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Research paper

Computerized power transformer monitoring based on internet of things

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Abstract

Distributed transformers are imperative equipment in power networks. Due to large amount of transformers distributed over a widespread area in power electric systems, the data acquirement and condition monitoring is essential concern. In spite of security and automation in plants, industrial environment is relatively critical for machines and humans. This study deals with a safety in industrial condition. A model has been designed to detect dangerous situations like breakdown that is the most essential parameter for occurring leakage current in substation and gas leakage based on faults data source file from distinguished sources. Reached outcome will be executed in IoT (Internet of Things) gateway design, to augment technical implementation with scalability. It consists of Node-MCU, node red server, mosquito server that serves as negotiator amid Node-MCU and node red server and Thingspeak IoT platform. Data processing has been completed at Thingspeak IoT platform so that the monitored quantity can be displayed frequently or at scheduled intervals of time. These processed results have been statistically further analyzed using SPSS software package.

Keywords: *Transformer Monitoring; IoT; Node-MCU; Node Red Server; Mosquito Server; and Thingspeak IoT Platform.*

1. Introduction

Power transformer condition monitoring is largely taken into consideration as extremely imperative Condition Monitoring (CM) methods in power systems. The spontaneous outages of transformers, owing to sudden malfunctions, are disastrous in various cases. Analysis and accurate monitoring play a crucial function in the life expectancy of a power transformer. There are countless suitable monitoring approaches for assessing the condition and likely emerging breakdown of a power transformer. Transformer monitoring approaches are typically high-priced and/or time using up. Nevertheless, cost-effective procedures are required for transformer monitoring, and one option is to apply loading and temperature information rated by the network [1], [2].

To have information about the state-of-health of the transformer, the monitored data and the incipient faults detected by the CM system should be analyzed to assess the transformer condition [3].

Oil of transformer serves as both coolant as well as insulator. Electrical and thermal stresses lead to the degradation of the transformer oil and affect the electrical, chemical and physical properties of the oil.

Deterioration of insulating oil and paper leads to the production of gases which gradually get dissolved in oil. The failure in transformers is due to deterioration of insulation over time. If these failures can be predicted with some degree of confidence, sudden shortcomings and interruption in power supply can be minimized [4].

Dissolved gas analysis (DGA) is a diagnostic tool that used to detect the incipient faults of power transformers through the correlation between the content of gases dissolved in transformers oil and a particular malfunction. Transformer failures are often due to the lack of the dielectric strength of oil insulation and will lead to a negative impact on electrical power systems. Early stage detection of transformer faults can reduce considerably the cost of repairing the damaged transformers and hence maintain the stability of the system. A number of conventional approaches that rely on gases concentration in transformers oils can be exploited to clarify transformer faults as in Dornenburg, Rogers, Duval triangle and key gases techniques [5].

A wireless surge arrester leakage current sensor using ZigBee protocol has been constructed and verified in a 230kV substation [6]. It is equipped to transmit over a distance of 400 m. In [7], a wireless capacitive sensor for monitoring voltage variations of MV/HV plant using ZigBee technology was proposed. Former monitoring solutions have likewise been suggested for practice with electrical plant [8]. Along with external interference and noise, wireless DAQ systems require protection against information loss errors and illegal right of entry to data. This is feasibly fixed by employing wireless equipment that has fierce security in accordance with data encrypting and network connectivity. Matters of loaded bandwidth, disturbance of the wireless signal as a result of electromagnetic interfering should be thoroughly investigated. If sensors and wireless spreaders are attached nearby high-voltage machinery, interference and high-frequency noise can have sensitive impact on their performance. For instance, a previous tentative results in [9], exposed a relationship among the failure consequences in vacuum and SF6 in addition to a severe deterioration in the bit rate of 802.11b wireless devices. WLAN sensors had been demonstrated to be applied in substations for metering and monitoring appliances in spite of incurred transmission interruptions because of noise that we as in tolerable restrictions [10].

