Remote Monitoring System for a Three-phase Electric Power Grid

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***Abstract*—This paper presents a solution for the remote monitoring of a three-phase electrical power grid. The solution is made up of three main parts: the data acquisition module which, at its core, has an ADE7758 integrated energy meter and uses a LoRa module for data transmission, the gateway which receives the data sent by the data acquisition module and sends it further to the database and the web application written in PHP, which interprets and displays the collected data. The presented solution was tested in various power measurement scenarios including long-term reliability check in a public lighting network. It also easily integrates into many kinds of low-voltage power networks and proved to be a very cost-effective and reliable alternative to other similar smart energy monitoring systems.**

***Index Terms*—remote monitoring, power grid, ADE7758, LoRa, IoT, gateway**

I. Introduction

Experts are arguing that we stand on the brink of the 4$^{\text{th}}$ industrial revolution [1], hence the need to create optimal ways of managing the probably most important resource, that makes all technological advances possible and lets us dream of future endeavours – electrical power.

In an age in which technology is becoming more and more accessible to the masses and science has seen awe-inspiring progress, remote controlled and monitored systems are in high demand. Whether it is for personal or public use, people have designed systems that can monitor and control almost anything you can think of, and the concept of IoT has become widely popular. In the last few years, electronic solutions for measuring electrical power, have quickly replaced the previous electromechanical technology, thus introducing the industry to the new digital era [2]. With the increase in automation and the world's economy becoming more digital, the need for advanced technology in monitoring and control of the power supply systems is paramount [3].

Following thorough studies and research on the current state of the market, we took on the challenge of building a reliable solution for monitoring the parameters of a three-phase electric power grid, designed to be a cost effective alternative to other similar solutions which, for many towns and small cities, are intangible.

To allow remote monitoring of electrical parameters, we decided on using an ADE7758 3-phase high-accuracy integrated energy-meter chip capable of retrieving per phase information [4]. Digital measurement of electrical power using the ADE7758 chip was demonstrated in [5]. The same chip was used in a wireless 3 phase motor control system in [6] and in a load forecasting system in [7]. These all prove the viability of smart energy metering using this integrated circuit.

To facilitate remote access to the measurement data and for control operations from a distance, various communication technologies are available, for example, ZigBee, Bluetooth, wireless, and wired LAN [8]–[11]. Our option for long-range communication is the LoRa protocol, which offers the highest usability in remote locations without direct Internet access [12]. However, for the increased reliability of the system, the option for additional wired communication links is also included. A conceptual overview of the communication system is presented in Fig. 1.

Of course, a remote control and monitoring system cannot be complete without a user interface, which is implemented in the form of a web application giving the highest accessibility to the data, from anywhere in the world.

