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Real-Time Monitoring for Power Transformer Using IoT

Ahmed M. Elmashtoly, Choong-Koo Chang†*
Dept. of Nuclear Power Plant Engineering, KEPCo International Nuclear Graduate School (KINGS), Ulsan, Korea.
Author: ahmed_mashtoly@hotmail.com*,** *†Corresponding Author: ckchang@kings.ac.kr*

1. Introduction

In this paper Internet of Things (IoT) will be used to represent the implementation of the 4^{th} industrial revolution on the new and the existing system of a power transformer. IoT plays an important role in real-time monitoring for the electric assets in the network. Real-time monitoring can be done by placing the sensors on the asset and then connected to a microprocessor board with suitable code, afterword this data can be sent to server/cloud for data analysis and real-time monitoring. This data can be accessed from different places at the same time not only for real-time monitoring but also for controlling the equipment (depending on the type of sensors and their function, to be installed on the asset). One of the most critical components is the power transformer, which will be discussed in this paper. The main objective of real-time monitoring for the power transformer is to indicate the abnormal event that may happen in real-time. The measured data will be displayed in the control room, to guarantee the reliable operation and good conditions for the transformer, notice maintenance needs at an early stage and helping to plan preventative actions which will reduce maintenance cost and labor. Also, this data will be used to calculate the health index (HI) of the transformer and the remaining useful life (RUL) as shown in Fig.1.

The main advantages of using IoT for real-time monitoring are: reducing the hardwire used for transmitting data from the sensors to the monitoring system; the server/cloud **can be accessed from different places not only one monitoring center**; IoT has become affordable since there are a large number of sensors suppliers and different microprocessor board companies(Arduino, Raspberry Pi, Intel, and beaglebone); and different competitors cloud services with different option of data analysis and management. The main topic of discussion will be the implementation of real-time monitoring based on IoT for the power transformer especially the unit auxiliary transformer (UAT) found in the APR1400 Nuclear Power Plant (NPP).

2. Current monitoring system

In the APR1400 NPP the UAT is used as the step down transformer for house load. There are two three-phase transformers, one for each division. Each one has two secondary windings (13.8 kV, 4.16 kV) and have the capacity and capability to provide power to two non-class 1E 13.8 kV switchgears, two class 1E 4.16 kV switchgears, and one non-class 1E 4.16 kV switchgear [1,2].

The current system for monitoring was done by connecting three transducers to the current transformer (CT) and voltage transformer (VT) and the output is the transformer ampere (A), power (W), and power consumption (WH). These values are sent to the Main Control Room (MCR) through the Process Component Control System (P-CCS). In the APR1400 NPP, there are three systems used to transmit the signal from the components to the MCR, one of them is P-CCS which used in the transformer monitoring system. In addition, there is one transducer connected to the Energy Management System (EMS) to the dispatch center.

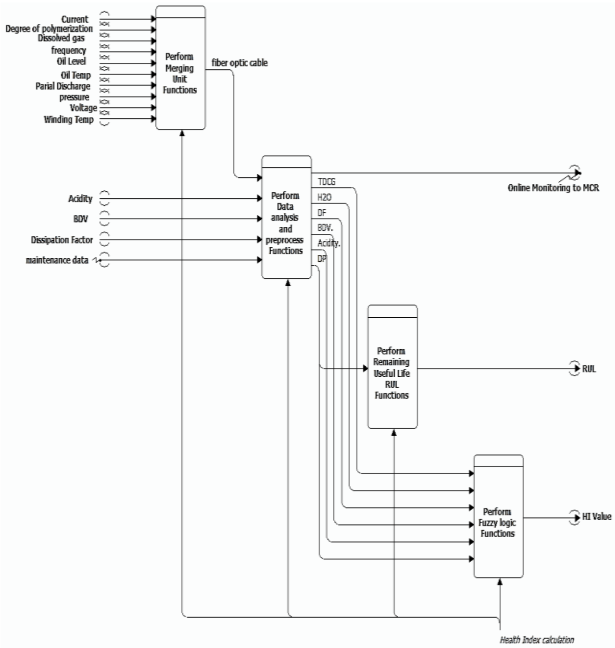

Fig. 1. Real-time monitoring, RUL, and HI Function block diagram using IDEF0.

