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REVIEW ARTICLE

Smart Monitoring System for Substation' Parameters and Automatic under Frequency Load Shedding

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ABSTRACT

Monitoring important parameters in electric power stations are very necessary for determining energy efficiency and diagnosing faults that may affect important equipment in substations. Internet of things technology provides the possibility of obtaining station data in real-time. In this research a monitoring system was designed, implemented, and examined in a high voltage substation, to monitor parameters that determine power quality, using a microcontroller (ESP32S), sensor (PZEM-004T), and temperature and humidity sensor (DHT11). The proposed system can provide data that help prevent power outages by relying on engineers who have the ability to analyze comprehensively the electrical energy. The system also provides the Automatic Under Frequency Shedding if the frequency in the stations falls below the normal limit, which contributes to maintain the efficiency and the quality of electrical energy in the substations.

Key words: AUFLS, Esp32, IOT, PZEM-004T, Smart monitoring system, Smart substations

INTRODUCTION

Substations are a significant part of the electrical power grid. Through these stations, the voltage level is converted from high voltage to low voltage using (transformer). The substation transfers power to distribution stations by the transmission lines.[1]

Monitoring electrical substations are necessary to detect faults and treat them, because if left unattended, it may lead to electrical problems and cause long-term consequences. These problems not only cause energy losses but also lead to electrical outages and losses in expensive equipment, in addition to injuries and accidents such as fire. Therefore, monitoring of substations and their equipment is important to ensure safety, protection, and stability in the electric power networks.[2]

In electrical power networks, there are many ways to locate faults, but engineering and technical persons have to make a manual effort to inspect equipment's to detect faults and identify them in the stations. The technology of the internet of things (IoT) offers the ability to track electrical issues in stations without spending extra effort and time.[3]

The IoT, commonly abbreviated as the word (IoT) is a term that has recently evolved; this refers to the new Internet age that enables communication and understanding between interconnected devices, as well as between separate devices and physical objects. The goal of the IoT is to use networks to create connections between objects while minimizing time and location limitations. The idea of the IoT enables objects to exchange data for communication purposes through wired or wireless connections. The IoT's real-time capability is consider a crucial feature for monitoring and managing power system applications. Therefore, machine operators are able to use the real-time monitoring system to make informed decisions on technological as well as electrical matters.[4]

Related Work, Mrs. John *et al*., 2017, suggested a power substation automation system using the Raspberry-pi microcontroller to automate a substation11kv.[5]

Tia *et al*., 2018, suggested a monitor device for the substations to monitor the equipment and operating environment of the stations in real time. The device consisted of three components hardware, software

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and network, the data are received through the communication protocol (IEC101 or IEC104) and the data are processed and transmitted to the monitoring center.[6] Pawar *et al*., 2018, suggested a system for tracking different gauges in power distribution transformers, a hardware component consisting of a microcontroller (PIC18F4550) and different sensors, a software component using SQL (Structured Query Language). (SMS) Short Message Service is send through the GSM/GPRS (Global System for Mobile Communications/ General Packet Radio Service) to engineers in case of an emergency.[7] Yaman and Biçen, 2019, suggested a transformers monitoring device based on (IoT) use a microcontroller (ArduinoMega2580), (DS18B20) sensor for the oil temperature sensing, (DHT11) sensor for temperature and humidity measurement, and sensor for floating magnet level, for oil level measurement. Data from the sensors are passed to the platform (Thingspeak).[8] Hasan *et al*., 2019, proposed a system for monitoring temperature and humidity inside the transformer and monitored the load amount on the transformers using the IoT and self-protection in case of maintenance delays. The system consists of Microcontroller (ArduinoNodeMcu), (current, voltage, oil sump temperature, and humidity) sensors.[9]

The analysis of the literature detect that there is no standard method for designing a monitoring device, and all the methods listed differ in terms of the type of microcontroller and the type of sensors used to simulate the functional circuit, and differ in the methods of connecting to the internet. In these systems, some defects have been found in terms of the type of microcontroller used where certain controllers do not have built-in Wi-Fi and the large number of sensors used raises the cost of the designed system.

