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# Low-cost real-time internet of things-based monitoring system for power grid transformers

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**ABSTRACT**

One of the most common causes of blackouts is unexpected failures at power system transformer levels. The purpose of this project is to create a low-cost Internet of things (IoT)-based monitoring system for power grid transformers in order to investigate their working status in real-time. Our monitoring system's key functions are the gathering and display of many metrics measured at the transformer level (temperature, humidity, oil level, voltage, vibration, and pressure). The data will be collected using various sensors connected to a microcontroller with an embedded Wi-Fi module (DOIT Esp32 DevKit v1), and then supplied to a cloud environment interface with a full display of all the ongoing changes. This technology will provide the power grid maintenance center with a clear image of the transformers' health, allowing them to intervene at the right time to prevent system breakdown. The method described above would considerably improve the efficiency of a power transformer in a smart grid system by detecting abnormalities before they become critical.



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## 1. INTRODUCTION

The internet of things (IoT) is a fast-increasing technology that links everything and enables effective communication between the linked "things". The IoT, also known as the internet of objects, refers to a remote system connecting objects; often, the system will be remote and self-designing, such as family unit machines [1]. The phrase "Internet of Things" has evolved to refer to several technologies and study fields that allow the internet to extend out into the physical world of tangible items. Traffic monitoring, healthcare, security, transportation and logistics, and daily living are the top five IoT applications. In this paper, we are going to take advantage of these IoT technologies to improve one of the functional prospects of a power grid.

A traditional power grid consists of a large number of loosely connected synchronous alternating current (AC) networks. It fulfills three main functions: generation, transmission, and distribution of electrical energy. Each network is centrally controlled and monitored in order to ensure that the power plants generate electrical energy as required within the framework of the electricity network [2]. Power grids also face a number of other challenges, including growing energy demands, reliability, security, new renewable energy sources, and aging infrastructure problems. To solve these challenges, the smart grid (SG) paradigm has proven to be a promising solution with a variety of information and communication technologies [3]. In power transmission, the electricity from power plants to remote load centers is carried over high-voltage transmission lines. SG uses different types of devices to monitor, analyze, and control the network, so it becomes useful for many tasks, like making important decisions based on energy needs. The monitoring devices are used in power plants, overhead lines, transmission towers, and distribution centers [2]. Whereas a power grid comprises numerous transformers that are needed for the transmission and distribution of electrical energy, one of the current vital goals is to assure the proper operation of these critical components while also extending their life [4]. This is now a feasible aim owing to IoT-based monitoring devices that can easily be implemented to monitor the functioning state of transformers at various levels of the grid [5].

Governments all around the world are focused on adopting and integrating smart grid technologies as the old grid infrastructure ages and struggles to keep up with rising power consumption. For years, the European Union has focused on it as a system to "efficiently offer ecological, economic, and secure power supplies". Many studies have been conducted in preparation for this trip [6].

Shastrimath *et al.* [7] developed a fault detection and protection system for power transformers based on Arduino. Instead of differential relays, Arduino was used to monitor transformer functioning and create tripping or alarm signals based on observed values. Fault signals were sent to a Wi-Fi module and displayed on the Blynk app. The control system was implemented using an Arduino ATmega328 microcontroller with a 16 MHz crystal. The temperature of the transformer was measured using an LM-35 temperature sensor. The voltage, current, and temperature readings were presented on the liquid-crystal display (LCD). In [8], a program that enables power levels and control devices to be obtained from any location on the planet was proposed. A sensor was put on the heap to identify the current, and a circuit was utilized to measure the voltage; power estimation was performed using these two, and control characteristics were discarded in a cloud database. The major aims of the study [9] were to monitor the electrical grid system process, reveal this system at a harmful level, monitor the current line, and minimize conventional system expenditures. In this work, an electrical microcontroller was set up to monitor a single-phase electrical device using an Arduino to read sensor voltage and current and then transfer measured data via a new Android application for wireless monitoring.

Pursuing the research work [7]–[9] that has been done in the same context, we designed a more precise and improved monitoring system that can collect the maximum information about a transformer's working conditions in real-time and provide visualization as well as the possibility of future analysis using the gathered data at a lower cost by using a simple design that can be easily implemented. This system will allow us to detect and correct the problem as soon as it occurs. This can definitely help us extend the transformer's life-time.

