16th International Conference on DEVELOPMENT AND APPLICATION SYSTEMS, Suceava, Romania, May 26-28, 2022

Analysis of Server Solutions Used for Microclimate Surveillance in LV / MV Switchgear Cells

Radu Fechet, Adrian Graur, Marius Prelipceanu, Dragos Vicoveanu
Ștefan cel Mare University of Suceava
Computers, Electronics and Automation Department
Suceava, Romania

***Abstract*—The present paper presents a short review and discussion of servers used for microclimate supervision in LV (Low Voltage) / MV (Medium Voltage) distribution cells. This solution can be extended to other electrical distribution equipment such as indoor transformers or Low Voltage distribution panels. Considering that the main environmental measurements are temperature, humidity, dust and atmospheric pressure, certain unfavourable conditions may lead to appearance of electrical discharges or partial discharges phenomena inside of the cells. Continuous monitoring is highly recommended to prevent it. Thus, continuous supervision of environmental parameters drives in early identification of deteriorating environmental conditions, and may, subsequently, act as a signal to local or regional coordination to take preventive or predictive measures.**

Keywords—preventive maintenance; predictive maintenance; IoT; Low Voltage /Medium Voltage distribution cells; servers

I. INTRODUCTION

In terms of field maintenance time, there are usually four different types of maintenance: proactive (the most common one), preventive, predictive, and reactive (undesired). From the standpoint of maintenance costs, the proactive is the least expensive, with higher prices for the predictive, preventive, and reactive types [1]. The main scope of preventive and predictive maintenance is to minimize the number of failures, and to rise the asset reliability. Both kinds of maintenance are part of a programmed activity.

The preventive maintenance is scheduled in advance based on specific papers (maintenance work orders). To increase the functional life of devices, this maintenance can be usually carried out annually or bi-annually as physical check of equipment to prevent emergency issues. In order to balance the cost for regular preventive maintenance, maintenance staff are forced to take rapid and suitable decisions regarding the devices and the maintenance periods [2].

Predictive maintenance can reduce labour and material costs and it is programmed based on the present state equipment or device conditions. Regarding scheduling, the difference between preventive and predictive operations is that the preventive type takes place at regular intervals, while predictive one is scheduled based on the asset condition. The implementation of a predictive type of architecture usually requires resources such as qualified personnel, involving costs that are often acceptable to many companies. On the other hand, predictive maintenance improves productivity [1].

Regarding the evaluation of equipment conditions, a set of non-destructive tests have been used: vibration analysis, thermal stability using infrared light sources, sound level determination, corona detection, acoustic (airborne ultrasonic and partial discharge), inside camera, oil analysis and many others dedicated online tests. In most of the cases, to reduce wiring costs, the onsite solutions require measurements which are often taken by wireless sensor networks (WSN). Recently, supervised machine learning algorithms have been applied in the field of predictive maintenance in order to estimate the operational lifetime of an asset [2], [3].

On the other hand, in the case of collaborative process automation systems (CPAS), the equipment maintenance is performed based on measurements along with the level of process performance. [4].

Offline environmental monitoring of equipment or online continuous monitoring are the basis of evaluation of predictive maintenance. Continuously, data collection can help preventive maintenance, and an earlier diagnosed event may go in a wrong direction later. Therefore, using new technological approaches as Internet of Things (IoT), large volumes of data can be acquired, and using specific analysis and techniques, an unfavourable event or a certain malfunction can be predicted in time. To prevent electrical damage due to partial discharge (PD) of the LV/MV switchgear, a continuous monitorization of the environment is needed for long-term operation.

Recently, new research presented a typical predictive maintenance implementation based on the experience of a medium-high size company which considers that the monitoring of the microclimate is decreasing the overall costs of the preventive maintenance operations [5], [6].

Moreover, in a study driven by Schneider [7], on their own cells, the main damages in LV/MV switchgear cells are the mechanical failure (approx. 30%) which can increase to 38% if maloperation adds up, Partial Discharge (PD) failures (approx. 26%) and others (vacuum 11%, VT 9%, lighting 6%, cable box 6%, cable terminal 3%, and water 1%). In a switchgear, a faulty connection of jumper cables, cable terminals and bus can generate heat increase. If there are no sensors to detect this rise in temperature, the result will be flawed. In a study of [8] and

978-1-6654-8162-5/22/$31.00 ©2022 IEEE

[9], the PD has led to final damage of a distribution cell in 27 months.