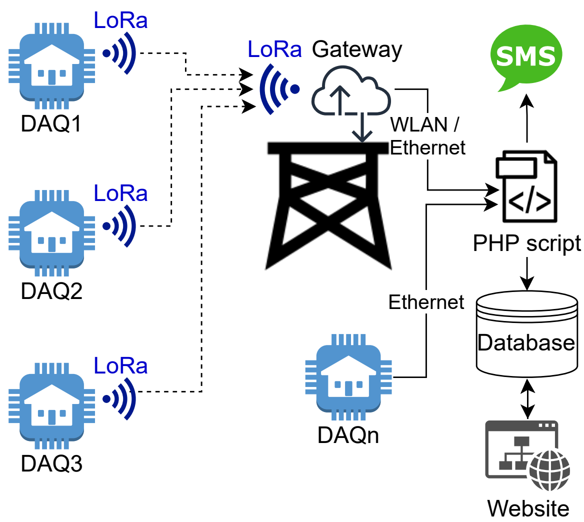

Fig. 1. Remote monitoring system architecture

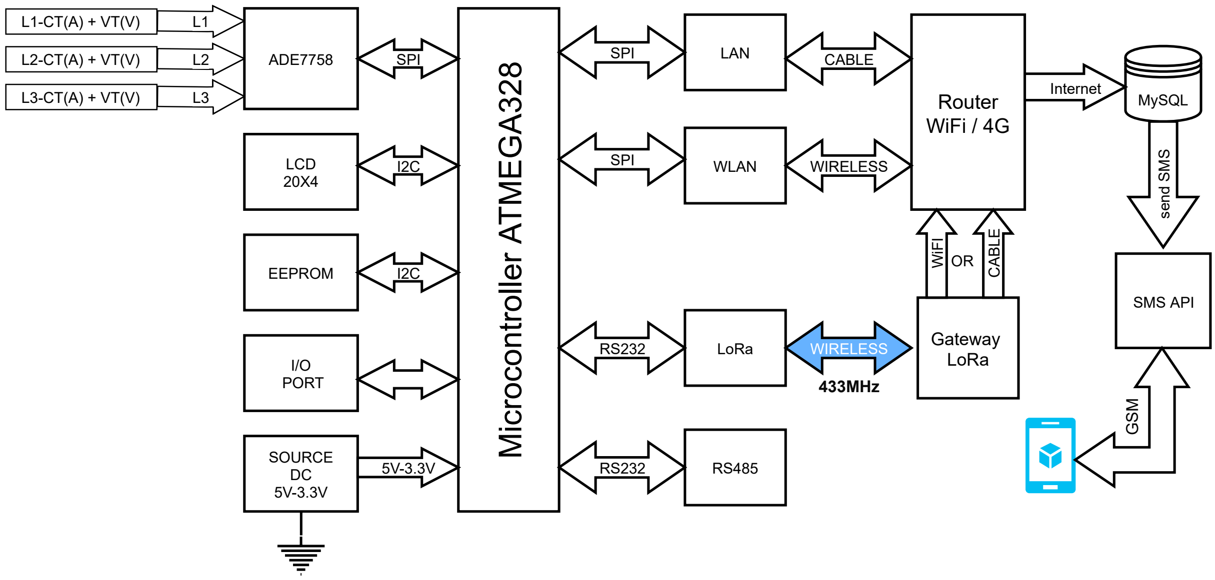

Fig. 2. Block diagram of the proposed system

II. System Overview

The proposed system is made up of three interconnected subsystems: a set of data acquisition modules (DAQ) connected to a common gateway which routes the data into an online database and a web application offering remote access to the collected data.

The DAQ modules implement the measurement on the power lines and upload all the data into the database by communicating on one of the following possible channels:

- Ethernet link, connecting the DAQ modules and the database directly – requires an active internet connection to every DAQ module
- WiFi link, connecting the DAQ module to an available wireless access point which in turn is connected to the internet – requires an active access point in the close proximity of the DAQ module
- long range radio link using a LoRa protocol between the DAQ module and a gateway, which in turn connects to the internet via Ehternet or WiFi – in this case only one internet connection is required for serving many DAQ modules.

The redundancy in transmission is essential for such a remote monitoring system, because the DAQ modules are not always installed in areas with a good internet connection, but also because the costs of implementing such a system would go up by installing an Ethernet link in every DAQ module. By enabling the DAQ modules to send the collected data to the database in three ways, we can assure the stability and reliability of the system, the accuracy of statistics and graphics which will be compiled using this data and the response time of the control loop.

These characteristics are important for a monitoring and control system in any electrical power grid, considering the following issues that should be resolved by the system:

- Reduce energy consumption
- Detect any defects in the power supply chain
- Detect any unauthorized device introduced to the system (theft)

To achieve these an always-on bidirectional communication is necessary, so the modules can be instructed to cut the power supply in case they sense any failure, and can also send out alert messages to one or more designated persons.

A full block diagram of a DAQ module and the connections to the database is presented in Fig. 2

III. The Data Acquisition Module

The data acquisition module is based on an 8-bit Atmel ATmega328 microcontroller and an Analog Devices ADE7758 integrated energy-meter. High range radio communication with the gateway is realised by a LoRa SX1278 module which offers data transmission to distances of up to 20km in optimal conditions. In the event of a communication loss, an on-board non-volatile memory can store data of up to 1200 data points until communication between this module and the gateway is reestablished. The integrated energy-meter is connected through a voltage divider directly to the phase lines for voltage measurement, and also to type CT current sensors with a ratio of 1:250 for current measurement. The sensors used are YHDC SCT013 split current transformers which offer a non-invasive way of measuring the intensity of the current. The sensors have a split core which can be wrapped around the cable (like a clamp) and the readings are done by electromagnetic induction. The maximum input current for the type of sensors used is 100A and the output current is 50mA [13]. The current transformer has a non-linearity of $\pm3\%$ and can withstand temperatures between -25° C and +70°C.