This paper explains applied IoT to the environment of the electrical power grid, and Real-time monitoring of substation data to enhanced substation reliability, performance, and efficiency. The proposed system is characterized by low cost and few numbers of devices compared with previous studies. The system aims to measure all important parameters at the same time in substations, these parameters include (current, voltage, appearance power, power factor, and frequency) using a microcontroller (ESP32), and (PZEM-004T) sensor, compute active power and reactive power by relying on the equations of the power triangle, measure (temperature and humidity) using (DHT11) sensor, and a relay module to control and to break the line feeder based on the frequency value.

Section 2 explains the proposed system. Design and theory of work in the section 3. Section 4 execute the project and present the initial results of the project. Checking the system at the real station and obtaining the real results in section 5. Section 6 includes the calculation of the error percentage in the proposed system. Section 7 gives the conclusions and future work. Section 8 contains the acknowledgment.

THE PROPOSED SYSTEM

Components

The module of the proposed system consists of several elements, Node MCU (ESP32S) for control and wireless communication, variable power supply (220V AC) to supply voltage to the system, any load for supply the system with current, temperature and humidity sensor (DHT11),(PZEM-004T) sensor to sense the values of voltage, current, power, frequency, and power factor, 4-channel relay interface board, used to control of equipment with large current.

The overall structure of the system

The system is split into two parts, the first part is the components of the hardware as shown in paragraph (2.1) and the programs are the second part. Using the (Arduino IDE) software and the programming language (C ++), the sensors are programmed. The ESP32 package and all of the required libraries to function (Cayenne MQTTESP32),(PZEM004 Tv03master),(DHT), (elapsedMillis), loaded from the web address,[10] then Uploading the code to (Arduino IDE) and getting the data on a platform called (My Computer Cayenne) in real time from which we receive data in the form of digital readings, graphs or tables (Excel).

Design and theory of work

ESP32 microcontroller module

The ESP32 is a dual-core board that is equipped with two Xtensa LX6 processor boards. It is launched in September 2016 by Espressif Systems to replace the μC ESP8266. A powerful embedded Wi-Fi and Bluetooth unit are included in the ESP32. The memory is immense (RAM 512KB), (16MB flash) furthermore 448KB of ROM, 520KB of SRAM, and two (8KB) of RTC memory.[11] ESP32 has 36 GPIOs, 14 of which are Analog to Digital Converter, ISP pins used to connect the ESP32 to the SD card reader. The VCC given for the ESP32 ranges from 2.2V to 3.6V. Micro USB used to upload the software and supply power to the board, or uses a (3.7V) battery to supply it with power.[12]

PZEM-004T sensor

PZEM-004T modulus developed by Peace fair Electronic (Ningbo Zhejiang, China). It accepts input voltage of 80 to 260 V AC, maximum current of 100A, and rate at 45-65Hz. It has an embedded processing capability of SD3004 SoC (produced by SDIC) specified for electrical power measurement.[13] The sensor (PZEM-004T) is used for voltage, current, frequency, power, and power factor measurements. To easily communicate with the microcontroller, the circuit of this sensor depends on the communication protocol (UART).[14]

PZEM-004T specifications

- Supplying voltage: 5VDC
- Input voltage: 80–260 VAC
- Measuring current: 0–100 A
- The frequency of operation: 45–65 Hz
- Range of power: 26000 W
- Interface: 5V TTL UART
- Precision of measurement: Grade 1.0.[14]

DHT11 sensor

The DHT11 is a Temperature and Humidity Sensor. DHT11 can be correlated with Microcontrollers such as ESP32, ESP8266, Raspberry Pi, Arduino and so on. In the operating temperature range of 0 to 50°C, it is capable of calculating relative humidity between 20 and 90 percent RH with an accuracy of ±5% RH. The temperature is also measured in the 0–50°C range with a ±2°C precision. With 8-bit resolution, all values are returned. This provides high unwavering efficiency and long-haul reliability.[15]

Relay module

This is a 4-channel relay interface board with low level5V, and each channel requires a driver current of 15–20 mA. It can be used to power several high-current devices and equipment. It is fitted with AC250V 10A or DC30V 10A high-current relays. It has a standard interface that can be directly operated by microcontrollers. This module is optically isolated for safety criteria from the high voltage side and prevents the ground loop when interfacing with the microcontroller.[16]