The Internet of Things(IoT) stands for the network of physical substances like vehicles, devices, buildings and other items that are implanted with software, electronics, sensors, and network connectivity. It facilitates these things to accumulate and interchange data. IoT tolerates objects to be detected and regulated abstractedly through the available network infrastructure, constructing prospects for more straightforward combination of the substantial world into computer-based systems concerning developed efficacy, accurateness, and cost-effective advantage. It converts an ordinary device into a smart tool that allows the user to access data from the device, analyze it and make the necessary changes in the device functioning [11].

Designing efficient system for power transformer monitoring will help in reducing the energy wastage by continuously monitoring and controlling the electrical appliances. The monitored values from sensors can be continuously stored and updated in a cloud database. There are many open source cloud platforms such as Ubidots, Xively and Thingspeak, etc. Controlling of the devices is the other task that could be done to save energy. Relays can be used as actuators to turn on and turn off the appliances as per the needs. Automation system online makes user to operate the system even when user is not in vicinity of the automation system [12]. This study describes IoT diagnostic model about breakdown that is the most essential parameter for occurring leakage current in substation and gas leakage based on faults data source file from eminent suppliers. Gotten outcome can be finished in IoT gateway design, to augment industrial application with scalability. The proposed system consists of Node-MCU, node red server, mosquito server that serves as mediator between Node-MCU and node red server and Thingspeak IoT platform. Data processing is achieved at Thingspeak IoT platform so that the quantity monitored can be displayed frequently or at programmed intervals of time.

2. Proposed system

The block diagram of the suggested system has been presented in Figure 1. Typically, the industrial monitoring field necessitates more manual capability to observe and control the technical parameters like temperature, humidity, gas, etc. This is the most forthcoming issues in the industrial zones. In the case of parameters are not checked and controlled appropriately, it leads to a destructive situations. Most of the industries are facing those categories of a situation because of some manual faults. To overwhelm these physical mistakes, industrial automation with IoT can be used.

The proposed system has the following parts:

Wireless Sensor Network (WSN) Nodes: Those nodes are distributed over power transformer monitoring zones. Each node is composed of GAS sensor to acquire gas data (C_2H_2, C_2H_4, C_2H_6, CH_4, and H_2) and Node-MCU. The sensor nodes are labelled with unique ID corresponding to transformer number inside zone. The built-in low power WiFi module of Node-MCU sends a string file of gas data to a central broker in schedule time. So, the main role of sensor nodes is to publish gas data to an Message Queuing Telemetry Transport (MQTT) zone (node1, node2,……node n) and subscribe to it using the central broker using MQTT node of Node-Red server.

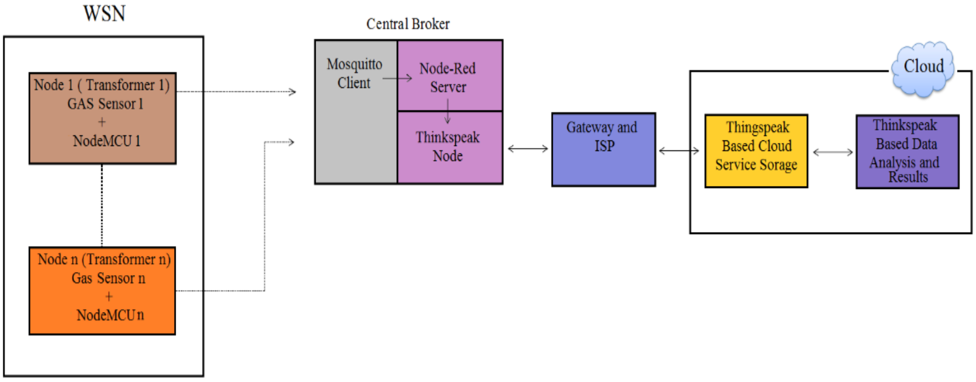


Fig. 1: Block diagram of the projected system.