## 2. INTERNET OF THINGS SYSTEMS AND REAL-TIME DATA COLLECTION

There has been a tremendous growth in the number of smart devices and their applications (e.g., smart sensors, wearable devices, smart phones, and smart cars). This is accompanied by a new form of interconnection between the physical and digital worlds, commonly known as the IoT [10]. Therefore, the core idea behind the Internet of Things is to connect numerous objects utilizing technologies such as radio frequency identification (RFID), sensors, actuators, and smartphones, allowing these products to communicate with one another. IoT relies on smart devices with a range of capabilities, such as sensing, networking, processing, and actuation, as a dynamic global network architecture, allowing people and things to interact in various and complicated environments [11].

Real-time data refers to information that is supplied as soon as it is collected. Real-time data is frequently employed in navigation and tracking and can be either static or dynamic, like in our system that collects diverse values at a specific time and then continuously repeats the same operation after a defined delay [12]. However, it is vital to highlight that real-time data does not imply that the data is immediately available to the end user. There might be any variety of bottlenecks in the data gathering infrastructure, bandwidth between multiple parties, or even the end user's personal computer (PC). Real-time data does not guarantee data in a specific number of microseconds, but it is still extremely essential in applications such as traffic global positioning system (GPS) systems, which display to drivers what is going on around them [13]. It is useful for all types of analytics initiatives as well as keeping people informed about their natural surroundings due to its capacity for fast data distribution. The model in the early days of computers was to capture any data for storage. With the growth of mobile devices and other technological breakthroughs, it is becoming increasingly common for software to simply transmit acquired data straight to an end user [14]. This data may be then used to improve products, services, and experiences. To get the most out of their investments, companies must ensure that they have the infrastructure in place to handle real-time data processing at scale [15].

## 3. FAULTS IN POWER GRID TRANSFORMERS

A defect might have an impact on transformer performance. Faults can appear in any transformer, new or old, and can lead to expensive transformer failures. All the problems that can occur at the transformer level can be classified as one of the two main fault types, which are external faults or internal faults. External faults are faults outside a transformer while internal faults are faults inside a transformer. Those two categories can be divided into sub-categories in this section [16]–[18].

### 3.1. External faults in a power transformer

#### 3.1.1. External short circuit of a power transformer

A short circuit can happen in two or three phases of an electrical power supply. It is determined by the voltage that has been short-circuited as well as the impedance of the circuit up to the fault location. A high fault current causes substantial mechanical strains in the transformer.

#### 3.1.2. Under frequency effect in a power transformer

The phenomena of a reduction in the transformer’s impedance with a drop in the applied frequency is referred to as the under-frequency effect in power transformers. When the frequency of a system is reduced, the flow in the core increases, and the impact is comparable to that of an overvoltage. The impact is strongest at low frequencies. Under frequency protection is used to lessen the impacts of this phenomena by detecting a fall in system frequency and immediately commencing a load shedding scheme to reduce system load.

#### 3.1.3. High voltage disturbance in a power transformer

High voltage and high frequency surges in the power system can occur as a result of any of the following: arcing ground if the neutral point is isolated; changing the operation of various electrical devices; and lightning strikes in the atmosphere. All of these can cause breakdowns in the insulation between turns adjacent to line terminals, which may create short circuits. There is always the possibility of system overvoltage due to the unexpected separation of a big load. Overvoltage in the system increases the stress on the transformer insulation. Core bolts, which ordinarily transport minimal flow, may be exposed to a significant component of flow redirected from the saturated section of the core beneath. Under such conditions, the bolt may get quickly heated, destroying both its own and the winding insulation.

### 3.2. Internal short circuit of a power transformer

#### 3.2.1. Inter turns fault in a power transformer

Due to a lightning surge on the transmission line, a power transformer linked to an electrical extra high voltage transmission system is highly likely to be subjected to large magnitude, steep slope, and high frequency impulse voltage. The voltage strains between winding turns grow so great that they cannot be sustained, resulting in insulation breakdown in some places. The transmitted surge voltage stresses the low voltage (LV) winding.

#### 3.2.2. Internal earth faults in a star connected winding with neutral point solidly earthed

The value of fault current in a star-connected winding with a securely earthed neutral point is determined by two major elements. Fault current is proportional to the leakage reactance of the part of the winding that connects the defective and neutral points of the transformer. It can be observed that the reactance reduces extremely quickly as the fault point approaches the neutral, and hence the fault current is greatest towards the neutral end. In this scenario, the earthing impedance should be zero.