A simplified version of the proposed schematics are presented in Fig. 3 and the populated boards are presented in

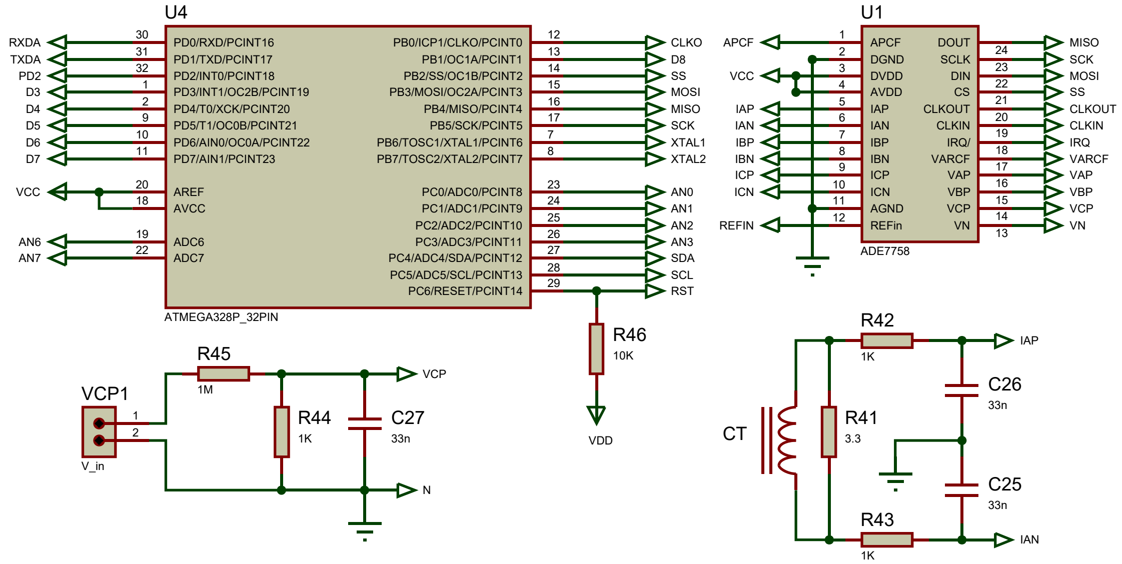

Fig. 3. Simplified schematics with the microcontroller, energy-meter chip and the measuring probe for a single phase