My device cayenne platform

My device cayenne platform is an IoT platform that allows IoT projects to upload data and create tracking by creating a website account on this platform's server, free of charge from the internet. Project data are show on the dashboard and this interface allows more than one project to be added, and each project has a code, depending on the communication protocol in particular (MQTT).[17]

MQTT

The abbreviation for MQTT is Message Queuing Telemetry Transport, which is a communication protocol. It is based on the (TCP/IP) protocol used to exchange data over the Internet. Created in 1999 by IBM, characterized by ease of use, uncomplicated, lightweight, low energy consumption, the transmission of information very quickly, does not required a large use of memory. It is also characterized by high reliability, depending on broker in its work (MQTT Broker).[18]

PROJECT IMPLEMENTATION AND OBTAINING THE INITIAL RESULTS

Hardware

Connecting the electrical circuit of the system is show in Figures 1 and 2.

Arduino IDE is a program used to generate the system's main code and download the required libraries. IDE stands for "Integrated Development Environment" and is an official program developed by Arduino.cc, which is used primarily to edit, compile and upload code to the board. This software is open source and readily accessible. This environment supporting C and C ++ languages.

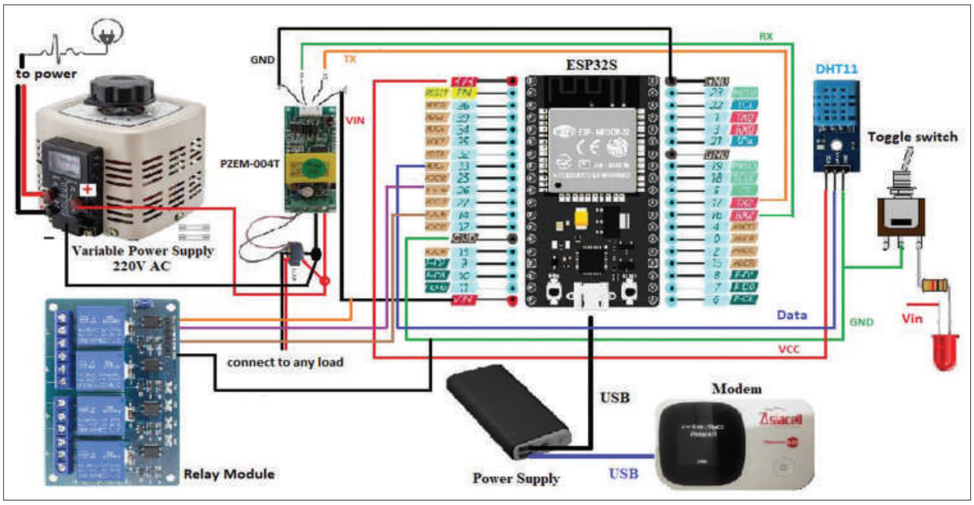


Figure 1: Electrical circuit of the system

Figure 2: Real circuit of the system

Software

The software used to implement the proposed system for monitoring the important parameters in the substation using the C ++ programming language and to execute the code using the Arduino IDE application is described in this section.

```
void loop() {
if (WiFi.status() == WL_CONNECTED) {
float h = dht.readHumidity();
float t = dht.readTemperature();
float volt = pzem.voltage();
volt=volt*1200;//[‘132000/110 ratio voltage line HV
float cur = pzem.current();
cur=cur*240;//1200/5 ratio current line HV
float S = 1.732*volt*cur;
float V=volt/1000;////in KV
float I=cur;//Amper
S=S/1000000;//appear power in MW
floatpf = pzem.pf();
floatang=acos(pf);//phase angle
float Q=S*(sin(ang));///reactive power MW
float P=S*(cos(ang));///active power MW
floatfreq = pzem.frequency();
if (freq< 49) {
digitalWrite(26, LOW);
}
else {
digitalWrite(26,HIGH);}
```

The flow chart is shown in Figure 3, explains the steps for implementing the system.

