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QUALITY OF SERVICE MONITORING IN ELECTRICAL DISTRIBUTION NETWORKS

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Abstract:

The Romanian regulations tend to align to European ones concerning the assurance of the quality of power distribution in terms of frequency stability, waveform distortion and the continuity of supplying. The main responsibility for monitoring the quality of energy parameters is of the distribution operators which are doing it more or less effective and transparent. Despite the fact that Romanian regulations stipulate that distribution operators must pay compensation to consumers under certain conditions that will be presented below, no one seems to be interested in investigating the circumstances that could compel operators to pay compensation. This paper present a solution for monitoring the continuity of the power supply that can be used by both consumers and operators. It involves a small piece of hardware equipment driven by a micro-controller which log all power outages and of the exceeding limit values for the nominal voltage, displaying the contents of the log on demand.

Key words: Quality of Service, Power Distribution, Energy Networks, Consumer Protection.

JEL classification: L15, L89, N74

INTRODUCTION

Electrical energy is a product and like any product, it must meet its own quality requirements. In order for an electrical equipment to work correctly, it is necessary that electrical energy be supplied to it at a voltage within a certain band around the nominal value. A large - significant - part of the equipment used today, especially electronic devices and computers, requires a good quality of electricity (Henryk Markiewicz, 2004). Electrical Energy in the distribution networks has a peculiarity: it cannot be stored and must be consumed while it is being produced. Thus, the measurement of quality indicators must be done at the time of its production. Due to the different perspectives of producers and distributors, on the one hand, and of the consumer, on the other, the energy quality indicators are defined by standards. The electrical characteristics of consumers' electrical appliances are also regulated by standards. After 2000, the electric power transport and distribution activity was privatized, becoming the property of some companies from Italy, Germany and the Czech Republic.

Unfortunately, as the media have revealed several times, the promised investments in the modernization of the companies have been delayed or never made. As a result, the quality of the energy distribution service suffers, especially in rural areas where investments are almost absent. According to *Affinity Energy*, (Evora, 2015), the larger percentage of power quality (PQ) issues is done by transient & surges (28%), followed closely by the voltage dips (24%), short interrupts (19%) and long interrupts (13%), figure 1. The low level of PQ leads to important costs, evaluated to $15 billion every year by the cited source.

At the level of the medium and high voltage chains, the suppliers and the distributors have the appropriate equipment for monitoring a large number of quality parameters but this monitoring is missing on the low voltage side. The reasons are multiple, both objective and subjective. The truth is that consumers expect a high PQ while carriers as well as distributors want to keep costs as low as possible because increasing the PQ requires spending and investment.

In this paper we present a low-cost solution for monitoring several PQ parameters in the distribution network, which can be used both at the consumer's home and at different key points of the distribution network.

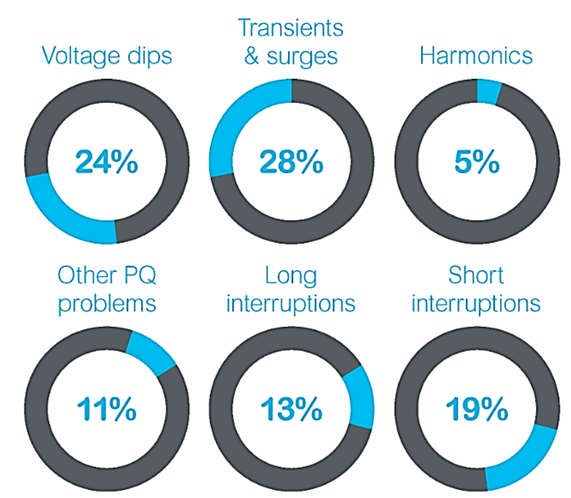

Figure no. 1. The weight of different causes in the power quality issues
Source: Evora, 2015

BACKGROUND

The Romanian institution in charge of developing energy regulations and supervising their compliance is ANRE (National Agency for Energy Regulation NAER). On July 1, 2021, the authority issued Order 46/2021 approving the Performance Standard for the electricity distribution service, which defines the concepts underlying the performance evaluation and, implicitly, the determination of the quality of distribution services. Regarding the continuity of electricity supply, the Order defines the following types of interruptions (ANRE, 2021):