The remaining effects after the production of the Partial Discharge (PD) phenomena are the electromagnetic waves which include acoustic waves (at ultrasonic and audio frequencies), heat, light, and different gases such as oxidative reactive species as O_3 (ozone) and NxOy: N_2O_5, N_2O, NO_3, NO_2, NO [12], [13], [14], [15]. Each physicochemical element (radio, heat, audio, gases) can be measured using specific sensors.

Recently, new research [10] has shown that a switchgear exposed to moisture can lead up to 30% in the damage of the bus. Moreover, the exposure to dust can be followed by a 19% damage of the switchgear bus. In [11], it is presented a similar test showing that the increase of the humidity leads to increase of occurrence of partial discharge activities. Therefore, the focus on early degradation of distribution cells considers condensation formation points, dust measurements (PM 2.5, PM10, PM100), O_3 release, nitric acid formation (HNO_3), atmospheric pressure, air quality and conductor insulation (PD activity). On the other hand, the continuous monitoring of the environment conditions and PD activity of a distribution cell is the solution for long-term operation for a distribution cell

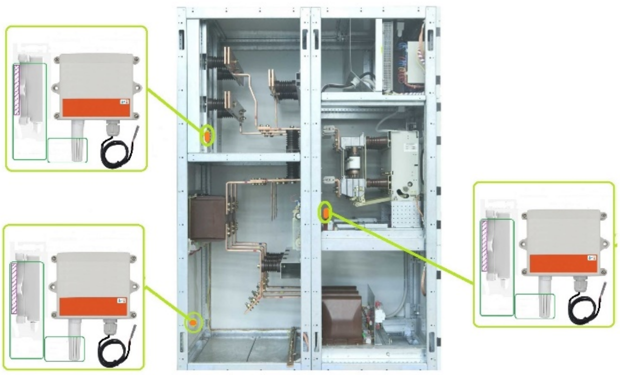

Fig. 1. Switchgear, environment sensors positioning in compartments.

Fig. 1 presents a schematic proposal for the emplacement of the environmental sensors inside the LV/MV switchgear cell. Each sensor is equipped with two measuring points for temperature, one measuring point for humidity, and it calculates the dew point. Regarding the calculation of the dew point, the formula in [18], which is of medium complexity for the entire interval of measurement, was chosen out of the many calculation formulas [16], [17]. If the second temperature sensor is 2°C below the dew point, condensation occurs, and the alarm must be signalled at the monitoring centre. The discussion about gas sensors (O3, NO2, N_2O_5) and PD activity, which are expensive, will be considered in a future study.

The proposed system considers the minimum system requirements. Low-cost, low-power, highly reliable and ready to use available components were used to achieve the desired functions of a monitoring workflow.

It is confirmed that the systems work as expected, with an architecture as shown in Fig. 2.

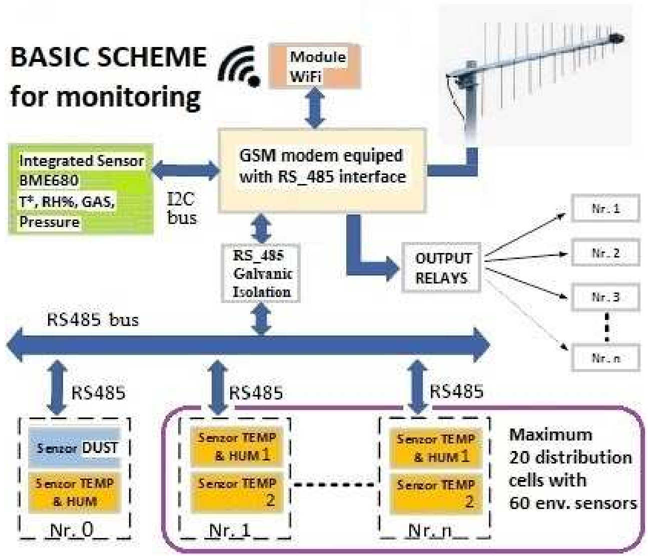

Fig. 2. Base schematic proposal for microclimate supervision in LV/MV distribution cells (LV/MV cell No.1, No.2, …, No.20).