THE INITIAL RESULTS AND INTERPRETATION

Results of monitoring sensors readings on the cayenne platform are displayed in Table 1, there are a total of nine channels used on the dashboard to show the sensors data, we observed the voltage value (235.800 kV), The current value (18.960 A) is according to the variable power supply, which we changed to get a variable Values. When writing the code for the system the voltage value was multiplied by 1200 and the current value of 240. These values are used depending on the converting ratio of the current and voltage in the secondary transformer at the substation. The values of active power P and reactive power Q determined using the mathematical equations.

The results at the power supply 198V are show in Figure 4 on the cayenne dashboard.

The Cayenne platform provides us with a data graph that shows the relationship between the time and value of the sensor. The graph shown in Figure 5 shows the frequency value readings from hour 4:20 pm to 4:50 pm. There is an increase and decrease in the readings depending on the value of the variable voltage supplied for the power supply (220V).

Table 1: The results at power supply 196V

Timestamp	Device	Channel	Sensor Name	Sensor ID	Values
2020-12-31 4:55:17	aseel	6	P MW	ca3b1ba0-4b6a-11eb-8779-7d56e82df461	6.814
2020-12-31 4:55:16	aseel	3	CURRENT A	c7c2c8a0-4b6a-11eb-a2e4-b32ea624e442	18.960
2020-12-31 4:55:16	aseel	4	S MVA	c88f8e80-4b6a-11eb-883c-638d8ce4c23d	7.743
2020-12-31 4:55:16	aseel	5	Q MVAR	c9adcfc0-4b6a-11eb-8779-7d56e82df461	3.678
2020-12-31 4:55:16	aseel	2	FREQUENCY HZ	c68edc80-4b6a-11eb-a2e4-b32ea624e442	50.200