1. Transient interruption - interruption with a duration (t) of a maximum of 3 seconds ($t \leq 3s$); short interruption - interruption lasting between 3s and 3 minutes ($3s < t \leq 3$ min.);
2. Long interruption - interruption of more than 3 minutes ($t > 3$ min.);
3. Planned outage - outage required for carrying out development works, re-engineering, exploitation or maintenance, announced before intervening in the network, electrical distribution, according to the provisions of the standard;
4. Unplanned interruption — interruption about which affected users were not notified in advance accordingly the provisions of the standard;

The order stipulates that the maximum number of short power outages should not exceed 10 per week. As for the voltage variation, a limit of ±5% is considered normal. However, larger variations are accepted under special conditions. Thus, a deviation of +5% to -10% is allowed if at any given time, 95% of the effective values measured fall within this range. Also, during any one-week time interval, 100% of the effective values, averaged over a period of 10 minutes, must not deviate more than +10%/–15% from the nominal voltage.

Other parameters subject to constraints are the frequency and the harmonic distortions. Based on our own measurements, there are not issues with frequency deviation which is less than 0.5 Hz, thus we can skip this kind of measurement in our approach. In terms of waveform purity, the determinations require expensive equipment that is inconsistent with our goal of maintaining a low product cost.

Anyway, in the case energy consumption for domestic purposes, the most disturbing non-conformities are the outages and the voltage variations. Household appliances work just as well at frequencies of 49 or 51 Hz, but not as well at variations greater than ±10% of the nominal voltage.

The Romanian Performance Standard stipulates that distributors will have to compensate consumers from the high voltage network, if the number of unplanned interruptions is greater than 10 per week. As the distributors do not monitor the parameters in low voltage networks, it is almost impossible to prove that in various situations the number of outages is larger than the admitted limit.

In short, our proposed implementation only monitors voltage level and voltage drops which are the most disturbing non-conformances and which are subject to financial compensation from the distributors. The device records each voltage variation outside the allowed limits and the date-time of the voltage drop and its recovery to normal values.

THE PRINCIPLE

The surveillance device is built around a microcontroller with a Wi-Fi interface, in order to keep a high accuracy of time measurement. From time to time, at every 5 min. more precisely, the microcontroller connects to an Internet time server, requesting the precise date and time. Between requests, the microcontroller keeps internally the actual time, with high accuracy. The internal clock is also useful during voltage drops when the Wi-Fi router is out of service and the connection with the time server is not possible until the power supply is restored.

The device is powered by a power module that also provides voltage detection signals, one for voltage variation and another for no power. The power module also charges a small LiPo battery that keeps the device powered during power outages. A 1000 mAh battery provides at least 72 hours of power reserve.

For the device functioning control, an OLED display was attached to the device, as shown in figure 1. During normal functioning it display the current time and when voltage drops occur, it display the state of the power supply and the number of the outages since the last device initialization.

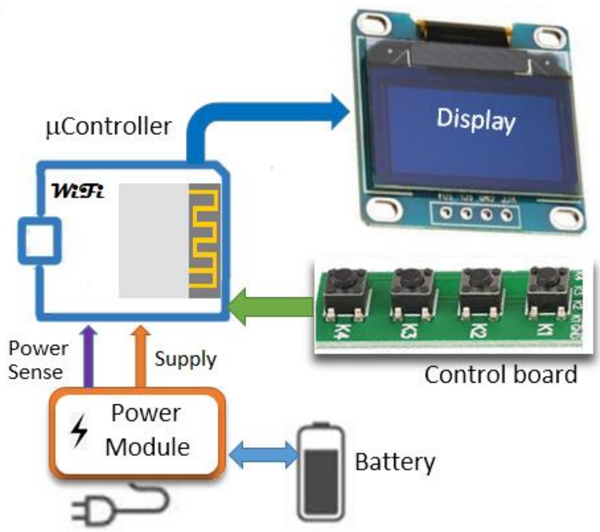

Figure no. 2. Block schematic of the sureveillance device

A control board is also necessary for different commands, as for displaying the content on the memory or device initialization.