#### 3.2.3. Internal earth faults in a star connected winding with neutral point earthed through an impedance

The value of fault current is determined by the earthing impedance as well as the distance between the defective and neutral points. The voltage at the fault site in this situation is determined by the number of windings turns that occur across neutral and the fault point. The fault current is also affected by the leakage reactance of the section of the winding that is connected to the faults and neutral. However, in comparison to the earthing impedance, it is relatively low, and it is plainly neglected since it is in series with considerably greater earthing impedances.

## 4. BUILDING THE MONITORING SYSTEM

Gathering the data from the transformer environment requires having different sensing units that will allow us to trigger the surrounding conditions of these power grid components. All the collected data will be processed by the programmable microcontroller that will send it via Wi-Fi to a cloud environment where it will be displayed and visualized. Therefore, our system can be divided into three main levels, as shown in Figure 1.

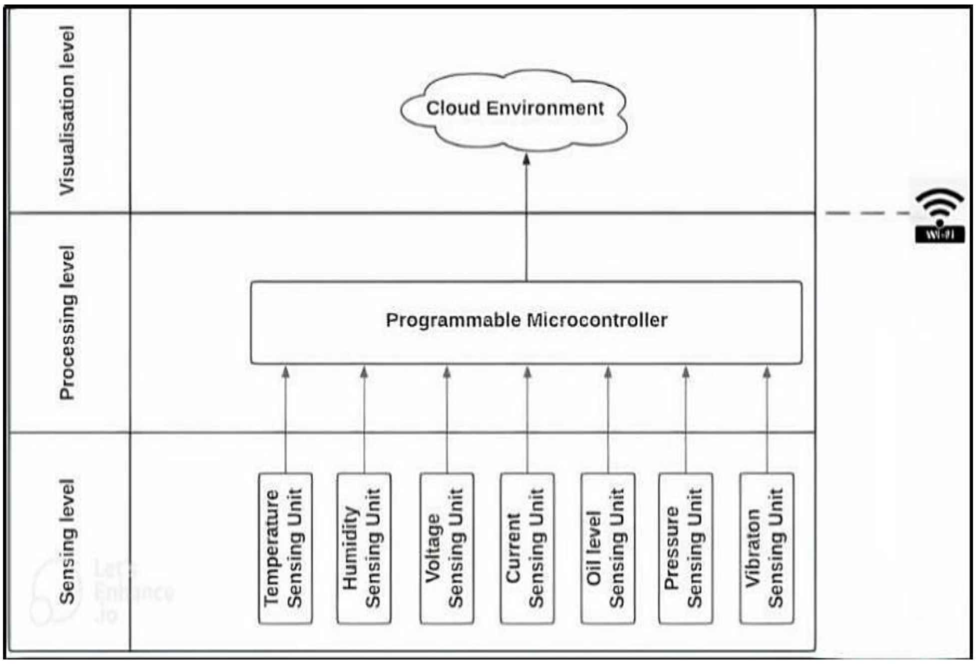


Figure 1. Levels of our monitoring system

### 4.1. Used tools and their estimated cost

The primary goal of this paper is to not only build a monitoring system for power grid transformers, but also to make this system simple and functional at a lower cost. For this reason, the chosen materials are as shown in Table 1. These materials are inexpensive and widely available. They are also easy to work with and do not require complex implementation steps.

#### 4.1.1. Hardware

Table 1 shows the hardware components used to build the system and how much each one costs, while Figure 2 shows how the components are linked together to form the system. The main component which is the ESP32 card costs only 10 dollars. The system as a whole cost less than 23 dollars in total.

Table 1. Estimated cost for used equipment

| Used equipment | Estimated cost |
|---|---|
| Doit Esp32 DevKit V1 | 10$ |
| DHT22 Temperature and Humidity sensor | 6$ |
| 2 Resistances | 1.5$ |
| Ultrasonic distance sensor-HC-SR04 | 3$ |
| SW-420 vibration sensor | 2.5$ |
| Total cost | 23$ |

#### 4.1.2. Software

ThingSpeak, an open-source program for internet-enabled device connections, was chosen as our cloud environment for free data presentation [19]. We made a private channel on ThingSpeak and then decided how many fields we wanted on it. As seen in Figure 3, we also labeled each field after the parameter we wanted to display on it.