The communication uses the 2G/2G/4G mobile network technologies. Specific mobile networks measurements need to be made before installing the GSM modem, depending on the area coverage on the LV/MV distribution cells site. The modem has a Linux Embedded Operating System with routing capabilities and supports the installation of various libraries for communication (RS_485, [19]) and security. A quality-of-service mechanism should also be implemented for all communication interfaces (i.e for RS_485 it is not implemented).

II. Server Solutions for Microclimate Monitoring in LV/MV Distribution Cells

A. Node-RED Server (Open Source)

Node-RED has been developed as a graphical programming language solution built in JavaScript on top of *Node.js* under Apache 2.0 license [20]. It implements a server side and clients can build programs with a structure of flowing operations. Flow based programming brings the novelty of structuring an application formed by a network of boxes and connections (i.e., nodes). The server was open sourced in 2013 and has been developed since then continuously

The main advantage of the Node-RED server is the use of a non-blocking event-driven model. The installation can run locally on a PC (Linux or Windows), on a device (like Raspberry-Pi or BeagleBone Black) or in the cloud (IBM cloud, AWS, Microsoft Azure, etc.). The application has a large support community and libraries (over 226 000 modules in Node's package repository where a dedicated ModBus library can be found). The main interface contains a dashboard, an optional add-on module, that lets you create live dashboards and therefore, it is recommended to be installed. Moreover, being a web browser programming editor, which offers to wire into flows to the palette using a large range of the *nodes* in a schematic way using drag and drop method, Node-RED need no other dedicated additional tools. For present application, in addition to core nodes and other nodes for messages parsing, HTTP and MQTT nodes are needed. Flows that were created are stored in JSON format, and starting with version 01.4, TLS security has been to the MQTT protocol.

Recently, few commercial hardware devices as RaspberryPi, Siemens-SIMATIC-IOT-2040, Samsung-Artik, Intel-IoT-Gateway or BeagleBone started to be delivered with the operating system along with the Node-RED already installed. Moreover, Fujitsu-INTELLIEDGE-A700-Appliance and Schneider-Electric-Harmony-HMIBSC-Core-Box have adopted the same solution.

Fig. 3 shows a declaration scheme of the measurement sensors in the compartment of a distribution cell using MQTT protocol on a Raspberry Pi4 board.

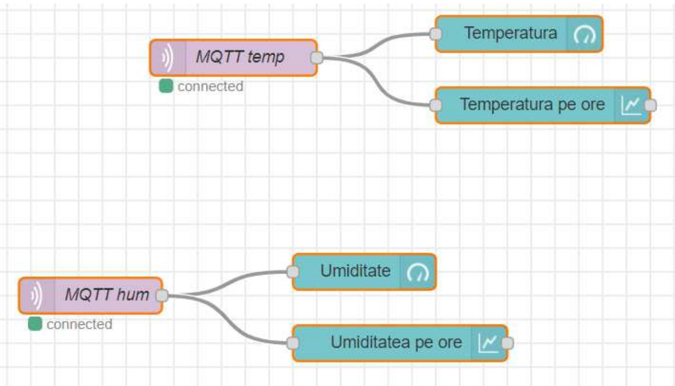

Fig. 3. Node-RED configuration interface, sensors nodes declarations.