THE PROTOTYPE

Hardware Architecture

In the implementation of the idea we used the flash memory of the microcontroller for storing information on the power outages and voltage variation. This solution helps to keep the total cost low, because it doesn’t require any additional storage modules. The power module connects to the power network by a regular USB charger, which supplies the whole device and a small AC transformer needed to provide the voltage to be measured and compared with reference voltages. The 5 V output from USB charger is used to supply the LiPo battery charger (M2 in the Figure 2) and also serve as witness of the power supply. Because all chargers have a capacitor at the output, the output voltage does not drop instantly when the power input outages. In order to obtain a quick response, a Trigger Schmitt was used and implemented with a 555 timer (U2 in Figure 2). A small resistor (R4) is connected to the 5V charger output in order to speed up the discharge of the internal capacitor.

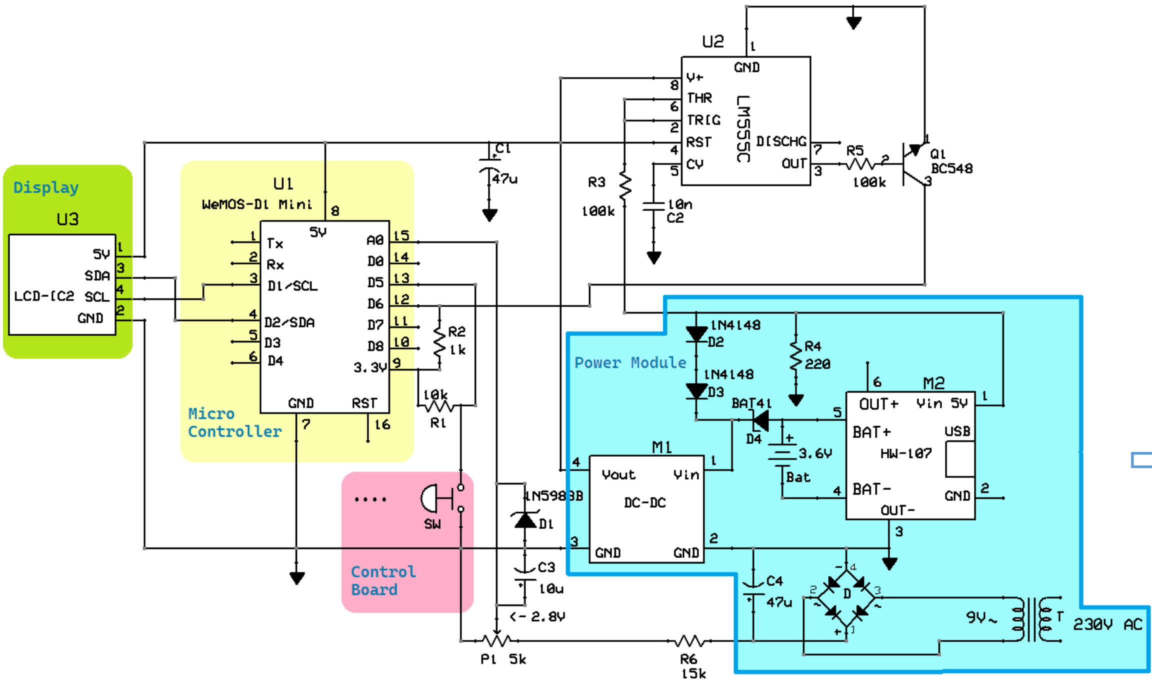

Figure no. 3. The electronic schematic of the device

The signal at the trigger (U2) output indicating the power outage goes from 0 to 5 Volts with a small delay of approx. 11 ms (Figure 3) and from this reason the outages shorter than 15 ms cannot be detected. The total time resolution of the device was set by software to 100 ms.
Because the battery voltage varies in large limits, 3.2 V and 4.2 V, an additional module was introduced (M1, Figure 2) which generates a stable 5 V output, regardless the battery charging level. This voltage is used to power all other circuits on the board.