Node-MCU is an open informant IoT stage. It comprises firmware that persists the ESP8266 Wi-Fi SoC from Espressif Structures that uses ESP-12 component. The "Node-MCU" term stands for the firmware as compared with the dev kits. It uses the Lua scripting language based on the eLua project [13].

Central Broker: The leading role of central broker is to collect transformer gas data from sensor nodes according to its timestamp (transformer ID is high related to data timestamp). Due to the number of fields limitations of Thinspeak's channels (eight fields for a channel), the central broker could send eight gas data at a time where one channel is used to implement the proposed system in this paper. So, to increase the number of nodes, two or three channels may use to monitor more transformers.

The central broker block has two sections. The First section is Eclipse Mosquitto, which is an unrestricted source message negotiator that applies the MQTT protocol varieties 3.1 and 3.1.1. Mosquitto is appropriate for usage for entirely devices from small power solitary board computers to complete servers. The MQTT protocol runs a flexible technique of messaging implementation via a publish/subscribe model. This makes it apposite for IoT messaging as in low power sensors or mobile varieties like embedded computers, phones microcontrollers. The Mosquitto project as well offers C library for applying MQTT, standard Mosquitto_pub and mosquitto_sub command line MQTT clients. Mosquitto represents effectual branch of Eclipse Establishment as iot.eclipse.org project [14]. The Second section is Node-Red server. It is a flow-based advancement tool resulted formerly by IBM for wiring self-possessed hardware devices, Application Programming Interface (API) and electronic services as part of IoT. It has flow editing browser that can be exploited for creating JavaScript purposes. Components of applications can be kept or assigned for re-use. The runtime is built on Node.js. The flows created in Node-RED are stored using JavaScript Object Notation (JSON). In view of the fact that version 0.14 MQTT nodes can make adequately configured Transport Layer Security connections [14]. The importance of Node-Red server in the proposed system is to collect gas data, time scheduling for sensor nodes and provide interface platform between central broker and cloud service based on Thingspeak platform. Figure 2 shows the Node-Red graphical section of proposed central broker for only two sensor nodes.

The node1 and node2 are MQTT nodes with same available subjects (node1 and node2) by Node-MCU. The data are published as string. Thus, json nodes can be used to convert those data to JSON format. Function nodes are used to separate five data values from JSON file with the following code:

```
var newMsg = { payload: msg.payload.C2H2 };
var newMsg2 = { payload: msg.payload.C2H4 };
var newMsg3 = { payload: msg.payload.C2H6 };
var newMsg4 = { payload: msg.payload.CH4 };
var newMsg5 = { payload: msg.payload.H2 };
return [ newMsg , newMsg2, newMsg3 , newMsg4 ,
newMsg5 ];
```

Five simple nodes for node-red which allow publishing data to Thingspeak are used to send gas data values to Thingspeak's fields with 15 seconds delay between values.

3. Thingspeak platform [15]

Thingspeak is an open source IoT relevance and API to collect and recover data from things employing the HTTP protocol via Internet or Local Area Network. It qualifies the conception of sensor cataloging applications, location tracking applications, and a public web of things with status updating.

Thingspeak was formally initiated by ioBridge in 2010 as supporting service for IoT applications. It has incorporated provision from the well-known computing software MATLAB. It has a local association with Mathworks, Inc. All of the Thingspeak records are integrated into the Mathworks' MATLAB documentation site and allowing listed Mathworks user accounts as valid login IDs on the Thingspeak site.

The central broker sends gas data to Thingspeak's channels according to time scheduling scheme. A Rogers's ratio method algorithm has been adopted to categorize transformer health statues [16]. Accordingly, the operator can have visual access to the data stream via Thingspeak channels with support of automatic cloud-based diagnosing for the transformer conditions by categorizing the signals along the gas values. The "Basic Gas Ratios" is standardized in the International Electrotechnical Commission (IEC) that is corresponding to Doernenberg ratios and Rogers's ratios in the ANSI/IEEE C57.104.

