Project design of the electric power quality analyzer using an open-source platform

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***Abstract*—This article deals with the issue of creating a network analyzer of the power quality using the open-source platform in the form of the Raspberry Pi microcomputer. This paper presents a proposal design of a measurement circuit for recording the AC voltage up to 1500 V and a subsequent analysis of the measured data.**

Keywords—power quality analyzer, voltage measurement, Raspberry Pi, power quality, open-source platform

I. Introduction

Problems with the power quality take a wide range of problems in varying time ranges from ten nanoseconds throughout the time of the stabilized condition or steady state. All of these problems are caused by the different reasons and therefore require different and unique solutions that can be used to improve the power quality and thus improve the stability of the delivered power and also increase the reliability of devices. Many power quality problems arise from the incompatibility between the power system and the devices connected to the system. It is known that non-linear loads create harmonic currents that can generate resonance in the power supply system. Most problems associated with the power quality therefore can be identified by voltage and current measuring [1].

II. Design of the Network Electricity Analyzer

At the beginning of the creation of the electricity quality analyzer, it was necessary to determine which electrical quantities would have to be measured and further analyzed. Measured voltage was chosen. From the number of measured voltage samples, it is possible to analyze, calculate various types of energy quality indicators such as voltage waveform, higher harmonic voltage components, short-term voltage changes and even transient phenomena [5]. From graphical dependencies of analyzed samples of measured instantaneous voltage values it is possible to determine the harmonic components of voltage and also the actual value of the frequency of the network.

A. Selection of essential information

Electricity measuring devices record large amounts of data. It is therefore necessary to choose the correct and useful valuable values from the measured data. An electrical energy metering device should, after analysis, inform the user about the overvoltage and voltage drop as shown below (Figure 3). The output should also contain information of effective voltage value during the measured section [2].

B. Choosing of open-source platform

As a next step, it was necessary to select the right type of open-source platform that will handle the entire measurement and process the measured data. Decision was done among the one of the most popular Arduino platforms UNO, MEGA, and Raspberry Pi b+ [4], [5]. Because authors had previous experiences with Arduino and Raspberry Pi, the choice was on the Raspberry Pi microcomputer, because it has a choice of operating system and can be used to further extension of the measurement properties that the power quality network analyzer can perform.

C. Design of the measuring circuit

One task was set how to measure with the Raspberry Pi an alternating voltage within the maximum range of ±1 500 V with the highest sampling frequency. The range of values of ±1 500 V has been selected because the peak value of short-time overvoltage in network supply normally does not exceed this value. Raspberry Pi is able to detect a direct voltage up to 5 V at its analog input. To achieve this measurement range, it was necessary to reduce the maximum AC voltage from –1 500 V to +1 500 V range to a measurable voltage range from 0 V to 5 V, so that Raspberry Pi can measure instantaneous voltage values [8], [9].

Reducing of the voltage to desired value was done with a 300:1 voltage divider. At a maximum rated voltage of +1 500 V, a current of 1.51 mA would occur on the first circuit (dividing resistors), a load of 2.26 W. Therefore, 5 W resistors were selected. The voltage reduction could also be done by a transformer that would galvanically separate the supply network from the measuring circuit. Galvanic separation is an advantage because the transformer does not transmit electromagnetic noise, and the measuring device can measure more accurately, and the measurement would not be affected. The disadvantage of the transformer is in the necessity to know the frequency range of the transformer, that is, what the maximum frequency value can transformer transfer from the primary side of the circuit to the secondary side. But, when we decreased voltage by the divider, the voltage value was still negative. It was necessary to design a voltage wave shift (offset) that could shift the negative voltage level to positive values in the range from 0 V to 5 V. To shift the voltage level from negative values to positive, an operational amplifier was used that moved the level by 5 V from the negative values to positive.