As a microcontroller an ESP8266 based module was used, the version WEMOS MINI D1 with Wi-Fi interface. The Wi-Fi is necessary in order to keep a high accuracy of time which is achieved by periodically reading an Internet time server.

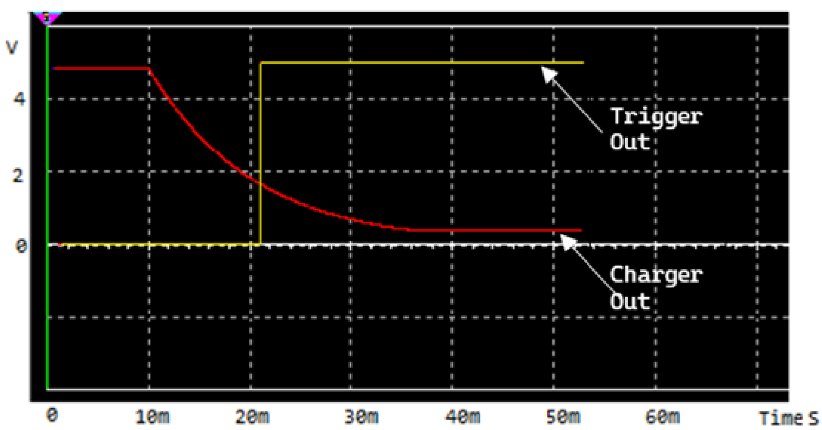

Figure no. 4. Obtaining the signal indicating the power outage

The software component

When powered on, the microcontroller tries to connect to the home Wi-Fi network using the *ssid* and the *password* provided in the declaration section of the sketch. It loops until the status of the *Wifi* object become equal to WL_CONNECTED then continues its initialization (figure 4).

```
void setup() {
  Serial.begin(115200);
  display.print("Connecting..");
  display.display();
  WiFi.begin(ssid, password);
  Serial.print("Connecting ");
  while (WiFi.status() != WL_CONNECTED){
    Serial.print(".");
    delay(500);
  }
  timeClient.begin();
  Serial.println("Connected");
  delay(100);
```

Figure no. 5. Connecting the device to the home Wi-Fi network

```
void loop(){
  getTime();
  delay(90);
  showTime(Time);
  testPower();
  surveyV();
  testReadBtn();
  milisec++;
  display.clearDisplay();
  timeUpdated==0;
}
```

Figure no. 6. The main program

The main program consists in some calls to several procedures whose names suggest what is doing each of them (Figure 5).
Even if *getTime()* function is called every 90 ms (approx.), the requests for the Internet time occurs every 5 minutes, as it can be seen in Figure 6. A loop runtime takes about 100 ms and thus, during one second many request to the time server are made. In order to prevent repetitive requests we used an additional variable *timeUpdated* which is set to 1 every time a request has been made.

Before updating time, the routine *getTime()* checks whether the device is connected to the home Wi-Fi network, otherwise the time runs under the internal clock (line two in figure 6). This check is necessary because we assume with high confidence that few users have a backup power supply for the router, so in most cases when the mains power is interrupted or the voltage drops below the minimum allowed value, the router cannot provide the necessary Internet connection and the updating time is useless.
If the connection is lost, the software tries to reconnect to the Wi-Fi in order to get Internet access and, thus, gaining access to the Internet time server. We found the solution we adopted to be more convenient to other available on Internet, e.g. (Random Net Tutorials).

```
if(timeClient.getMinutes()%5==0 && timeClient.getSeconds()==0 && timeUpdated==0){
  // update time every 5 minutes
  if(WiFi.status() == 3) {
    timeClient.update();
    Serial.println("Update time");
    timeUpdated=1;
  }
  else {
    WiFi.disconnect();
    WiFi.reconnect();
  }
}
```