An array of ratios of certain key combustible gases as the fault type indicators. These five ratios are [16]:

Ratio 1(R1) $=CH_4/H_2$

Ratio 2 (R2) $=C_2H_2/C_2H_4$

Ratio 3 (R3) $= C_2H_2/CH_4$

Ratio 4 (R4) $= C_2H_6/C_2H_2$

Ratio 5 (R5) $= C_2H_4/C_2H_6$

The Rogers ratio process essentially relies on R1, R2, and R5 ratios. The soundness of this technique is under parallel results of higher number of failure examinations with the gas investigation for each circumstance. Table 1 provides the standards for the three key gas ratios corresponding to proposed case analyses. These ratios, along with Rogers, are relevant to gases in use from the gas space or relay and extracted gases from the oil. The failures categories in Table 1 have been are chosen by relating some circumstances from the number of fault types formerly proposed by Rogers [16].

At what time mineral oil has typical magnitudes of liquefied gas, it specifies no emerging fault in the transformer. When the magnitude goes beyond the standard boundary, tester frequency must be augmented because beyond the normal limit designates several small categories of fault in the transformer. Before the fault turns out to be dangerous, several additional arrangements must be considered to prevent serious faults of other equipment. When the value overdoes the performance constraint, it means particular critical circumstances have been reached, and elimination of transformer from service must be taken into account [17].

4. System implementation

The proposed IoT power transformer monitoring system based on Thingspeak platform is composed of three main sections as shown in Figure 1.

The first part is sensor nodes for gas data acquisition via NodeMCU. The data is collected and saved as string file and forwarded to central broker. The flow chart of this process is shown in Figure 3.

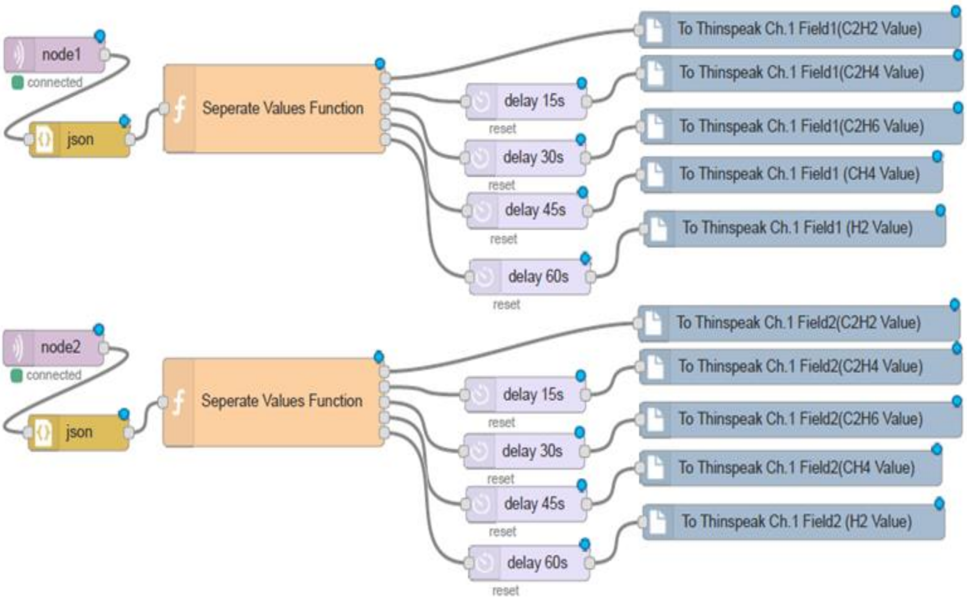


Fig. 2: Adopted Node-Red server in this study for two sensors nodes

Table 1: Rogers Ratios for Key Gases

Case	R2=C2H2/C2H4	R1=CH4/H2	R5=C2H4/C2H6	Suggested fault diagnosis
0	<0.1	>0.1 to <1.0	<1.0	Unit normal
1	<0.1	<0.1	<1.0	Low-energy density arcing-PDa
2	0.1 to 3.0	0.1 to 1.0	>3.0	Arcing-High-energy discharge
3	<0.1	>0.1 to <1.0	1.0 to 3.0	Low temperature thermal
4	<0.1	>1.0	1.0 to 3.0	Thermal<700 ^{o}C
5	<0.1	>1.0	>3.0	Thermal>700 ^{o}C