To send data from a device to the Node-RED application using the MQTT protocol, the user can deploy the *mosquito* utility, which can be found for both Linux, Linux Embedded and Windows distributions. The port normally used by MQTT is 1883, for the Node-RED server is also 1883, but it can communicate on other ports in other applications. The MQTT protocol uses a type of technique of *publish* and *subscribe* to a *topic*. This technique is very useful especially in IoT technology in which communication is based on GSM/3G/4G mobile networks, thus offering the possibility to give commands back to a remote IoT device without the need for its IP address. Next, an example of a commands without TLS security that contains the MQTT service to send data to the Node-RED server simulating various sensor values (publish to topic *temp* and *hum* with valid credentials for *user_name* and *password*) is presented:

mosquitto_pub -h Node_RED_Server_IP_or_HOST_NAME -p 1883 -t temp -m "123" -u user_name -P password

and

mosquitto_pub -h Node_RED_Server_IP_or_HOST_NAME -p 1883 -t hum -m "654" -u user_name -P password

Even if Node-RED has proven to be a great choice, it has also some limitations related mainly to embedded systems memory management handling a maximum of 100 simultaneous requests on the Ethernet side. More information about the limitations of the Node-RED server can be found in the forum (https://discourse.nodered.org/).

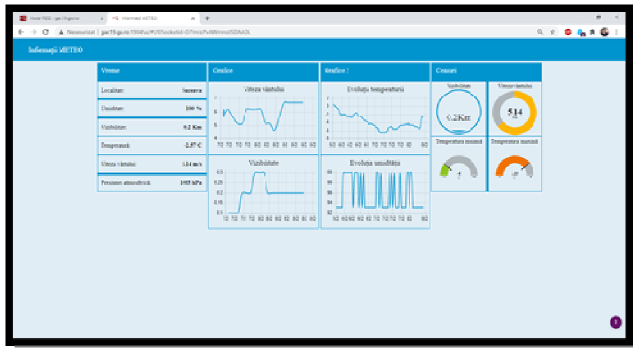

Fig. 4. Node-RED example of a graphical interface, sensors with history.

Fig. 4 presents the user interface for the long-term history of the data acquired. In this case, the server is very useful to build a map of sensors, to have the logging data for the history, a visual debugging tool, to convert message format, parsing and to identify syntax issues in communication between remote sensors and various types of other servers.

The great advantage in using the Node-RED server is the flexibility of implementation that is due to the existence of a diverse range of libraries that can be installed in accordance with the installed version. Older libraries that have not been updated may not be loaded in newer versions of the server.

A disadvantage would be that this platform has a limited number of processing nodes declared and, according to the information on the forum, it could handle a maximum of about 400 sensors, so it would be suitable for small and medium-sized systems.

B. ThingsBoard for IoT (Open Source only for Community Edition)

ThingsBoard Community Edition it is an open-source IoT Platform licensed under Apache License 2.0 that it used for IoT solution for device management, data collection, processing and visualization [21]. The company ThingsBoard, Inc. was founded in 2016, and it is quite new in this kind of market. To use the *ThingsBoard* server platform, connectivity packages must be installed in the router with Linux Embedded operating system. Based on communication packages, specific scripts must be declared to match the key-value content in JSON format accepted by this software.

The *ThingsBoard* can be used as an HTTP Server with other protocol supported: MQTT, LoRaWAN, SigFox, using *ThingsBoard IoT Gateway* the supported protocols can be extended to: OPC-UA, ODBC, REST, SNMP, BLE, CAN, BACnet si ModBus. For protocols that do not appear in the list, support is provided upon request. HTTPS or MQTT (over SSL) protocols can be used for transport encryption. To install the ThingsBoard server and its services, it must be followed ThingsBoard installation documentation available on open-source resources [21]. The first choice is the installation of the low volume open-source PostgreSQL Database, recommended by ThingsBoard for a reasonable load (< 5000 messages/sec). Thus, the software can be defined for the main switchgear sensors and configured on the general map to test the communications protocols including MQTT. Each device in *ThingsBoard server* has unique access token credentials that is used to setup connection. Credentials type is pluggable, but X.509 certificates support is not yet implemented. One of the main advantages of the ThingsBoard is that it allows for the creation of a very user-friendly, intuitive, dashboard, having no more than 30 widgets. The dashboards are built from these elements and can show the status of each implemented device. Testing the data sending procedure for ThingsBoard server, in the case of Linux distributions or embedded Linux, *cURL* application can be used as separate software package using commands specific for each operating system. The command *cURL* works for all OS, meaning Windows, Linux and macOS. For Windows 10-b17063 version, the application *cURL* is available by default. An example of syntax using *cURL* for a local *ThingsBoard* server is provided below:

curl -v -X POST --data "{"temp":23,"humid":52}" http://ThingsBoard_Server_IP:8080/api/v1/$ACCESS_TOKEN /env_sensors --header "Content-Type:application/json" , and for a remote *ThingsBoard* server the syntax is:

curl -v -X POST --data "{"temp":42,"humid":73}" http://ThingsBoard_Server_IP:8080/api/v1/$ACCESS_TOKEN /env_sensors --header "Content-Type:application/json"