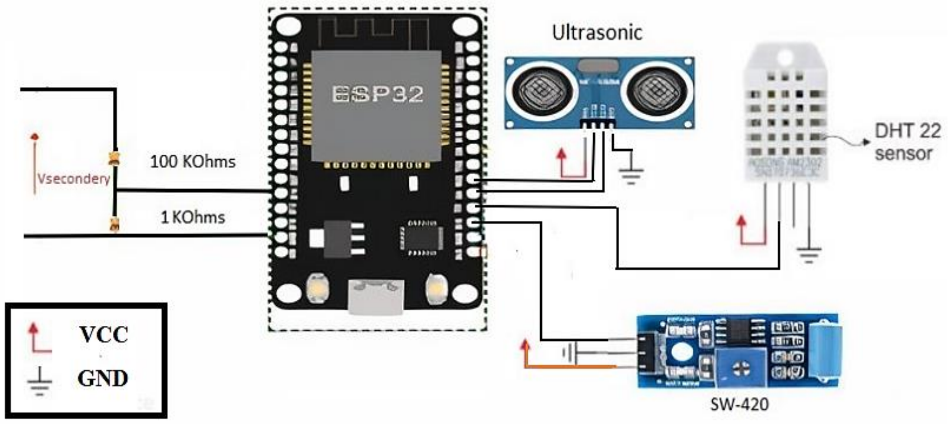


Figure 2. The monitoring system

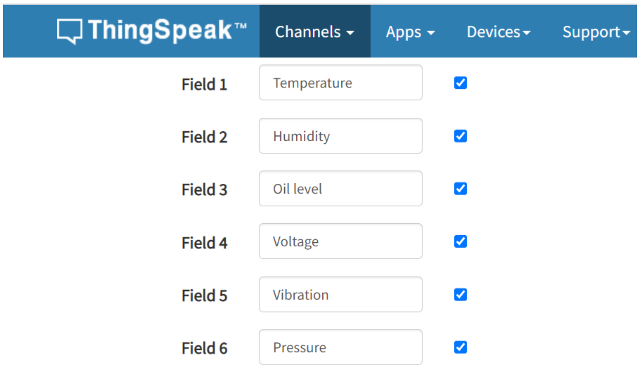


Figure 3. Names of channel fields

## 5. METHODOLOGY DEVELOPMENT

### 5.1. Building the test system

Transformers are typically housed in oil tanks, big drums, or pipelines. If a transformer is put in a tank, the tank must be completely sealed to avoid oil spillage in the event of a leak. The tank is often filled with a cooling substance, such as oil. The cooling agent is used to disperse the heat generated by the transformer when it is in operation. Therefore, to test the system, we used a small transformer (input voltage: 220 V and output voltage: 12/24 V) and an alimentation bloc that can create 220 V. We put the transformer in a 20-centimeter-high container filled with mineral oil (oil density=0.84 g/cm$^3$) to simulate the environment of a genuine power grid transformer, as illustrated in Figure 4.

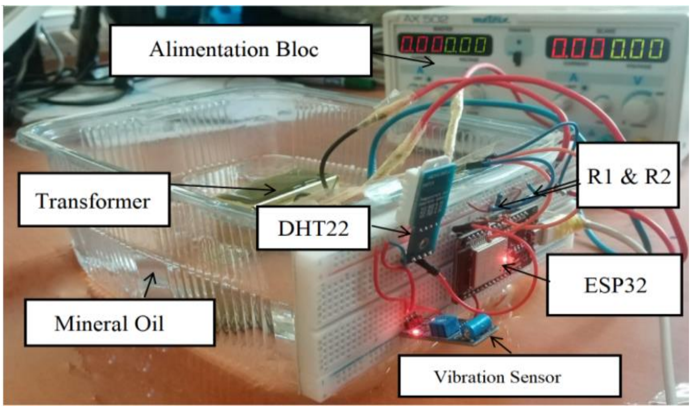


Figure 4. The global view of the testing environment

### 5.2. Data collection
#### 5.2.1. Temperature and humidity sensing
We used a DHT22, which can measure both values with very acceptable precision (temperature accuracy of 2%-5% and humidity accuracy of 5%). The temperature range of the DHT22 is 40 to 80 °C [20], whereas the maximum temperature of a normal transformer is supposed to be 40°C [21]. This means the measurement range provided by DHT22 is enough for our system.