Figure no. 7. Every 5 minutes a time update is made

As for voltage variation, a different branch of the power module is used. It supplies a rectified and filtered voltage from a 9 V transformer in the secondary winding. Since the single analog input A0 of the microcontroller accepts a maximum input voltage of 3.3 V DC, a resistive divider is used to adjust the voltage for A0 to 2.8 V DC, corresponding to the main supply voltage of 230 V AC. This value comes from an elementary calculation taking into account the 10-bit resolution of the analog-to-digital converter (ADC) of the microcontroller used, as well as the variations accepted for the mains supply voltage. The software implementation of this approach is displayed in figure 7.

```
char daysOfTheWeek[7][4] = {"Du", "Lu", "Ma", "Mi", "Jo", "Vi", "Si"};
const int I2C_DISPLAY_ADDRESS = 0x3C;
const int SDA_PIN = D2;
const int SDC_PIN = D1;
int nominalVoltage=900; //coresponds to 230V
int minVoltage=nominalVoltage*0.9; //207 V
int maxVoltage=nominalVoltage*1.1; // 253 V
bool modified =false;

void setup() {
  Serial.begin(115200);
  if(!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) {
```

Figure no. 8. The nominal voltage of 230V corresponds to a value of 900 in the range from 0 to 1023. Hence the corresponding values for the minimum and maximum values of the accepted voltage limits.

When the device is put into operation for the first time it checks for the files keeping the records of outages and of exceeding the limit values for the power voltage. As initially they are missing, they are created and corresponding messages are sent to the Serial monitor, figure 8. The files are kept until they are deleted by the operator by pressing a button on the control board.

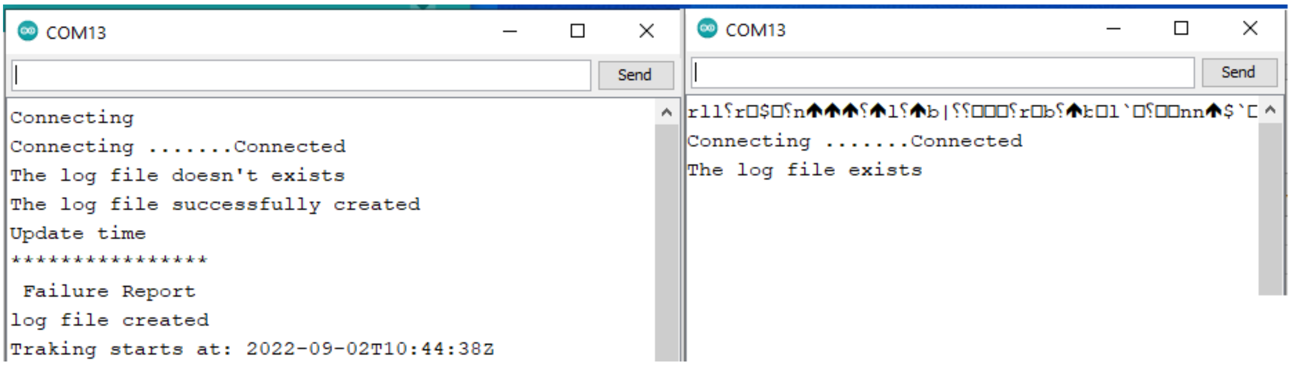

Figure no. 9. At the first use of the device, no file exist in the filesystem of the microcontroller flash memory. Afterwards the file is kept and new records are appended.

In normal conditions, the display of the device shows the current time. When the first voltage outage occurs, the display shows the number of total outages (1 for the first disruption). During the missing of the main power supply, an informative message in yellow color is also displayed (Figure 9). In this time, the information on the event is written in the flash memory of the controller. The same for the exceeding of the voltage limits, in a separate file. The content of the files are available on pressing different buttons on control board (Figure 1). The control board includes a button for erasing the content of the flash memory. Both log files are removed with a single click.

Samples of the logs contents are shown in figure 10.