Current monitoring system for transformer in NPP is not fully computerized. Currently, data for winding temperature, oil level, and top oil temperature need to be read from the transformer panel by a technician, which may cause the reading error, inaccuracy, and longtime delay to get the reading value. This system is limited to be displayed in the MCR, and one value (W) only for EMS. The usage of copper wire may affect reading errors, especially for long-distance cables. The usage of four transducers increases the power consumption for instrument and control power even though the required transducer power is very small. The dissolved gases in transformer oil are done by laboratory testing periodically (The industry recommendation is to take samples once a year) which cannot indicate real-time the causes of the fault inside the transformer.

3. Proposed real-time monitoring system

The proposed online monitoring system of UAT consists of two subsystems, first is real-time monitoring and the second is the HI and RUL calculation by the fuzzy logic controller as shown in Fig. 1. As mentioned earlier, this paper focus only on the real-time monitoring system. This system using different sensors to measure the winding temperature, oil level and temperature, dissolved gases in the oil, current, voltage, power, and partial discharge.

3.1. IoT layers

The IoT has four layers as illustrated in Fig. 2. The first layer is the device layer which includes two sub-layers. Things sub-layer which will be the (temperature, level, DGA, online partial discharge, current, and voltage) sensors. And gateway sub-layer that will be merging unit (MU) microcontroller-based. The MU can accept digital and analog inputs from different sensors and has only one fiber optic cable output as shown in Fig. 3.

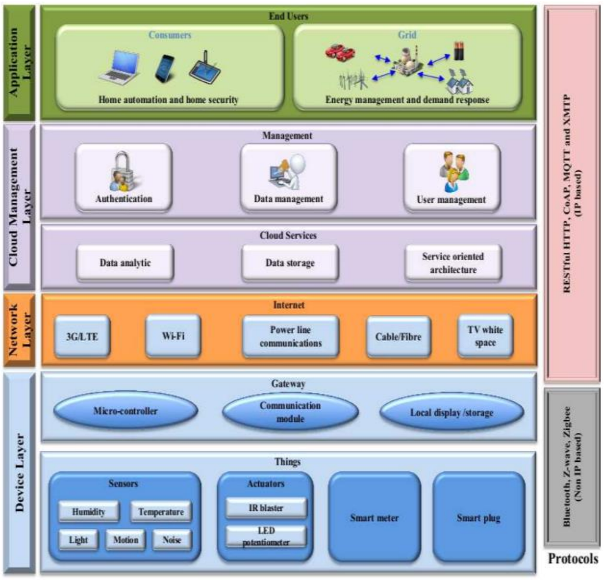

Fig.2. IoT four layers and the related components [3].

The second layer is the network layer, the fiber-optic cable will be used as connecting the device layer to the application layer. The usage of fiber instead of Wi-Fi is to keep the security requirements and to avoid electromagnetic interference with Wi-Fi signal since this asset is a power transformer.

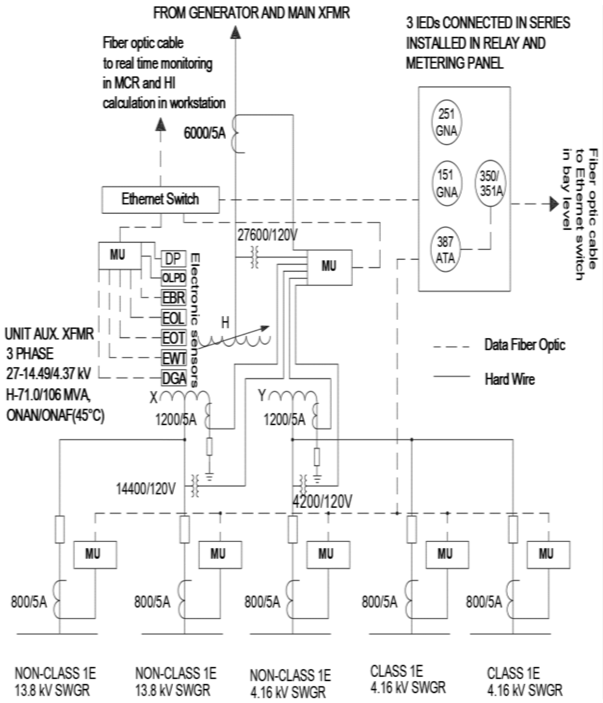

Fig.3. Configuration of the proposed online monitoring system.

The third layer is represented by the cloud management layer, a physical server will be used inside the plant to keep the security requirements. The current issue is the cybersecurity problem in case of connecting this server to the internet, so the data which will be monitored by IoT can be divided into safety class and non-safety class data. The non-safety class data will be monitored using the internet network from different places using proper authentication for the users. This server will be used for data storage and analysis for the health index calculation as shown in Fig. 1.