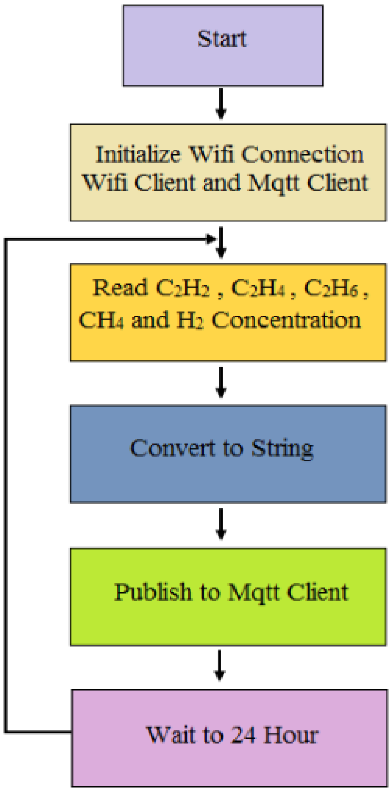


Fig. 3: System Flow Chart.

The central broker which represents the second part of the proposed system read the published data and forwards those data to Thingspeak platform. The forwarded data is saved in eight fields of a Thingspeak channels. The third part is the online MATLAB program in Thingspeak. The program read the saved data and processes it according to gas ratio rules shown in Table 1 for classification purpose. A sample of Thingspeak based online MATLAB code for the gas ratio classification for gas data saved in field number one is shown below.

```
% Channel ID to Read Gas Data
readChannelID =381747;
readAPIKey = 'MM9Z3IFG8C1U1ERZ';
[Gas_Data, time] = thingSpeakRead(readChannelID, 'Fields',2,
'NumPoints',5, 'ReadKey', readAPIKey);
data=Gas_Data';
R1=data(1,4)/data(1,5);R2=data(1,1)/data(1,2);R3=data(1,1)/data
(1,4); R4=data(1,3)/data(1,1); R5=data(1,2)/data(1,3);
Gas_Ratio_Table=[];
Gas_Ratio_Table=["Unit Normal";"Low Energy Density Arcing
";"Arcing,High Energy Discharge";"Low Temperature Thermal
";"Thermal<700 C";"Thermal>700 C"];
T1=["Not Active";"Not Active";"Not Active";"Not Active";"Not
Active";"Not Active"];
Gas_Ratio_Table=[Gas_Ratio_Table T1];
if (R2<0.1 && (R1>0.1 && R1<1 ) && R5<1)%% case 0
 Gas_Ratio_Table(1,2)="Active";
 end
if (R2<0.1 && R1<0.1 && R5<1 ) %% case 1
Gas_Ratio_Table(2,2)="Active";
end
if ((R2>=0.1 && R2<=3) && (R1>=0.1 && R1<=1) &&
R5>3) %% case 2
 Gas_Ratio_Table(3,2)="Active"; end
if (R2<0.1 && (R1>0.1 && R1<1) && (R5>=1 && R5<=3))%%
case 3
 Gas_Ratio_Table(4,2)="Active";
end
if (R2<0.1 && R1>1 && (R5>=1 && R5<=3)) % case 4
 Gas_Ratio_Table(5,2)="Active"; end
if (R2<0.1 && R1>1 && R5>3) % case 5
 Gas_Ratio_Table(6,2)="Active"; end
Gas_Ratio_Table; T = array2table(Gas_Ratio_Table 'Variable-
Names',{'Fault_Type','Fault_Status'});
```

5. Results and discussion

Based on above methods and algorithms, gas concentration data [18] are published to the Thingspeak's eight fields via eight sensor nodes to test the operation of the proposed system. The sensor nodes spend about 90 seconds to release five readings of gas concentration for each sensor node. A sample of data published to field one of node1 and fault classification results captured from Thingspeak window are shown in Figures 4 and 5.