For a local client assuming that the *mosquitto* package and the MQTT protocol are installed in the router, the syntax for transmitting the temperature, relative humidity and dew point received from an RS_485 sensor to the *ThingBoard* is:

mosquitto_pub -d -h "localhost" -t "v1/devices/env_sens/tel" -u "$ACCESS_TOKEN" -m "{"temp":25, "humidity":75, "dewpoint":20}"

MQTT protocol is also used to control the I/O from a remote sensor with dynamic IP (see Fig. 5). You can deactivate some sensor functions in this way. Furthermore, the MQTT protocol can support traffic encryption. As it can be observed, starting with version cURL 7.70.0, the MQTT protocol is included at very basic level. Moreover, it can be seen some modification at the QoS level 0 is and the TLS with no support.

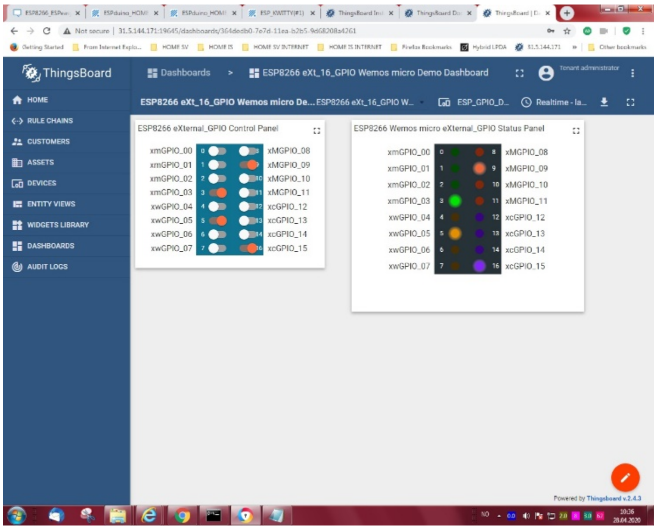

Fig. 5. ThingsBoard using MQTT protocol to control I/O expander (PCF8574 with I2C bus) from a remote sensor.

An experimental study was carried out on the power supply and WiFi side. The Smart sensor in the main diagram was connected via WiFi to the router that transmitted data about the level of WiFi reception of the sensor. So, as shown in Fig. 6, some malfunctions can be visually identified quickly if the historical logs are used for a month, for example. The red rounded area with empty spaces represents the malfunction on the ThingsBoard server (power failure) and the others are the degradation/recovery of the sensor WiFi RxLevel (RSSI RxLevel, Receive Signal Strength Indicator).

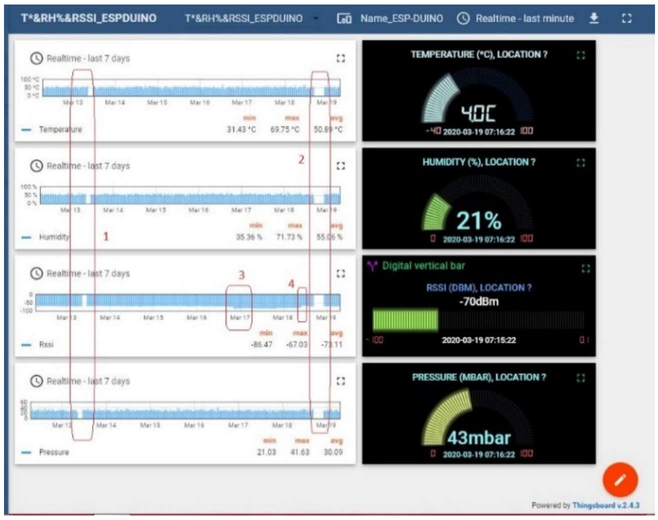

Fig. 6. ThingsBoard experiment with sensors malfunction.