#### 5.2.2. Voltage and current sensing
We just need to build a voltage divider between our board's VCC and ground pins to monitor voltage and then compute current because the ESP32 can already receive analog input between 0 and 3.3 V. The resistance values R1 and R2 must be carefully set to offer a sufficient measuring range. The resistances of R1=100 kOhms and R2=1 kOhm were chosen to enable a maximum measurement of 300 V. The measurement range supplied is adequate because the maximum voltage across the transformer secondary under consideration will not exceed 24 V (the maximum output voltage of the transformer we used to verify system performance). Figure 5 depicts the voltage divider we used to gather voltage measurements around the transformer secondary. If this last has a different voltage range, it is easy to substitute resistances in the system with others that have acceptable values while respecting the 0 3.3 V in (1) [22].

$$V_{out} = V_{secondary} * R2/(R1 + R2) \quad (1)$$

The reason behind excluding current visualization is that its value depends directly on the voltage value, which means that observing voltage changes is enough to know how the current at the level of the transformer secondary is changing as well. Here is the equation that represents current values based on voltage value (Ohm's law).

$$I = V_{out}/R2 \quad (2)$$

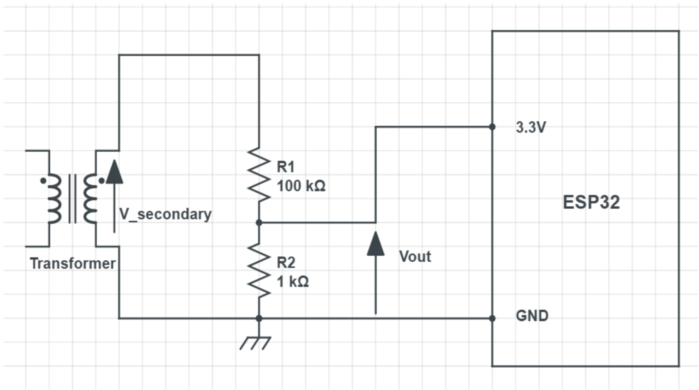


Figure 5. Voltage divider implementation

#### 5.2.3. Oil level and pressure sensing
We measured the distance between the upper portion of the transformer container and the upper portion of the oil using an ultrasonic distance sensor-HC-SR04 as shown in Figure 4, which allowed us to compute the oil level using (3):

$$O = H - D \quad (3)$$

where *O* is oil level, *H* is transformer container's height, and *D* is distance between the upper part of the transformer container and the higher level of the oil. For the pressure it is calculated using (4) [23]:

$$P = O.r.g \quad (4)$$

where *O* is oil level, *P* is liquid pressure on the upper surface of the transformer, *g* is gravitational constant of earth, and *r* is oil density.

#### 5.2.4. Vibration sensing

To identify any kind of unstable movement at the transformer level, we utilized a SW-420 vibration sensor. This module includes a potentiometer, a vibration sensor, and an LM393 comparator chip to provide an adjustable digital output dependent on the amount of vibration. The potentiometer may be changed to alter the sensitivity to the appropriate amount. When activated, the module produces a logic level high (VCC) and a logic level low (GND). There is also an integrated LED that illuminates when the module is activated [24].

#### 5.2.5. Microcontroller programing

We used C code to program our microcontroller (DOIT Esp32 DevKit v1) in order to get data from all the sensors in the system and then send it via Wi-Fi to a cloud environment for the next step of data visualization. The code was written using Arduino IDE. We imported the ESP32 card library and chose it as our development board. All the needed libraries such as ThingSpeak and Wi-Fi libraries were also imported.

### 5.3. Data visualization

After we construct a private channel, where each parameter represents a channel field, all of the collected data is shown in real time in a ThingSpeak platform interface. message queuing telemetry transport (MQTT) is the communication protocol utilized between the collecting system and ThingSpeak [25]. The collected information is processed and graphical representations are created in the ThingSpeak interface. Users can watch the process of data collection, transmission and visualization in real time as well.