Table 2 shows the detailed gas concentrations for sensor node number 1,2,3,4,5,6,7 and 8 at the Thingspeak's field number 1,2,3,4,5,6,7 and 8 respectively. Fault classification results from Thingspeak window are shown in Table 3.

There are single obvious fault technical issue regarding unit normal at node 1 and Thermal <700 C at node 3, while dual fault practical matters have been detected at nodes 2 and 5 concerning Arcing, High Energy Discharge and at nodes 3 and 6 concerning Thermal >700 C. On the other hand, there is no obvious fault for Low Energy Density Arcing and Low-Temperature Thermal issues for all nodes. These processed findings can be statistically further analyzed using Statistical Package for the Social Sciences (SPSS) from BM SPSS 24 used for data analysis. Table 4 explains the general descriptive statistics of above findings in Table 2 concerning minimum and maximum values of gas concentration after specified periods in all nodes as well as their corresponding mean (M) and standard deviation (SD). The highest mean value was (M = 2842.13; SD = 5231.443) at node 2 after 0 sec, followed by (M = 2841; SD = 3527.857) after about 15 sec in node 7. The lowest mean value was (M = 356; SD = 442.068) after about 45 sec at node 7, followed by (M = 1900; SD = 3486.654) after about 60 sec in node 2.

The reliability of field study based on Cronbach's Alpha has been also investigated using SPSS simulator. George and Mallery [19], had given the following criteria to determine Cronbach's Alpha value as follows: "≥ .9 – Excellent, ≥ .8 – Good, ≥ .7 – Acceptable, ≥ .6 – Questionable, ≥ .5 – Poor, and ≥ .5 – Unacceptable". Accordingly, the Cronbach's Alpha for the adopted monitoring system in this study is 0.905 that represents the excellent performance. So, based on above results, we conclude that the proposed online power transformer monitoring has excellent processing time with excellent reliability for faults analysis.

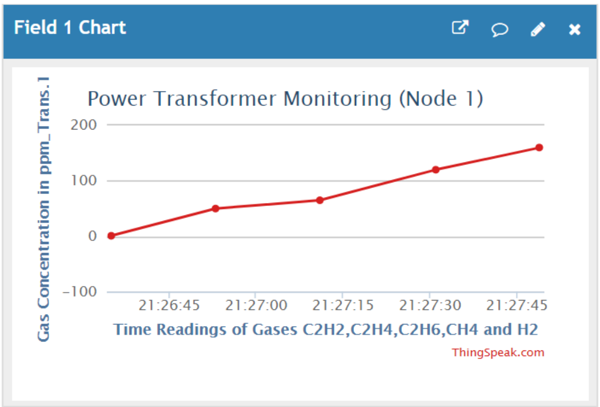
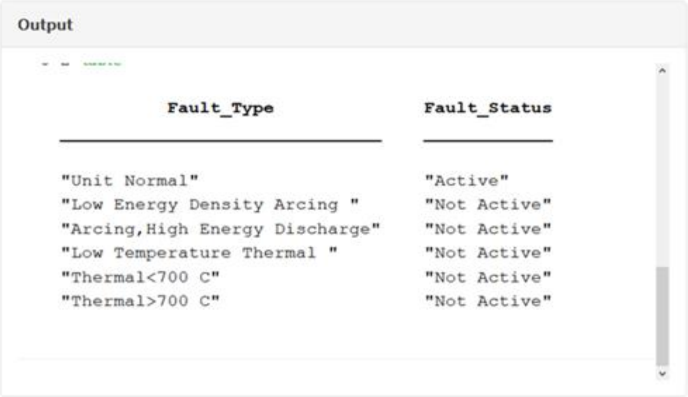