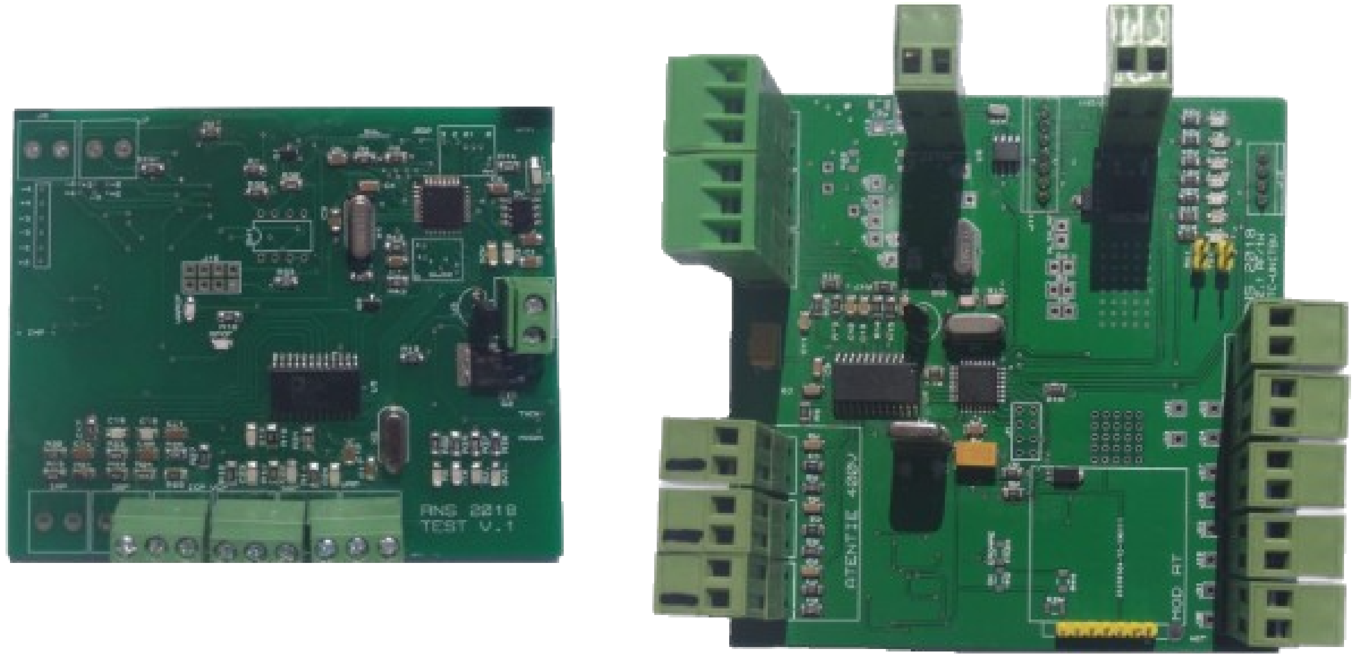

Fig. 4. DAQ modules (version 1 to the left, version 2 to the right)

Fig. 4. There were two version of the PCB designed in Proteus and produced in prototype quantities.

The first version of the PCB was tested in various scenarios and erroneous data was observed on the phase 3 power measurement. After a quite long and tedious analysis process going through every part of the PCB and sensor connected to that wronged reading, we discovered that the traces shown in red in Fig. 5a were too close to the ADE7758 chip, causing the wrong readings.

In the second version of the PCB, the offending traces were rerouted and a ground plane added underneath the ADE7758 chip (see Fig. 5b). This second version of the PCB was then again tested using various scenarios in order to establish whether there are any more faults that needed mending. After passing all tests locally, in order to assure that the readings were highly accurate, it was also submitted to one of the leading laboratories for metrology and calibration in Romania. All the current, voltage and power measurements proved to be very accurate, and an ISO compliance certification was issued for this second version of the PCB.

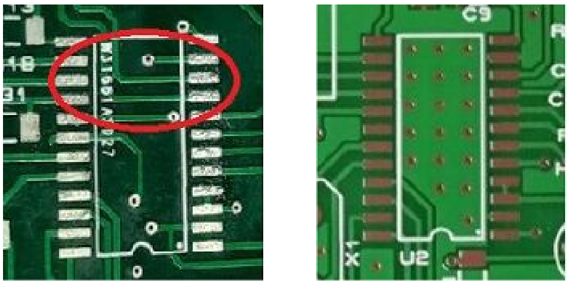

Fig. 5. Bad tracing underneath ADE7758 (a) and the corrected version (b)

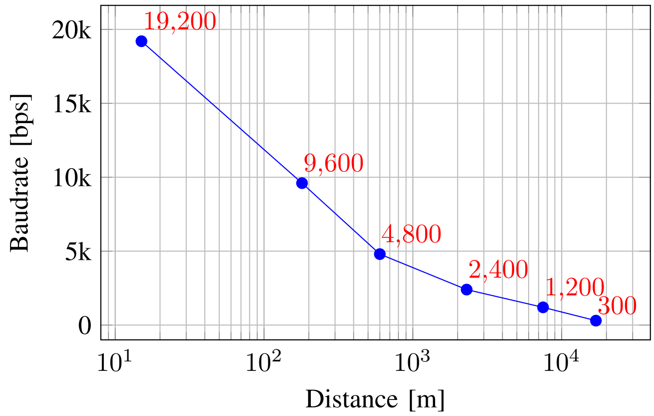

Fig. 6. Transmission data rate vs. distance

The DAQ is designed to read data related to the quality of electricity, namely: voltage up to 400V, currents up to 1000 A (depending on what type of current transformer we use), active energy, reactive energy, power factor, frequency, and the sequence of phases. At the same time it can measure the temperature, the light intensity of the environment (in case of use in public lighting systems this is very useful for determining when to turn on the lights), it is also equipped with 2 relay outputs with a power of 2A for control and 6 inputs for different states of other modules (position of fuses, contactors).

IV. The Gateway

This is the module that (as its name says) acts as an intermediary between the DAQ modules and the server used to store the collected data. It is constructed on a LoLin platform, which uses an ESP8622 microcontroller and is able to connect to an Ethernet network through WiFi or cable. It is also equipped with a LoRa SX1278 module used for long-range communication with low data rates [14].

The gateway is made up of two modules, which work together to ensure a link between the DAQ modules and the database (and in the end the web application) – one is a radio module (an EBYTE E32-433-30D LoRa with a frequency of 433MHz and an emitting power of 1W – or 30dbm – capable of long distance transmissions) which ensures communication with the DAQ modules, the other one is an integrated WLAN module with an ESP8266EX microcontroller which is responsible for the database connection. The communication between the two modules is ensured by the UART serial bus. The data received from each DAQ module is concatenated and sent to the database via a POST request. Multiple gateways can be setup and used in the system to widen its capacity.