### 5.4. Data analysis

For this step, we can use MATLAB analysis as ThingSpeak already supports this feature, which can provide us with further but also basic information about the aggregated data [26]. MATLAB analysis of recorded data is necessary to see what patterns are occurring and whether or not there are any peaks in the data. Important information may be derived from the recorded data, such as the highest values, minimum values, and average values of the various observed parameters. This data may be used to see whether there are any significant variances in the transformer conditions observed at different times of day. For more developed analysis, the collected data can be analyzed using other sophisticated tools, but as this paper's objective is to only build a monitoring system, we will not get into any deep analysis.

## 6. RESULTS AND DISCUSSION

### 6.1. Temperature

We altered the room temperature (we set the cooling system to 16 °C). The aim of this modification is to test if the surrounding temperature will change as a result. The graph below indicates that after turning on the cooling system at 16:42, the temperature began to fall until it reached about 16 °C, as shown in Figure 6.

### 6.2. Humidity

As we switched on the cooling system, the humidity rose from 53.5% at 16:42 to above 56.5% at 16:52. Which can be seen in Figure 7. When the system turned on, the atmospheric relative humidity (RH) increased by 3%. This indicates that there was an increase in the moisture level in the air and that our system is able to detect and record humidity changes.

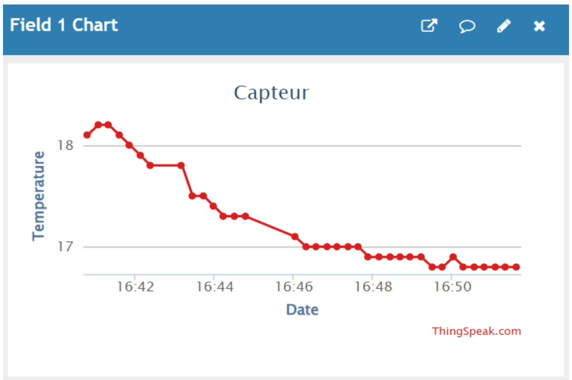


Figure 6. Temperature visualization on ThingSpeak

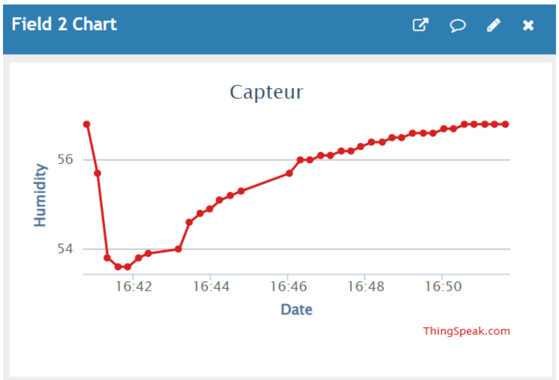


Figure 7. Humidity visualization on ThingSpeak

### 6.3. Oil level

At first, the oil level was 175 mm; when we reduced it to 150 mm at 17:36, the system displayed the change in oil level value; for the rest of the time, we kept changing the oil level between 150 mm and 200 mm to see if the system accurately measured the oil level. As a result, we got the graph shown in Figure 8. This result indicates that the system is measuring the oil level accurately and sending the measures to our ThingSpeak channel in real time.

### 6.4. Voltage

Using an adjustable alimentation block, we altered the voltage in the transformer's primary and obtained a Vsecondary that increases when we raise the voltage in the primary and decreases when we lower the voltage in the primary. The values we obtained were adequate with the changes in alimentation voltage. Figure 9 shows the changing values of voltage in decivolts.