Fig. 4: Gas Concentrations for Sensor Node 1 at the Thingspeak's Field 1.



```
        Fault_Type                          Fault_Status
 ──────────────────────────────────         ────────────

"Unit Normal"                               "Active"
"Low Energy Density Arcing "                "Not Active"
"Arcing,High Energy Discharge"              "Not Active"
"Low Temperature Thermal "                  "Not Active"
"Thermal<700 C"                             "Not Active"
"Thermal>700 C"                             "Not Active"
```

Fig. 5: Fault Classification Results for Non-Healthy Situation of Node1.

Table 2: Gas in Ppm Concentrations for Each Sensor Node within Specified Periods

Time Hour:Minute:Second	After 0 sec	After about 15 sec	After About 30 sec	After about 45 sec	After about 60 sec
Node1 from 21:26:35 GMT+3 time period	1	50	65	120	11
Node2 from 21:29:36 GMT+3 time period	12752	6517	353	4345	9474
Node3 from 21:32:48 GMT+3 time period	0	2480	326	619	80
Node4 from 21:35:23 GMT+3 time period	1	862	328	584	266
Node5 from 21:37:58 GMT+3 time period	224	145	11	107	127
Node6 from 21:40:16 GMT+3 time period	16	1242	144	369	137
Node7 from 21:43:13 GMT+3 time period	9671	9924	1404	8784	4906
Node8 from 21:45:31 GMT+3 time period	72	1508	217	770	199

Table 3: Fault Classification Results for Healthy Situation of Each Sensor Node

Node Number	Unit Normal	Low Energy Density Arcing	Arcing, High Energy Discharge	Low Temperature Thermal	Thermal <700 ^{o}C	Thermal >700 ^{o}C
Node1	Active	Not Active	Not Active	Not Active	Not Active	Not Active
Node2	Not Active	Not Active	Active	Not Active	Not Active	Not Active
Node3	Not Active	Not Active	Not Active	Not Active	Not Active	Active
Node4	Not Active	Not Active	Not Active	Not Active	Active	Not Active
Node5	Not Active	Not Active	Active	Not Active	Not Active	Not Active
Node6	Not Active	Not Active	Not Active	Not Active	Not Active	Active
Node7	Not Active	Not Active	Not Active	Not Active	Not Active	Not Active
Node8	Not Active	Not Active	Not Active	Not Active	Not Active	Not Active

Table 4: Descriptive Statistics of Gas Concentration in All Nodes

	No. of Nodes	Min.	Max.	Mean	Std. Deviation
After 0 sec	8	0	12752	2842.1	5231.4
After about 15 sec	8	50	9924	2841.0	3527.8
After About 30 sec	8	11	1404	356.0	442.06
After about 45 sec	8	107	8784	1962.2	3087.1
After about 60 sec	8	11	9474	1900.0	3486.6

6. Conclusions

The IoT wireless technology is being selected in this study for faults monitoring of transformers. Engaging this system for real-time monitoring of power line with an open standard such as IoT helps to keep costs down and condensed power consumption. Acquired data can be processed in IoT gateway design, to augment industrial operation in power networks. The suggested monitoring system essentially involves Node-MCU, node red server, mosquito server that serves as mediator between Node-MCU and node red server and Thingspeak IoT platform. Data processing is achieved at Thingspeak IoT platform so that the quantity monitored can be displayed frequently or at programmed intervals of time. The processed records have been statistically analyzed using SPSS simulator. Based on this simulator finding, the projected online power transformer monitoring has excellent processing time (after about 90 sec for each node) and excellent reliability of 0.905 of Cronbach's Alpha that can be adopted practically for faults analysis of power transformer. In addition to simple configuration and cost effectiveness of system elements, the proposed monitoring system in this study has proven statistically by SPSS simulator to be highly reliable in usage as compared with related reported studies in [1-12]. Also, it can provide monitoring reports at any required intervals with various fault status details anywhere online.

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