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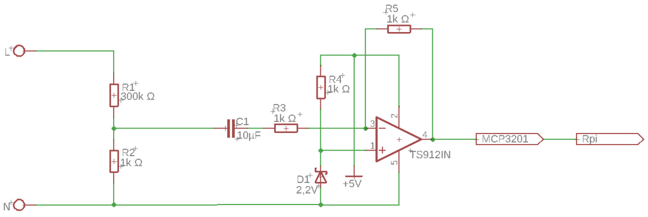

Fig. 1. Diagram of the connection of the primary measuring circuit (it was not successful circuit and therefore it was later modified)

Fig. 2 shows the voltage from the output of the operational amplifier measured by a laboratory oscilloscope, of a network “ideal” 230 V effective voltage, with maximum values of ±325 V by decreasing and shifting to positive values from 1.67 V to 2.71 V The signal was converted from analogue to digital in shape using the 16-bit AD converter MCP3201 at a sampling rate of 3000 samples per second. The plotted graphical dependence of the measured voltage with Raspberry Pi can be seen in Fig. 3, where the number of samples is on the horizontal axis and the vertical axis is the electrical voltage. As one can see, the measured signal in Fig. 3 differs greatly from the measured signal of an oscilloscope. Deformation of the voltage wave was caused by considerable noise, which was transmitted through the common neutral point of the network and the measuring circuit.

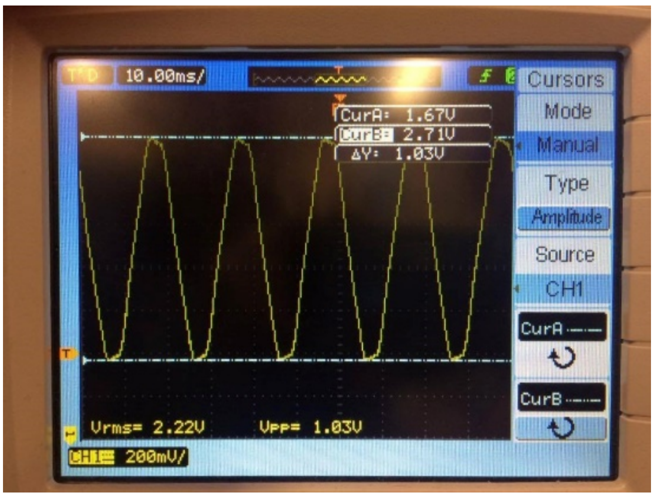

Fig. 2. Measured voltage characteristics from the output of the operational amplifier

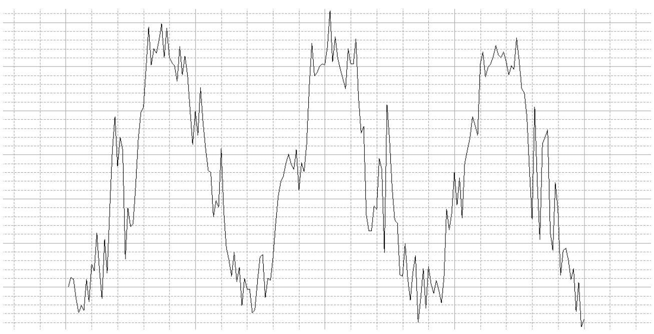

Fig. 3. Measured voltage values using Raspberry Pi from the output of the operational amplifier

The vertical axis (Fig. 3) contains the measured sample voltages and the number of samples *n* is on the horizontal axis. As shown in Fig. 3, the read signal was largely shaken. The 230 V effective voltage was measured, which, according to the standard, must not exceed ±10 % of the nominal value 230 V. The source of this noise was at the common ground point of Raspberry Pi and all the components together with the neutral network conductor. The problem was solved by the galvanic separation of the measured object and the measuring circuit. One option could be to use a transformer, but it would be necessary to know its frequency characteristic, because of the fact that high frequency voltage samples could be read. The isolation amplifier was then used for the galvanic separation. A new measuring circuit had to be designed to take samples of the instantaneous value of the voltage at the highest sampling rate and, in particular, without recording unwanted noise.