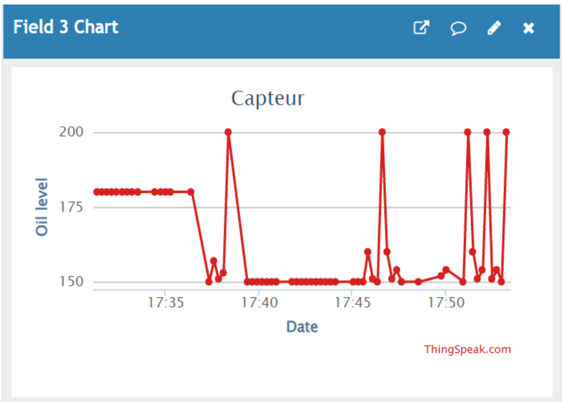


Figure 8. Oil level visualization on ThingSpeak

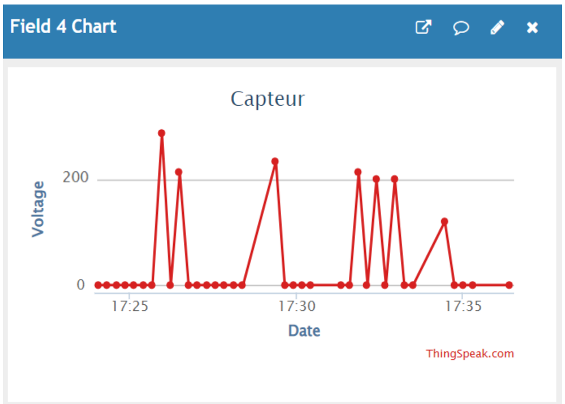


Figure 9. Voltage visualization on ThingSpeak

### 6.5. Vibration

We used a phone vibrating close to our transformer for the vibration test. At 17:14, we raised the vibration slightly, resulting in a greater vibration value reported on our chart. When we reset the phone vibration to 19, the chart illustrated in Figure 10 showed a decreasing vibration that reached 19 by 17:18. This decrease in vibration was due to the change we made. These results indicate that the vibration levels in transformers are measured in line with our goal.

### 6.6. Pressure

The pressure imparted to a solid body covered by a liquid is determined by the density and level of the liquid. We altered the oil level many times, resulting in variable pressure readings presented on the pressure chart based on how much we varied the oil level. The system gathers pressure measurements in real time, as shown in Figure 11, indicating that the system is working as planned.

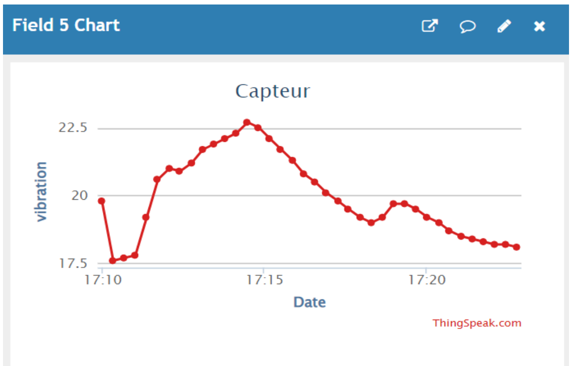


Figure 10. Vibration visualization on ThingSpeak

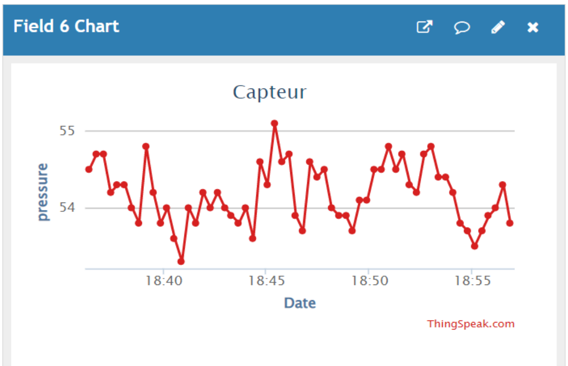


Figure 11. Pressure visualization on ThingSpeak

### 6.7. Discussion

Unlike the systems previously discussed in the introductory section, which do not take into account all of the conditions affecting the transformer’s performance, the system shown in the results section collects values of different parameters in real time and reflects any change in the transformer's surroundings. This monitoring system will provide the monitoring center with the needed information to act at the appropriate moment before a failure occurs on the transformer’s level. Normal values of all the studied parameters can be set for the system to generate alerts whenever a value is not within its normal range. The data can also be used to extract useful information on the changing behavior of environmental conditions in correlation with each other, which can allow further system development in the future.

## 7. CONCLUSION

In this study, we built a low-cost, real-time IoT-based monitoring system for power grid transformers. This system has several advantages since it allows us to gather and display data in real time with high accuracy at a lower cost with no implementation complexity and, most importantly, it is practical and feasible. The distance between the monitored transformers and the monitoring center is no longer a concern because the visualization cloud interface may be viewed from anywhere. Using the collected data, further analysis may be performed to extract important information about the transformers’ behavior based on the surrounding circumstances for future purposes, such as designing more efficient cooling systems or other enhanced systems.

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