One of the most important steps during testing and calibration was determining the maximum communication distance without loss of information. The tests were run under optimal atmospheric conditions (clear sky and 23 degrees Celsius), with the antenna of the gateway situated at a height of approximately 8m above ground linked to the receiver by 2m of cable and the transmitter situated at a height of 2m above ground with an emitting power of 0.5 W.

As you can see from the graph in Fig. 6, for the lowest transfer rate, we can obtain a maximum communication distance, while for the maximum transfer rate, the distance is reduced to only 15m [15].

V. The Web Application

The last link in this chain, is represented by the web application, which not only receives the data from the gateway or directly from the DAQ modules storing it into the database, but also alerts the user via email and/or SMS of any irregularities or problems in the analyzed system.

The web platform is also used to display the data, create graphs or set limits for each data that will be received from the gateway. This web application can be accessed from any device, at www.volt.greenvolt.ro. Access to the data is password protected.

The web application is written in PHP and uses a MySQL database. This web module comprises two main parts: a PHP script which receives the data and inserts it into the database and the user interface.

A. The PHP script

In the database, certain upper and lower limits were defined for each value read by the system. Once the values are received by the script, it will compare these values to the limits and trigger an alert (per email and/or SMS), if any of the values is below or above the given limits. Immediately after triggering the alert, it will set a ”don’t send alert” flag to true to make sure the alert is only sent out once. This script also adds the read data to the database, saving the sender module id and the current timestamp.

B. The user interface

The user interface (which is password protected), displays four pages (a dashboard, a list, a graphics page and a settings page). On the main page of the website (the dashboard), we can follow the readings of the values in real time. This real-time display is done using an AJAX call once every 10 seconds. The dashboard also makes use of the limits (that are set using the settings page), so all correct values are displayed