D. Filtering of the deformed signal

To filter off the noised signal, it was necessary to separate the neutral point of the network or separate the entire measuring circuit from one another. Fig. 4 shows the measured voltage after separating the relevant grounding of the components and the neutral point of the network.

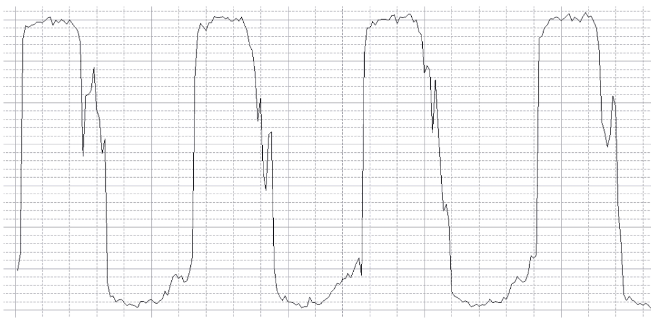

Fig. 4. Measured voltage values using Raspberry Pi after separation of common network points

As one can see from Fig. 4, the measured signal is more accurate, but not precisely, and so that the signal can be processed and analyzed to determine the electrical energy quality parameters.

E. Galvanic separation of the measuring circuit

In order for the network voltage analyzer to correctly read the input analogue values, it was necessary galvanically separate the designed network analyzer from the measured object (socket circuit of an effective voltage value of 230 V ±10 %). Separation was performed using an insulating amplifier (AMC1100). The final measuring circuit is shown in Fig. 5 and connection with real components in Fig. 7 [3].

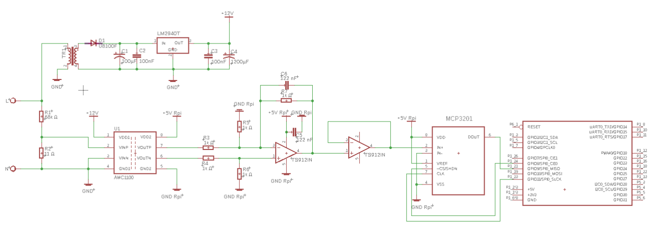

Fig. 5. Galvanically separated measuring circuit for measuring the instantaneous voltage

F. Configuration of Raspberry Pi

On the Raspberry Pi model b+ there was installed the Raspbian operating system without graphical user interface. Raspbian is built on the Debian Stretch operating system, which includes basic preinstalled programs like Python, C, Java, Mathematica. Connection to Raspberry Pi is possible via SSH, which must have been enabled so that an empty SSH file was placed on the SD card. After Raspberry Pi starts the file is loaded, SSH will be enabled, and then the file will be deleted. After activating SSH, it was possible to connect to Raspberry Pi, which had a dynamically assigned IP address. If there is no DHCP server that allocates the Raspberry Pi IP address, it is possible to connect via an RJ45 cable that is directly connected to the computer, or it is also possible to directly connect the Raspberry Pi output to the monitor as the microcomputer contains a graphics processor. Raspberry Pi has one SPI bus that contains two chip selections. By default, the SPI master driver is disabled and needs to be enabled. To enable SPI bus activation in the Raspberry Pi graphical configuration interface (raspi-config), you also need to enable the "dtparam = spi = on" parameter in the config.txt file located in the /boot/ folder. Using the "ls -l / dev/spi*" command, you can see the connected devices on the SPI bus and thus verify the functionality of the SPI bus. The output from the command looks like this:

```
pi@raspberrypi:~ $ sudo ls -l /dev/spi*
crw-rw---- 1 root spi 153, 0 May 15 23:27 /dev/spidev0.0
crw-rw---- 1 root spi 153, 1 May 15 23:27 /dev/spidev0.1
```