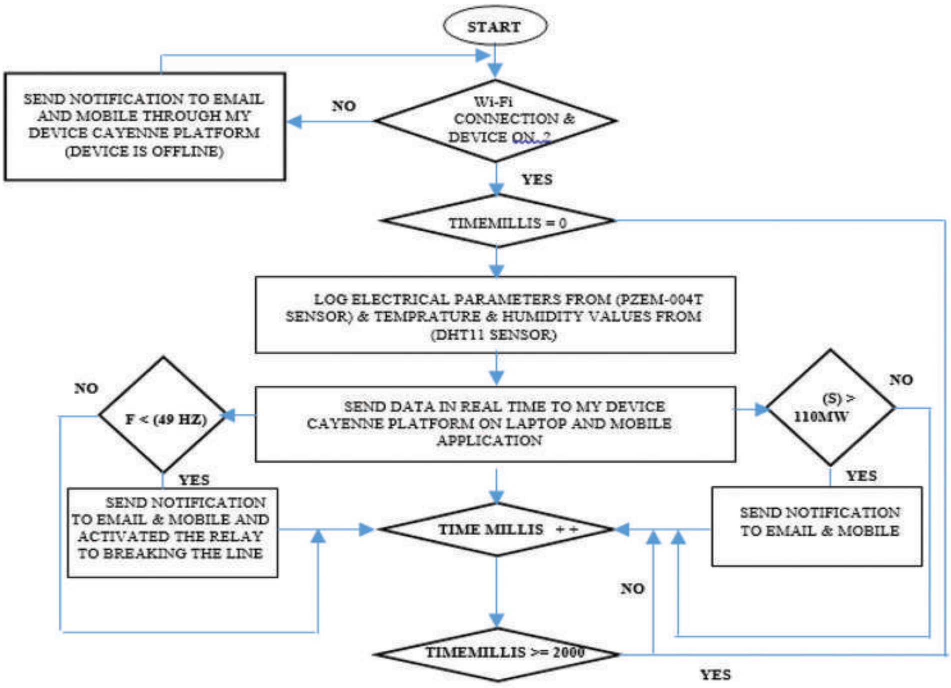


Figure 3: Flow chart of the steps for implementing the system

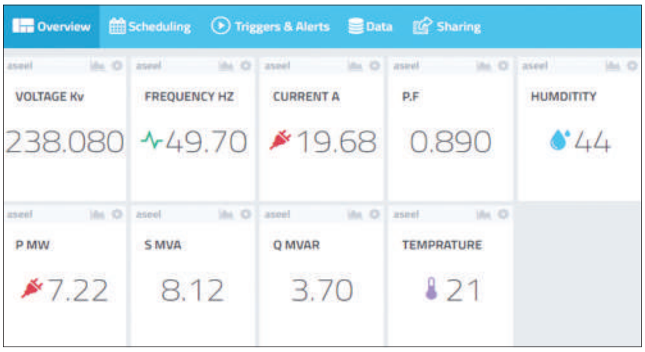


Figure 4: The results at power supply 198V

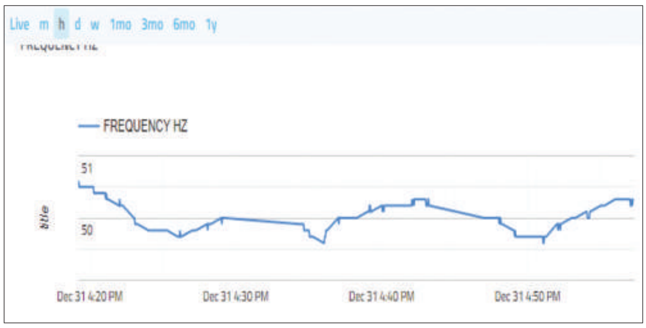


Figure 5: Graph of the frequency values

TESTING THE PROPOSED SYSTEM AT THE REAL SUBSTATION

Connecting the system to the West Mosul station 132 KV

The proposed system connected at the outputs of the secondary transformer at the West Mosul station 132 kV. Where the terminal for the voltage is connect to the voltage output of the secondary transformer, and the terminal for the current is connected to the current output of the secondary transformer. Figure 6 shows the device's connection inside the station.

The data were obtained through the Cayenne platform on the laptop and the phone after connecting the system to the station and switching it on, it was checked that the readings were roughly equal to the real values in the station gauges, as show in the figure below. Figure 7

Figure 6: Connecting the device in the substation

Figure 7: Gauge of voltage at the station

shows the reading of voltage in the gauges at the station equal to 127.35 KV, Figure 8 shows the reading of voltage on the Cayenne platform equal to 127.32 KV, we note that the difference between the two readings is 0.03, which is very small, indicating the efficiency of the proposed system.

Figure 9 shows the reading of the current gauge in the station equal to 221.34A, at the same time we noticed the reading of the current on the Cayenne platform equal to 220.80A as shows in Figure 10, we note the difference between the two readings (0.54), a small difference resulting from the noise caused by the electromagnetic waves, wires and other sources of noise.

Figure 11 shows the reading of the frequency scale in the station equal to 50.42 Hz, and at the same time we noticed the reading of the frequency on the Cayenne platform is equal to 50.4 Hz as shown in Figure 12, we noticed the difference between the two readings (0.02), no difference roughly speaking, it indicates the efficiency of the proposed system.

Figure 13 shows the reading of the power gauge in the station equal to (46.50MVA), and at the