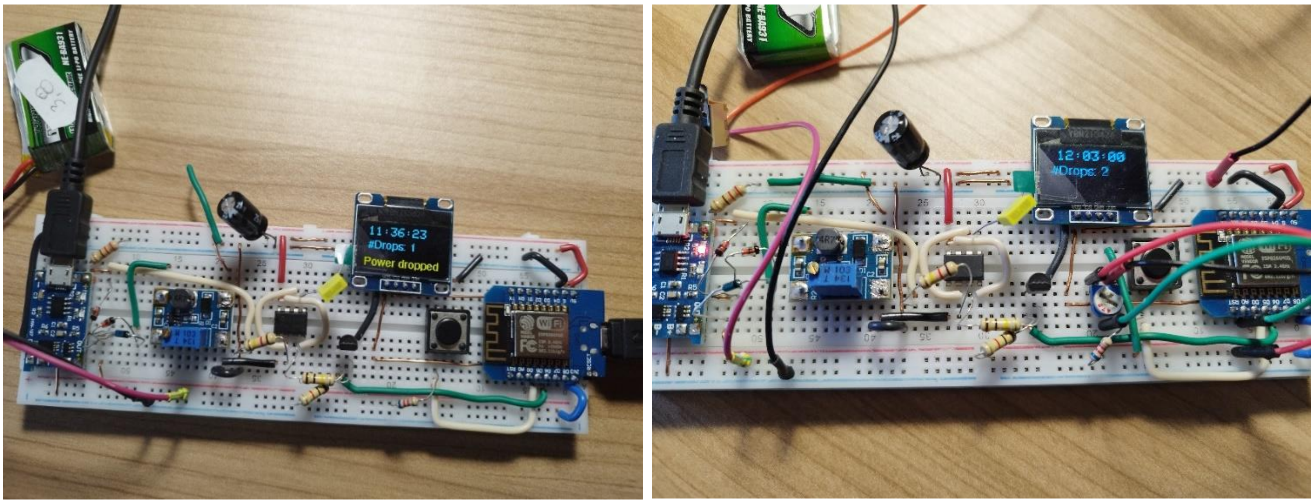

Figure no. 10. Two different states of the device and the correspondent messages displayed