Fig. 6. List of connected devices on the SPI bus

It is possible to use 3 different libraries that process the signal through the SPI bus. The first library is SPIDEV, which does not access the bus directly but uses the Linux driver to access the SPI bus. This library was used as a first one when creating a program in the Python programming language (we left this option) [6]. The program showed some limitations as the maximum sampling rate did not exceed 3000 samples per second. Consequently, the WIRINGPI library was used, with the advantage of accessing the hardware register directly. The library was used to code in the C++ programming language. The maximum frequency achieved was approximately 13 000 samples per second, which is a very favorable sampling value. For example, this frequency could be increased by overclocking the processor, as the A/D converter is ideally capable of sampling at a frequency of up to 100 000 samples per second. The created electrical quality measurement device works as an offline analyzer, so it stores the collected voltage values in a file. Saved data must be transferred to another computer to process the results. The transmission of the measured data can be directly via the SSH connection, or Raspberry Pi also contains an FTP server that can be connected to an ftp client, and it is then possible to transfer the data to an external processing device. *Note from authors*: in next steps we work on on-line network analyzer using of Raspberry Pi.

Raspberry Pi can be configured as a web server that can instantly process the measured data and graphically illustrate a software cron running (tasks scheduler) in the background to update the web server display for every major change. However, these options also have their limitations, all at the expense of the Raspberry Pi performance, which would limit the sampling rate [3].

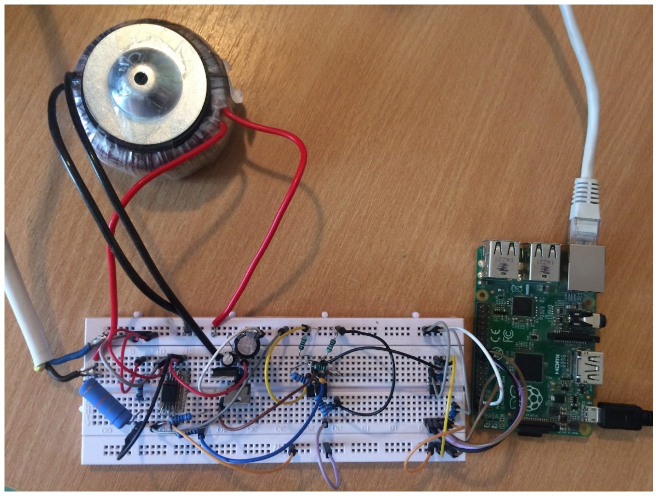

Fig. 7. Connecting of the electrical energy quality measurement circuit

Measured and plotted voltage values of a galvanically separated measuring device are shown in Fig. 8. The sampling frequency was approximately 13 000 samples per second. The data reading program from the four-wire synchronous serial bus (SPI) was created in the C++ programming language.

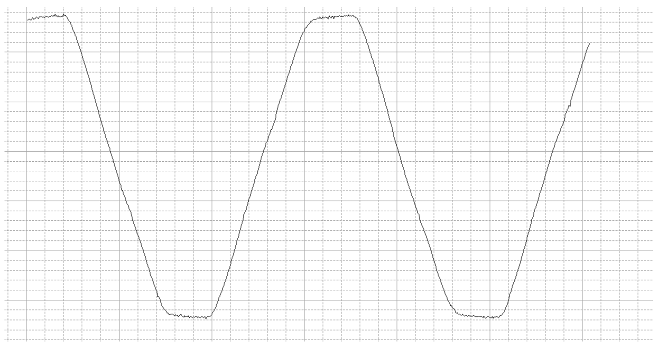

Fig. 8. Measured voltage values by galvanically separated measuring circuit

III. Evaluation of the Measurement of Electricity Quality Parameters

A. Voltage measurement

The constructed power quality device records voltage values and then processes these data in MS Excel. Fig. 9 shows the voltage pattern after switching on two electric kettles where the peak voltage dropped by about 12 volts. The voltage was measured for 1 second. The voltage pattern in Fig. 9 is approximated to the positive part of the peak voltage values for better visibility of the voltage change after the kettles were connected.