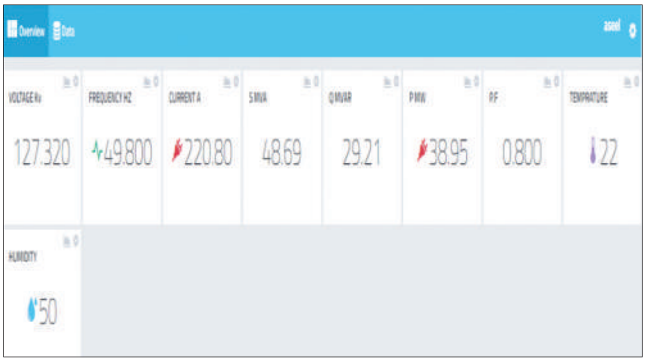


Figure 8: Reading of voltage on Cayenne platform

Figure 9: Gauge of current at the station

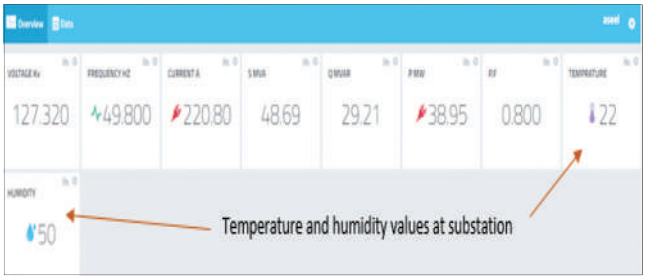


Figure 10: Reading of current on Cayenne platform

Figure 11: Gauge of frequency at the station

same time we note that the reading of the power on the Cayenne platform is equal to (46.29MVA) as shown in Figure 14, we noticed the difference between the two readings (0.21), that is, the values are approximately equal. The values of the active power and the reactive power can be verified by relying on the equations of the power triangle, where the apparent power (S) is equal to the square root of the sum of the square of the value of the active power (P) and the reactive power (Q).

IMPLEMENT THE RELAY PART IN THE STATION AND CONTROL THE FEEDER DEPENDING ON THE FREQUENCY VALUE

A 110V feeder line was inserted to the (COM) pin of the relay device, the (NO) pin in the relay device was connected to the (trip) at the station.
After connecting the device and turning it on, we noticed the line is in the (ON) state, and when the frequency drops below the limit that was set in the programming, noticed that the relay is activated

Figure 12: Reading of frequency on Cayenne platform

Figure 13: Reading of power at the station

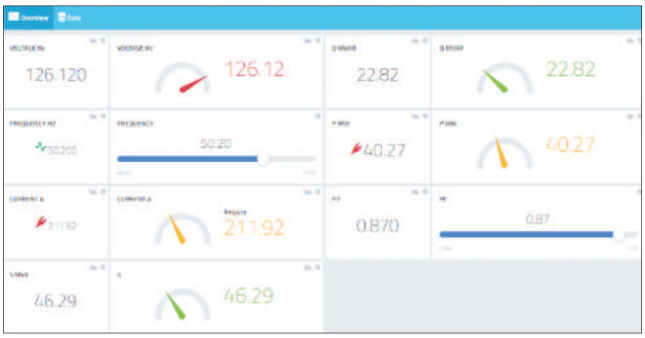


Figure 14: Reading of power on Cayenne platform

automatically and the line's state changes to (OFF), as shown in the figures below. Figure 15 shows the line in the (ON) state, Figure 16 shows the line in the (OFF) state.
Figures 17 and 18 show the frequency readings on the (Cayenne platform), and reached the reading a value less than the threshold limit (49 Hz), the relay is activated and the line is changed to the (OFF) state.
In the case of (OFF) an (SMS) (Short Message Service) alert arrives on the phone device, as shown in Figure 19.

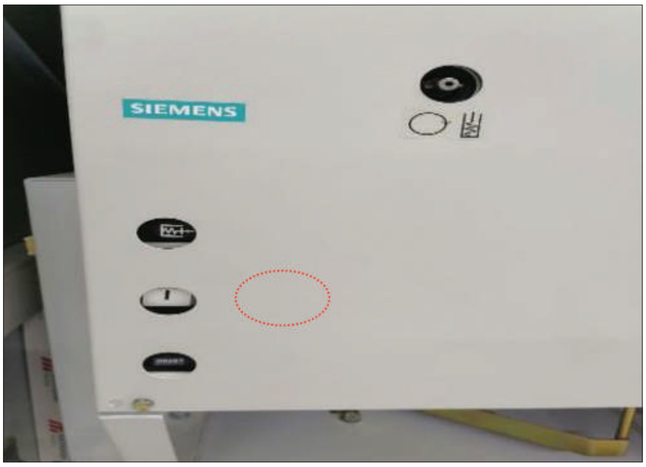
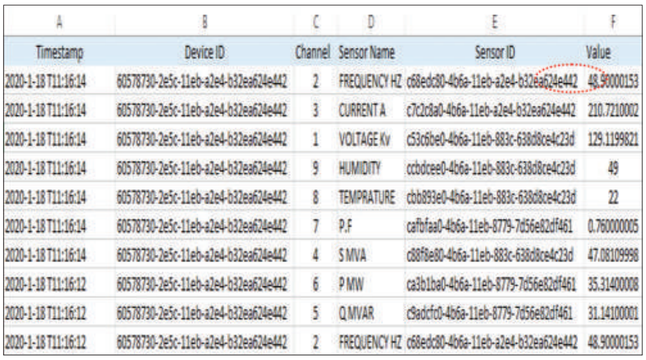


