major factors:

- ratio of current transformer,
- load resistor value,
- accuracy of measuring the voltage on the analog input.

Calibration was done in the program, thus the value of the A/D converter (0 ÷ 409) was multiplied by the calibration number, thanks to which we get the real value of current. This value was compared with a device for verifying the accuracy. For this analyzer there was used voltage source Elgar CW1251.

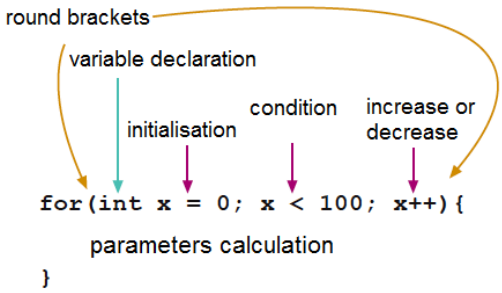


Figure 7. Command “for” procedure

C. *Voltage measurement*

For the measuring of voltage there was used measuring circuit on a printed circuit board (Figure 3). Voltage is brought through the overvoltage protector to the voltage divider, which reduces the amplitude of the measured voltage to a desired value $U_{desired}$ (value from peak to peak):

$$U_{des} = U_{L1} \cdot \frac{R_4}{R_1 + R_4} = 707{,}1\,\text{V} \cdot \frac{4\text{M}7}{10\text{M} + 4\text{M}7} = 226\,\text{V} \quad (2)$$

This voltage is consequently fed to the voltage transformer (Figure 9), which is similarly as in case of current transformer measuring processed into the suitable voltage for the A/D converter in the range of 0 V to 5 V. This process is shown in Figure 8.

Calibration was done in the program, thus the value of the A/D converter (0 ÷ 1023) was multiplied by the calibration number, thanks to which we get the real value of voltage. This value was compared with a device for verifying the accuracy. For this analyzer there was used voltage source Elgar CW1251.

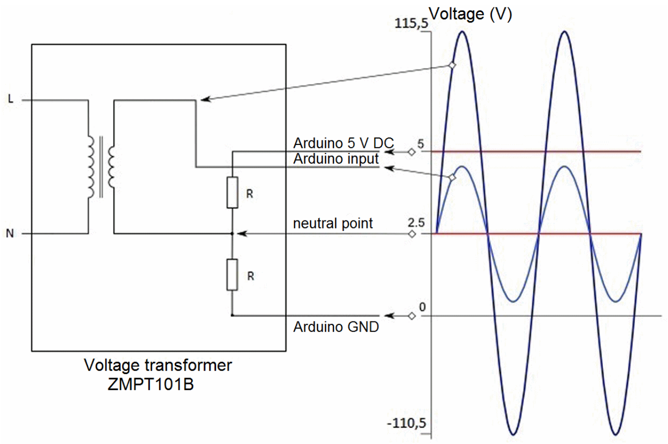


Figure 8. Voltage measurement

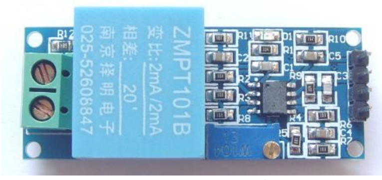


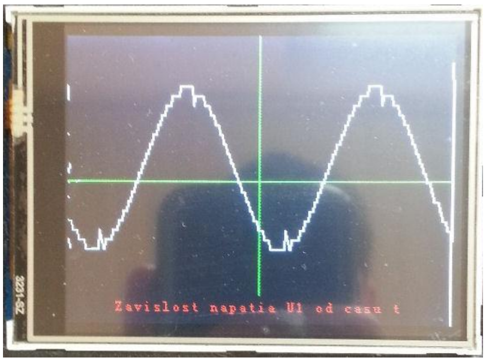
Figure 9. Voltage transformer

In the case of voltage, and also in the case of current measuring, the sampling and the calculation should operate in parallel to each other. That is, if there was terminated sampling of one phase by variable of type “A”, automatically there should start up sampling of the variable of type “B” and the calculation of the parameters “C” should be in parallel with sampling “B” calculated parameters of the variable “A”, on the other hand . During the sampling of variable of type “A” the algorithm should enumerate the parameters of variable of type “B”. But designed analyzer this function does not offer. Hardware is not enough to suffice the really fast parallel measuring, together with recording and displaying on the screen. The designed analyzer after sampling of parameters calculated them and then re-sample the analog signal of measured network (so there are some “holes” in data).

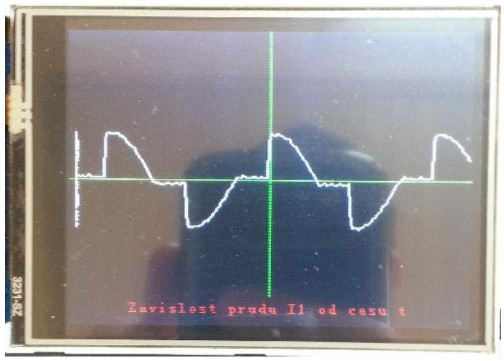
D. Measurement/calculation of another electric quantities

Analogically to previous quantities, there were realized in inner algorithm the calculation of another important electric quantities, such as:

- Frequency (f)
- Active and apparent power (P; S)
- Power factor ($\cos\varphi$)
- Oscilloscope function (Figure 10)



a)



b)

Figure 10. Oscilloscope voltage (a) and current (b) characteristics during the measuring of device of the power factor equal to 0,6

E. Measurement for determining the measuring error

According to determining the measuring error, there was used for comparing the measuring error testing device Elgar CW1251, that has 1 % error of measuring. According to this device there were realized a lot of test, that were used for set of calibration constant in algorithm.

V. CONCLUSION

The presented results of electric power quality analyzer design using of open-source platform Arduino should provide the basic knowledge to build a cheap and relatively accurate measuring device. This device could be used as a device of class S (Survey) performance only, because of the speed of measuring, recording data and post-process calculation. If one could use better performance, there should be used two board of Arduino or use multi-microprocessor platform.

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ADDRESSES OF AUTHORS

Ing. Dušan Medveď, PhD., Technická Univerzita Košice, Katedra elektroenergetiky, Másiarska 74, Košice, SK 04210, Slovak Republic, Dusan.Medved@tuke.sk

Ing. Patrik Šťastný, Technická Univerzita Košice, Katedra elektroenergetiky, Másiarska 74, Košice, SK 04210, Slovak Republic, Patrik.Stastny@student.tuke.sk