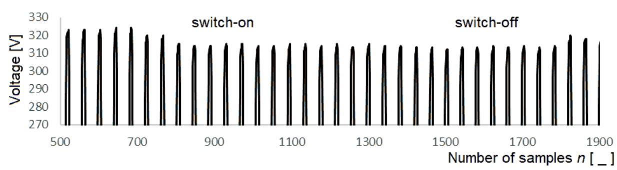

Fig. 9. Simulation of voltage waveform deformation by turning on electric kettles

There was necessary to calibrate and also compare the accuracy of the created device. Therefore, two measuring instruments were compared, namely the ENA330, which reads the values of the sample rate 38 400 samples per second [7] and the created measuring instrument using Raspberry Pi model b+, which sampled at a frequency of 2050 samples per second. The sampling frequency of Raspberry Pi was deliberately limited in order to determine whether this sampling frequency will be sufficient. The measurement results are shown in Fig. 10.

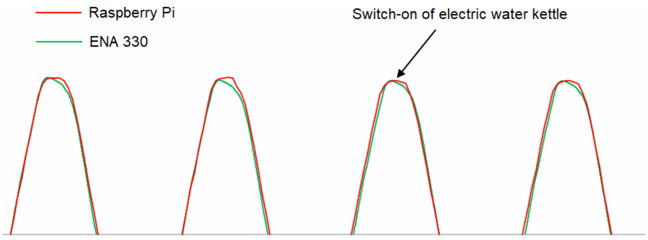

Fig. 10. Comparison of electricity quality measuring instruments

By comparing the measured voltage waveforms, it was found that the designed power quality instrument measured very similar voltage values as the ENA330, where the ENA330 is accurate to ± 0.1 %. By turning on one electric kettle (Fig. 10), you can see a slight drop in voltage, but it is not as significant as when you turn on two electric kettles as shown in Fig. 9.

B. *Higher harmonic measurement*

From the measured instantaneous voltage values, the higher harmonic components of the voltage were analyzed. In this case, Raspberry Pi was created only to capture the measured data, and the next analysis was realized offline (using a desktop computer). Determination of higher harmonic components was realized in MS Excel program, where using the built-in function of Fast Fourier Transform it was possible to determine the higher harmonic components of voltage. The anti-aliasing filter was set to filter higher frequencies from the 25th harmonic voltage component.

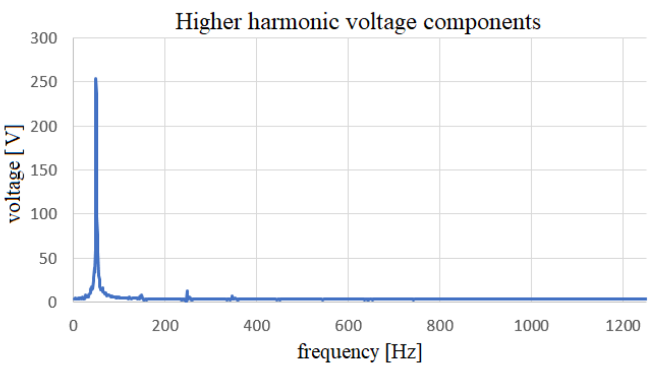

Fig. 11. Harmonic and inter-harmonic components of voltage

IV. Conclusion

On the basis of the obtained results, it can be stated that the proposed measuring circuit exceeds the minimum normalized data acquisition rates (mentioned in standard STN EN 50160). The maximum obtained write speed was 13 000 samples per second. The proposed measurement device has a broad perspective of further extensibility in the direction of autonomous data collection and further processing of the measured data [3]. The next steps of authors will be to enhance the measuring accuracy and adding the on-line processing within the Raspberry Pi.

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