Figure 15: ON state

Figure 16: OFF state



Timestamp	Device ID	Channel	Sensor Name	Sensor ID	Value
2020-1-18 T11:16:14	60578730-2e5c-11eb-a2e4-b32ea624e442	2	FREQUENCY HZ	c68edc80-4b6a-11eb-a2e4-b32ea624e442	48.90000153
2020-1-18 T11:16:14	60578730-2e5c-11eb-a2e4-b32ea624e442	3	CURRENT A	c7c2c8a0-4b6a-11eb-a2e4-b32ea624e442	210.7210002
2020-1-18 T11:16:14	60578730-2e5c-11eb-a2e4-b32ea624e442	1	VOLTAGE Kv	c53c6be0-4b6a-11eb-883c-638d8ce4c23d	129.1199821
2020-1-18 T11:16:14	60578730-2e5c-11eb-a2e4-b32ea624e442	9	HUMIDITY	ccbdcee0-4b6a-11eb-883c-638d8ce4c23d	49
2020-1-18 T11:16:14	60578730-2e5c-11eb-a2e4-b32ea624e442	8	TEMPRATURE	cbb893e0-4b6a-11eb-883c-638d8ce4c23d	22
2020-1-18 T11:16:14	60578730-2e5c-11eb-a2e4-b32ea624e442	7	P.F	cafbfaa0-4b6a-11eb-8779-7d56e82df461	0.760000005
2020-1-18 T11:16:14	60578730-2e5c-11eb-a2e4-b32ea624e442	4	S MVA	c88f8e80-4b6a-11eb-883c-638d8ce4c23d	47.08109998
2020-1-18 T11:16:12	60578730-2e5c-11eb-a2e4-b32ea624e442	6	P MW	ca3b1ba0-4b6a-11eb-8779-7d56e82df461	35.31400008
2020-1-18 T11:16:12	60578730-2e5c-11eb-a2e4-b32ea624e442	5	Q MVAR	c9adcfc0-4b6a-11eb-8779-7d56e82df461	31.14100001
2020-1-18 T11:16:12	60578730-2e5c-11eb-a2e4-b32ea624e442	2	FREQUENCY HZ	c68edc80-4b6a-11eb-a2e4-b32ea624e442	48.90000153

Figure 17: Reading the frequency on Cayenne platform

Figure 18: Graph of the frequency values

Figure 19: Alert on the phone

Figure 20: Graphs for 1 h on Cayenne mobile application

RESULTSON CAYENNE PLATFORM

Figure 20 shows the readings of four channels, voltage, current, frequency, and active power in graphs on the Cayenne mobile application for 1 h, from 8:30 pm to 9:30 pm.

CONCLUSION AND FUTURE WORK

In this paper, a proposed system for monitoring and controlling substations based on IoT in the electrical substations is designed and tested, to reduce disasters and economic losses in the important equipment in the stations. The parameters monitored included voltage, current, power, frequency, power factor, active power, reactive power, temperature, and humidity. The PZEM-004T and DHT11 sensors are used to obtain the parameters, and the relays are used to control the line feeders. Data are transmitted continuously and displayed in real-time on the Cayenne platform through the ESP32S module. The proposed system was tested at the 132kV West Mosul station, and readings were obtained in real-time on the Cayenne platform on a laptop and phone. The implementation of the system reduces the severity of disasters in the stations and is considered as to step for transition from traditional substations to smart substations. The system has proven its feasibility, as the smart substation saves the time and effort that the engineers and technicians spend in obtaining the important readings in the stations and knowing the station's stability, where it can be recovered. Daily, weekly, and monthly data can be retrieved due to the MQTT cloud supported by the Cayenne platform. In the future, the proposed system can be developed by linking more than one monitoring system for multiple substations together, so that the responsible authorities can monitor and control these systems remotely.

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