Zooming in the above logs shows the information presented in Fig. 7. Both Area 1 and 2 represent Server down (Main power failure), and Area 3 and 4 show the decrease of RSSI sensor level to -86dBm and recovery to about -70dBm after local intervention.

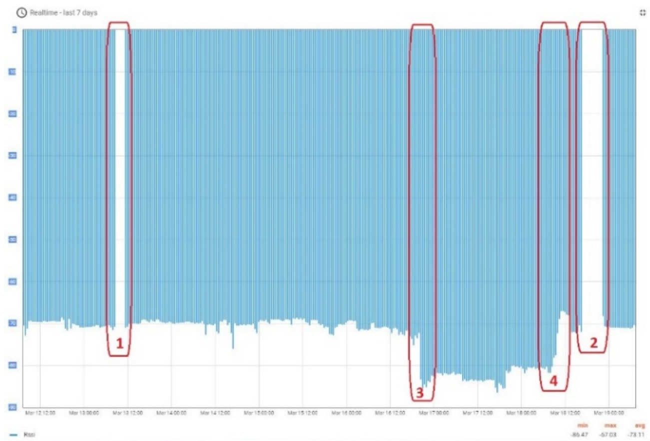

Fig. 7. ThingsBoard experiment with sensors malfunction, Zoom In for Power Failure and WiFi RxLevel.

The advantage of using Thingsboard platform is given by the easy-to-understand documentation, demo movies, training offers, forum answers, examples of use cases (environment monitoring, fleet tracking, smart energy, smart farming, smart metering, smart office, smart retail, water metering, etc.) and examples to connect various hardware platforms to ThingsBoard.

A disadvantage is that the free of charge community edition does not offer a long history of the log data received and or export to another data format. On the other hand, the paid version P*rofessional Edition* has many advantages. The *ThingsBoard Professional Edition* offers more facilities, more historical data, and export of data in *csv* or *xls* file format, but these improvements imply monthly costs [22].

To test different monitoring software included in the supervision centre, two HP Proliant 360 G7 have been installed in a portable 19inch rack, and two 10TB raid-hdd. The system was originally designed with two servers for redundancy, but in the development of the project it was found that there are more open-source monitoring systems on the market than initially estimated. For this reason, redundancy has been dropped for the time being to focus on testing all identified open-source servers and provide the best solution for monitoring.

The 19-inch rack is still under construction and must be populated in the future with temperature and humidity sensors together with a special monitoring system for the power supply. The power supply monitoring system will verify the voltage and the current for each phase from the three-phase system and will perform harmonic analysis. A battery backup is also considered.

C. *ThingSpeak cloud for IoT (free for 8 sensors)*

The ThingSpeak server work with IoT addresses projects and allows cloud data collection along with advanced analysis using MATLAB [23]. ThingSpeak is a platform that allows to integrate, view and analyse data sent by the sensors network.

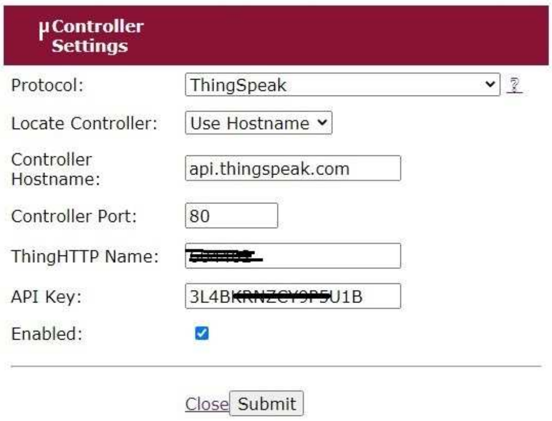

Fig. 8. ThingSpeak cloud server declaration example need for GSM router.

Data can be sent from instant views of real data, and alerts can be sent later using web services such as Twitter® or/and Twilio®. Using function MATLAB® analytics in the ThingSpeak cloud, MATLAB code can be written and executed to perform analysis, pre-processing, and visualization. ThingSpeak allows scientists and engineers to build IoT systems prototype without hard work of configuring servers or developing web software. An example of configuration of the ThingSpeak server on an IoT development board web page with ESP8266 is shown in Fig. 8.