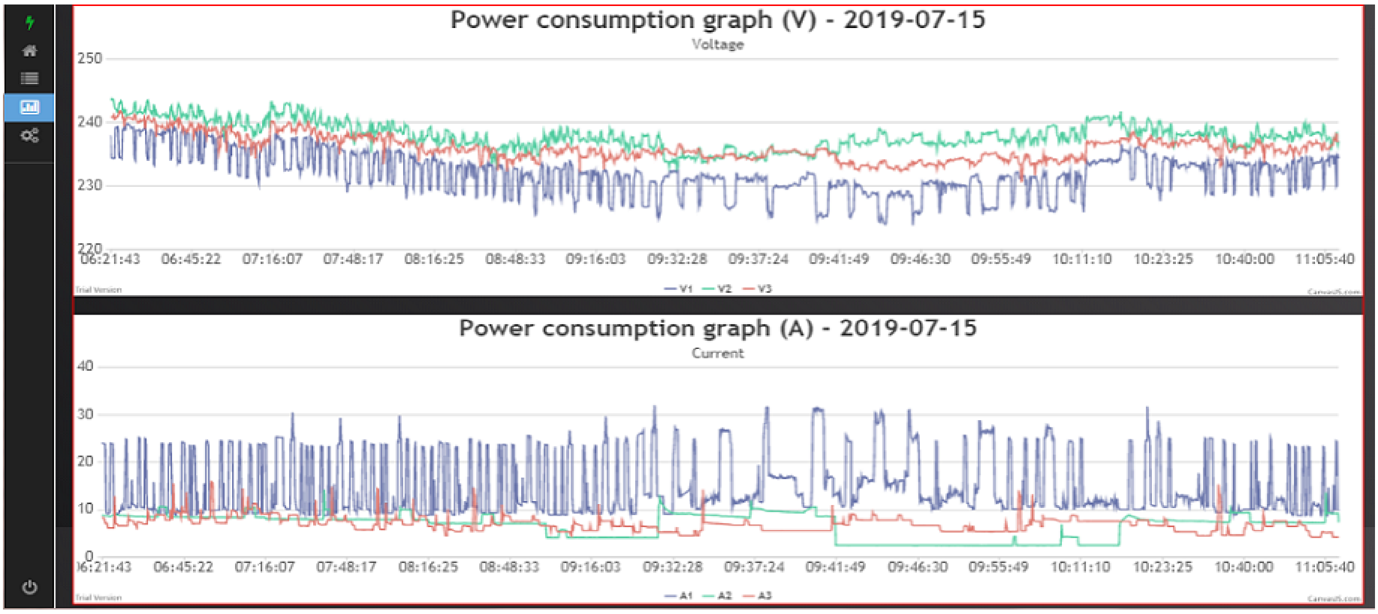

Fig. 7. Graphics page

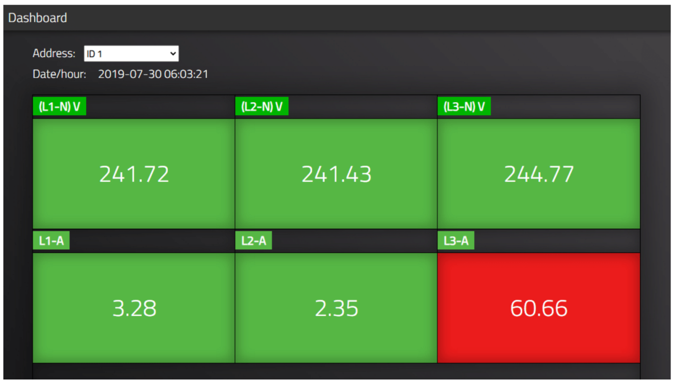

Fig. 8. Dashboard

in green, the values that are above limit are displayed in red and the ones below limit are displayed in blue as shown in Fig. 8.

The settings page allows the user to set the limits for each parameter. The text that will be sent to the user via SMS, in case the values are not within the set limits, can also be defined using the settings page. As was mentioned in the previous subsection, once an alert is sent, the SMS functionality is blocked, so as to not send multiple alerts for the same issue. The user can unblock this functionality from this same settings page, so the sending of alerts is resumed.

In order to make the data more easily readable, a graphics page was added, which displays two graphs (one for current, the other one for voltage). The graphs are created using a JavaScript library called canvas.js. Fig. 7 shows the graphics page for the data collected during a community event, in which many single-phase consumers cause an unbalanced load on the network. This manifests in higher than usual voltage fluctuations on a single phase. Using the monitoring system, such unbalances could be mended fast, assuring a steady and reliable supply of energy.

VI. Conclusions and Future Work

The article has described a remote monitoring system for a three-phase electric power grid which was designed as an alternative to more commercial solutions. It was a challenge we took on, out of a desire to offer our community a chance to profit from all the technological advances of our time at affordable prices. The system is made up of three parts that work together – the data acquisition module, a gateway module and the web application. The flexibility and reliability of the system is given mostly by its ability to transmit the data from a reading point to the database, even if there is no active internet connection at the reading place – the data being sent via the LoRa module, to a gateway which can receive data from multiple reading modules and sends it to the database.

Table I contains an approximate prototype level cost for a DAQ module and gateway. Not including one-time costs for laboratory equipment, development and testing expenses and recurring fees like web hosting services, telecommunication subscriptions, etc., this list still shows the cost-effectiveness of the proposed solution compared to other industrial solutions which can reach even up to an order of magnitude higher pricing [16]–[18].

The system has proven its efficiency and utility on multiple occasions, in a real environment (on fares, concerts and public shows), not only under test conditions. Currently, the DAQ modules are used for gathering data from the public lighting network of the town of Cristian in Brasov county, Romania. After about a year of continuous operation we can safely say that the system is still fully functional with all components

TABLE I
BILL OF MATERIALS

Component	*Price*	Component	*Price*
Data Acquisition module		Gateway	
PCB	$3	WiFi module	$12
ATMEGA328	$2	LoRa	$15
ADE7758	$14	Case	$10
CT-X	$27	Power supply	$5
Passive components	$3	*TOTAL*	*$42*
EEPROM	$1		
RS485	$1		
LoRa	$15		
CASE	$10		
Fuse	$10		
Power supply	$5		
TOTAL	*$91*		

working properly together, collecting and transmitting data to the database, as well as sending out alerts in case of failures (be it a burnt lamp, a network cable with problems or a suspicious increase in consumption).

Currently, a 3rd version of the DAQ module is under construction. This version will have an increased capability of acquiring the data, using 15 current transformers and 10 digital ports. Version 3 can be equipped with an Ethernet 100BASE-TX IEEE802.3u module, a WiFi 2.4GHz IEEE802.11 module or a LoRa 433MHz with a TX power of up to 1W. Even a combination between these is possible thus it will also be able to act as a gateway.

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