The fourth layer is the application layer which will be the display panel of the electric workstation and dispatch center. This system will be work as a real-time monitoring system and not controlling the UAT operation. The control will be the responsibility of the electric protection system.

3.2. Sensors

For both transformer windings (EWT) and oil temperature (EOT) measurements, MAX6675 will be used, with Type-K thermocouple wire and direct measurement of temperature data collected on the I2C protocol that deal with analog inputs. The thermocouple measurement unit in Fig. 4 is incorporated. [4]

Electronic oil level (EOL) sensor using ultrasonic reflective transceiver is used to indicate oil level in the transformer tank because when the level increases it means the pressure increases in the transformed due to high temperature. On the same principle the reduction of the oil level means there is a leakage in UAT.

CT or Electronic CT which is used to measure the current of primary side (27kV) and two secondary sides (13.8 and 4.14 kV) of UAT.

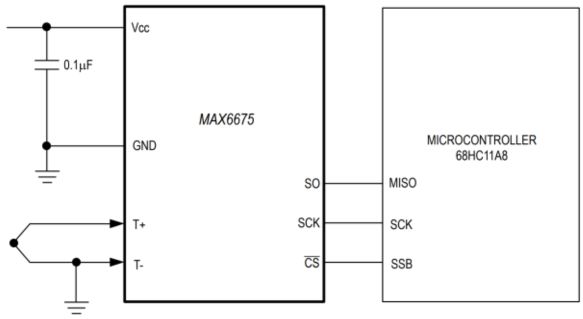

Fig. 4. Max6675 thermocouple measurement unit

VT is used to measure the voltage of the primary side and two secondary sides of the UAT.

Online Partial Discharge (OLPD): ultrasonic partial discharge analyzer will be used to measure the number of Partial discharges Per Second (PPS), the amplitude and the waveform of the partial discharge. In addition, it detects the location of the partial discharge inside the transformer which will help in the maintenance plan for the transformer.

Dissolved Gas Analyzer (DGA): Multiple gas sensors measure multiple gas levels in the transformer instead of just hydrogen. It is used for gases and moisture monitoring, during normal operation, hydrogen (H_2), Methane (CH_4), acetylene (C_2H_2), ethylene (C_2H_4), ethane (C_2H_6), carbon monoxide (CO) and carbon dioxide (CO_2) are released into the oil at low concentrations. Under fault conditions, specific gases are generated at levels above that of normal operation. The DGA device reduces the requirement of performing a lab analysis and provides information faster on the health of the transformer. The main advantage of a multi-gas monitoring device is the detailed breakdown of the various gases generated [5].

Electronic Buchholz relay (EBR) is used to indicate the amount of gas collected on it, and for oil surge as well [6].

3.3. Alarm setting

After connecting all these sensors to the MU/Arduino Uno, the data will be sent through fiber-optic cable to the electric workstation. The real-time monitoring system will not only display the measured value but also display an alarm on the screen when the measurement reached or exceeded predetermined values. But for CT and VT only show the value without an alarm because of the UAT is designed to have the capability of providing the power for all house load of NPP.

Table I shows the alarm value for each parameter that will be displayed with different colors and flashing on the electric workstation screen. For winding and oil temperature the alarm values are fixed for the oil-immersed transformer. DGA limits are given by IEEE standard, with the gas collection and oil surge being calculated beforehand.

Table I: alarm values for each parameter

Parameter	1st alarm	2nd alarm
Winding Temperature	at 120 ºC	at 140 ºC
Oil Temperature	at 90 ºC	at 110 ºC
Partial discharger	Display the amplitude, waveform, and location of partial discharge in the transformer	
DGA for new transformers	H_2: 200 ppm CH_4: 150 ppm C_2H_2: 1 ppm C_2H_4: 100 ppm C_2H_6: 200 ppm CO: 400 ppm CO_2: 2500 ppm	H_2: 400 ppm CH_4: 250 ppm C_2H_2: 5 ppm C_2H_4: 200 ppm C_2H_6: 350 ppm CO: 800 ppm CO_2: 5000 ppm
From Buchholz relay	Gas collection: 250 CC Oil surge: 90-160 cm/sec	

4. Real-time monitoring prototype.

To apply this system for the power transformer, a prototype is constructed to confirm the connection of hardware serial (analog input) and software serial (digital input) of different sensors type. Also, verify the synchronization of sending all measured data together at the same time using CONTEXT function, and to define how the data will be analyzed in the cloud/server platform.