Fig. 9. ThingSpeak example of charts with data from sensors; for a free account, a maximum of 8 charts is offered.

Similar settings will have to be defined in the Linux embedded router together with other parameters specific to each cloud, among which: authorization key, number of retry attempts in the cloud, timeout, etc. For free account and tests, ThingSpeak offers a maximum of 8 charts, as shown in Fig. 9. Another limitation is that data is sent to a chart at least once every 15 seconds. If it tries to send faster than 15 seconds from the same IP, the cloud application refuses the connection

ThingSpeak allows free service for non-commercial projects (approx. 8,200 messages / day). For larger projects or commercial applications, four different types of annual licenses are offered: Standard, Academic, Student, and Home. ThingSpeak purchasing allows the storage of 33 million messages in one year (~ 90,000 messages / day). A unit also offers the possibility to create a fixed number of channels on ThingSpeak. More information can be found on their web address [24].

III. Conclusions

Partial discharge alarms are informative, normally should not be interfere from main operations, and these alarms should be routed to asset management teams. The life of the switchgear can often be extended by incorporating appropriate predictive and preventive maintenance. The current design offers a solution to monitor temperature, relative humidity, and dew point calculation for at least 3 compartments inside a switchgear cell. The current solution aims to observe and react if the switchgear is properly maintained based on sensor information.

Node-RED server has the advantage of providing an Open-Source solution to create a medium-sized monitoring system. Due to the flexibility of the implementations, it is also pre-installed on some industrial equipment. A disadvantage would be the limited number of sensors that can be monitored and the limited number of parallel processing of several requests.

If sensors with a static IP in the field are used, monitoring servers can read data from sensors using technologies like HTTP GET, or SNMP trap. On the other hand, if a sensor with a dynamic IP in the field is used to gather data from sensors, HTTP POST and MQTT protocol are very suitable for this particular purpose. Thus, the ThingsBoard server has the advantage of already including HTTP POST and MQTT protocol. Further research and the use of special software agents could allow the MQTT protocol to be integrated in other monitoring servers like CACTI, Pandora FMS (opensource community), NAGIOS, ICINGA, ZABBIX or PRTG [25]-[29]. A ThingsBoard disadvantage would be that in the free community edition version, the histories are for a maximum of 1 month.

The advantage offered by Cloud ThingSpeak is the maximum of 8 free maps with a refresh rate of 2 minutes (8 sensors, every 15 seconds). For 8 sensors-case, some Matlab analytical functions are offered free of charge (for example histograms, correlation functions, etc.). The disadvantage would be the need to purchase an annual license for a larger number of sensors.

ACKNOWLEDGMENT

This work was supported by:

1. the project "Integrated Center for Research, Development and Innovation in Advanced Materials, Nanotechnologies, and Distributed Systems for Fabrication and Control (MANSiD)".

2. the project "Supporting the research of excellence within the Ștefan cel Mare University of Suceava" financed by the Romanian National Council for Higher Education Funding, CNFIS, project number CNFIS-FDI-2020-0615.

3. research contract number 172/8.02.2021 between "Ștefan cel Mare" University of Suceava and the ElectroAlfa International Botosani company (https://electroalfa.ro/).

4. other sponsor: EGGER Radauti, (https://www.egger.com).