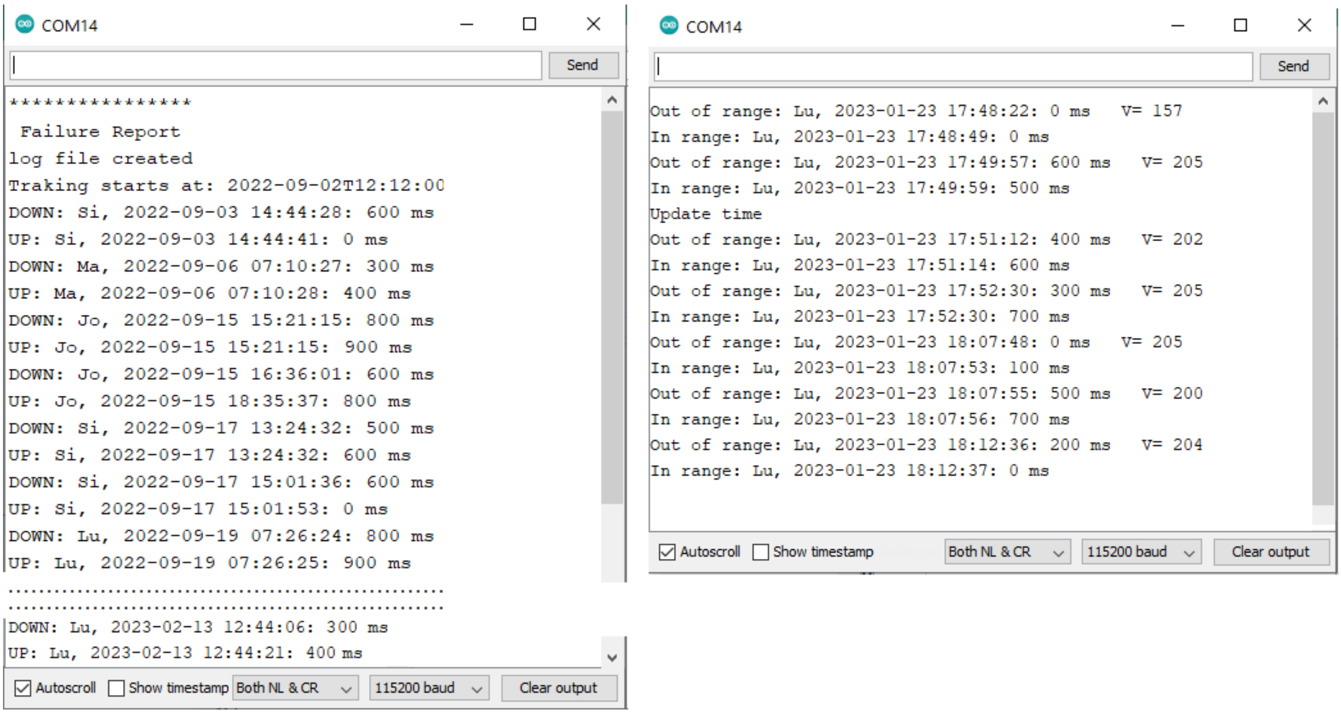

Figure no. 11. Logs of power outages (left) and voltage out of range (right)

RESULTS

The experiment was done in two neighboring villages in the plateau area of Moldova, namely Plopeni and Tișauti and in Suceava City. During our experiment we noticed that in the rural regions the number of non-conformities is significantly larger than in urban regions. In rural areas there is a greater variability in seasonal behavior than in urban areas.

As causes we assume that while in the urban areas there is a predictability of consumption depending on the season, in rural areas the things are much more complicated. In the villages, during the summer until the end of autumn, many residents use sawmills to cut the wood needed for heating. There are also many exterior repair or landscaping works for which several tools with high energy consumption are used intermittently: welding machines, angle grinders, concrete mixers, etc. On the other hand, distribution companies grant building permits for new consumption points, both residential and production/services (concrete and asphalt mixing plants, car service workshops, motels, gas stations, etc.) without adapting the transport capacity of electricity to the new consumptions. In general, distribution companies are not interested in developing the distribution network as long as the maintenance costs do not exceed the investment cost. And if the population does not know their rights to claiming financial compensation, the operating costs will remain low for a long time.

CONCLUSIONS AND FURTHER DEVELOPMENTS

In this paper we proposed a low-cost solution for monitoring the main power parameters that are the most bothersome for household consumers. If approved by the responsible authority, equipment like this can be used as evidence to demonstrate the low quality of energy distributed in low-voltage networks and consumers to be reimbursed according to the regulations in force.
However, the solution we proposed has some limitation, the content of the flash memory of the microcontroller can be accessed only by the device and displayed on the Serial monitor and copied from there and transferred to an external file.

As a direct improvement is to replace the storage medium with an external SD card and use a file format compatible with one of the common DBMS, like SQLite. Thus, the content of the SD card can be easily read by any PC running SQLite. This will increase the cost of the device a little, but not by much.

Another development is the transfer of local records to an IoT server. As soon as the power supply returns to nominal values, the device updates the IoT server records. This is the best solution that can be used by power distribution operators to monitor large areas where repetitive power outages are reported.

As for the study itself, we consider it useful to be extended to several regions of Romania and for several forms of relief, considering the fact that the sources of charging the electrical network are different from one area to another.

BIBLIOGRAPHY

1. ANRE. (2021, 06 15). *Standarde de performanta.* Retrieved from ANRE: https://www.anre.ro/download.php?f=fqh7hqk%3D&t=vdeyut7dlcecrLbbvbY%3D
2. Evora, A. D. (2015). *Infographic: Understanding the impact of Power Quality.* Retrieved from https://affinityenergy.com/power-quality-infographic/
3. Henryk Markiewicz, A. K. (2004). *Voltage Disturbances, Standard EN 50160 - Voltage Characteristics in Public Distribution Systems.* European Copper Institute, UK.
4. Random Net Tutorials. (n.d.). *Reconnect ESP8266 NodeMCU to Wi-Fi Network After Lost Connection.* Retrieved from Random Net Tutorials: https://randomnerdtutorials.com/solved-reconnect-esp8266-nodemcu-to-wifi/