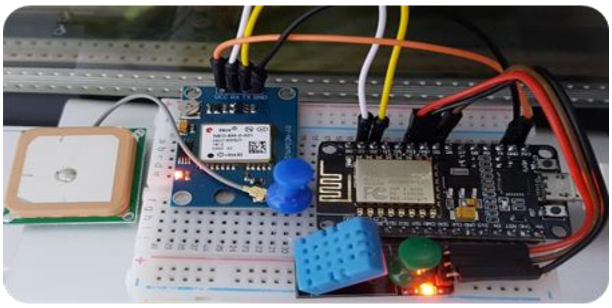

Fig. 5. NodeMCU board with NEO-6M, and DHT11

This prototype will be only using two sensors, trying to simulate the connection of analog and digital inputs. For low cost implementation DHT11 sensor is used for temperature and humidity which is connected with

NEO-6M which is a GPS sensor both sensors are connected to an Arduino NodeMCU microprocessor board as shown in Fig. 5. The communication is done using ESP 8266 Wi-Fi module which sends the GPS, temperature, and humidity data to the IoT cloud platform (Ubidots).

The connection for NEO-6M sensor is by connecting Rx and Tx pins from the sensor to D1 and D2 pins on NodeMCU. And for DHT11 connecting data pin from the sensor to D5 pin on NodeMCU.

the Arduino IDE base on C++ is used to write the code. The output of GPS sensor is longitude and latitude which need to send at the same time to the cloud synchronize with the temperature and humidity at the same time, so COTEXT function is used to send all the data together to the cloud.

5. Results

The collected data from temperature, humidity, and GPS sensors are sent to the IoT cloud through ESP8266 Wi-Fi.

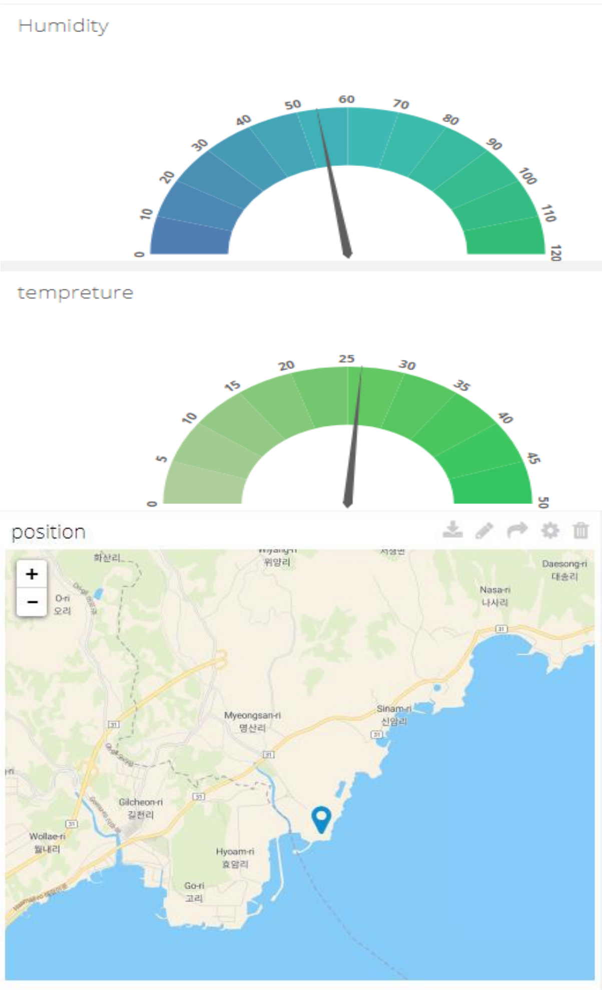

Fig. 6. The measured value of temperature, humidity, and location in real-time on Ubidots IoT cloud

The message queuing telemetry transport (MQTT) protocol is used to leverages the client-server communication details in the background sends measured data to the server and receives commands from the operator. In the IoT cloud platform, the measured and historical data can be analyzed and displayed from any place you can log in to the cloud in real-time as the results shown in Fig. 6 [4].

6. Conclusions

IoT has the potential to significantly change to monitoring systems for any equipment to real-time monitoring. The proposed system can be applied for new and existing transformers, which will reduce the maintenance cost, time, and labor. The accuracy of the measured value depends on the accuracy of the sensor and the place of installing the sensor in the transformer.

Implementation of the IoT system for a huge number of a transformer to the same server with suitable categorization will help in making a good prediction system for transformer faults that may happen during its lifetime.

Acknowledgements

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