REFERENCES

[1] Peng Kern (2012). Equipment Management in the Post-Maintenance Era: A New Alternative to Total Productive Maintenance (TPM). CRC Press. pp. 132–136. ISBN 9781466501942. Retrieved 18 May 2018.
[2] Amruthnath, Nagdev; Gupta, Tarun (2018). "Fault Class Prediction in Unsupervised Learning using Model-Based Clustering Approach", 2018, doi:10.13140/rg.2.2.22085.14563.
[3] A Rykov, M. The Top 10 Industrial AI use cases. Available online: https://iot-analytics.com/the-top-10-industrial-ai-use-cases (accessed on 28 January 2020).
[4] Information on Web link: https://www.eaton.com/us/en-us/products/medium-voltage-power-distribution-control-systems/switchgear/fundamentals-of-medium-voltage-switchgear.html
[5] https://library.e.abb.com/public/3c3e5714dae64f78b4fe525be5377569/9AKK107992A1474_PDCOM%20partial%20discharge%20monitoring%20of%20SWICOM%20system_Presentation.pdf, slide 6
[6] https://library.e.abb.com/public/ebc1fec49d09412fa4db60178f4717fe/9AKK107991A1983_ABB-Whitepaper-DataCenter-Benefits-of-monitoring-and-diagnostic-solutions.pdf, page 11
[7] https://schneider-electric.com
[8] Information on Web link: https://eatechnology.com
[9] Neil Davies, Simon Goldthorpe, 2009, "Testing distribution switchgear for partial discharge in the laboratory and the field", Cired 20th International Conference on Electricity Distribution, Paper 0804
[10] IEEE Standard 493-1997
[11] Simon Goldthorpe, Robert Ferris, Simon Hodgson, 2009, "Use of web based partial discharge monitoring to extend asset life", Cired 20th International Conference on Electricity Distribution, Paper 0530
[12] Hassan Javed, Kang LI, Guoqiang Zhang and Adrian Traian Plesca, Experimental Study on Air Decomposition By- Product Under Creepage Discharge Fault and Their Impact on Insulating Materials, J Electr Eng Technol.2018; 13(6): 2392-2401, http://doi.org/10.5370/JEET.2018.13.6.2392, ISSN(Online) 2093-7423, https://www.researchgate.net/publication/328262433
[13] Kang Li, Hassan javed, Guoqiang Zhang, "Experimental Study on Ozone Production under 50 Hz Corona Discharge Used for Fault Diagnostic," Proc. 2nd International conference on Machinery, Materials Engineering, Chemical Engineering and Biotechnology, pp. 456-460, Chongqing, China, Nov 2015. DOI:10.2991/mmeceb-15.2016.90.
[14] Hassan JAVED, Kang LI, Guo-qiang ZHANG, and Adrian Traian PLESCA, "Online Monitoring of Partial Discharge by Measuring Air Decomposition by products under Low and High Humidity", International Conference on Energy, Power and Environmental Engineering (ICEPEE2017), pp. 186-191, Shanghai, China, April 2017, DOI10. 12783/dteees/icepe2017/11837, https://www.researchgate.net/publication/316472592, April 2017.
[15] R. Schwarz, T. Judendorfer, M. Muhr, "Review of Partial Discharge Monitoring techniques used in High Voltage Equipments," 2008 Annual Report Conference on Electrical Insulation Dielectric Phenomena, pp. 400-403, 2008. DOI:10.1109/CEIDP. 2008.4772825.
[16] Lawrence, Mark G. (February 2005). "The Relationship between Relative Humidity and the Dewpoint Temperature in Moist Air: A Simple Conversion and Applications". Bulletin of the American Meteorological Society. 86 (2): 225–233. Bibcode: https://ui.adsabs.harvard.edu/abs/2005BAMS.86..225L, https://doi.org/10.1175%2FBAMS-86-2-225
[17] Sonntag D., "Important New Values of the Physical Constants of 1986, Vapour Pressure Formulations based on the IST-90 and Psychrometer Formulae" Z. Meteorol., 70 (5), pp. 340-344, 1990.
[18] Martin Wanielista, Robert Kersten and Ron Eaglin, 1997, Hydrology Water Quantity and Quality Control. John Wiley & Sons. 2nd ed.
[19] (available at https://pdfserv.maximintegrated.com/en/an/Guide_Serial_Communication_Protocol_RS-485.pdf)
[20] (available at https://nodered.org/)
[21] (available at https://thingsboard.io/)
[22] (available at https://thingsboard.io/pricing)
[23] (available at https://thingspeak.com)
[24] (available at https://thingspeak.com/prices)
[25] (available at https://www.cacti.net/)
[26] (available at https://www.nagios.org/)
[27] (available at https://icinga.com/)
[28] (available at https://www.zabbix.com/)
[29] (available at https://www.paessler.com/).