Evolution in Electrical and Electronic Engineering Vol. 4 No. 1 (2023) 509-516

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Transformer Oil Temperature Detection Utilising a Thermal Resistor Sensor

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DOI: https://doi.org/10.30880/eeee.2023.04.01.060
Received 19 January 2023; Accepted 20 February 2023; Available online 30 April 2023

Abstract: This project aims to design and develop a thermal resistor-based transformer oil temperature detection system with high accuracy. The power transformer is a crucial component in the electrical power system, and monitoring its health is essential for maintaining an uninterrupted supply of electricity. The oil-immersed type of transformer uses mineral oil as a cooling medium to prevent failure due to high temperatures. Temperature detection is necessary to ensure that the transformer operates within safe temperature limits, per industry standards and regulations. This project proposes the use of a thermal resistor-based sensor known as the DS18B20 for temperature detection in transformer oil. Testing of the developed sensor has been carried out using a mineral-based transformer oil with a refractive index value of 1.4732, 1.4782, and 1.4786 which has been heated using the hot plate. The temperature sensor output voltage was recorded and analyzed for a temperature range of 30℃ to 80℃. The sensitivity of the sensor in measuring transformer oil temperature is 0.0209mV/℃ for both refractive index values of 1.4732 and 1.4782. For the transformer oil with a refractive index value of 1.4786, the sensitivity of the sensor is 0.0210mV/℃. The sensor system tested on all the oil samples exhibited a high linearity performance of 0.99 with 99.1% accuracy. The sensor compatibility for each sample achieves a promising value in its sensitivity, linearity and accuracy performances.

Keywords: Transformer oil, DS18B20, Thermistor

1. Introduction

The electrical power system consists of three main processes in supplying electricity to the consumer. It is known as generation, transmission, and distribution [1]. The placement of power transformers completed the electrical supply chain. Therefore, it is important to monitor the health of the power transformer in maintaining an uninterruptable electrical supply. Power transformers in the power grid help to step up or step down the voltage during the power transmission process [1][2]. The

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type of transformers used in the power grid is the oil-immersed or dry type. The oil-immersed type used mineral oil as a cooling medium for the transformer to prevent failure due to high temperatures [3]. Overheating in the power transformer is usually caused by the high demand for power consumption and it will directly shorten the lifespan of the power transformer [4].

Based on the Permissible Regulator of Oil-immersed Transformers and Standards (1991), stated that the temperature of the transformer does not surpass $40°C$ for the air-cooled type with an average of $30°C$ in 24 hours [5][6]. According to Dr Anup Mishra, the standard temperature range of the power transformer is within the range of temperature from less than $35°C$ to greater than $45°C$. However, the standard may vary based on the power transformer type and size. Therefore, this project decided to utilize the electronic temperature sensor in detecting the temperature of transformer oil due to its great characteristics in achieving more accurate measurements.

This paper aims to design and develop a high-accuracy thermal resistor-based transformer oil temperature detection while identifying its performance in measuring transformer oil. Moreover, to test the workability of the system in measuring a degraded transformer oil sample. Applying an electronic sensor known as the DS18B20 waterproof sensor that acts as a thermistor in measuring the temperature of transformer oil.

2. Materials and Methods

The materials and methods section will discuss the method of completing this project. It starts with the designing process of the sensor in the software, flowchart, and the workflows of the project. Then, the equipment list is needed for the experimental setup to collect the data needed for this project. The transformer is replaced with a hotplate in this study to reach the desired temperature that is produced by the real transformer if it is overheating.

2.1 Experimental Setup

This section shows the experimental setup used for oil temperature detection by using the DS18B20 sensor. The list of equipment is tabulated in Table 1 with its specification, design model, and quantity used. The equipment list for the project was set up and placed as in Figure 1 to conduct the experiment.

Table 1: List of equipment for the experimental setup.

No	Item	Part Number	Quantity
1	Hotplate with Stirrer	UC152	1
2	Atago Refractometer	PAL-RI	1
3	Thermometer Probe	TP300	1
4	Temperature Sensor	DS18B20	1
5	Arm stand		2
6	Beaker		1

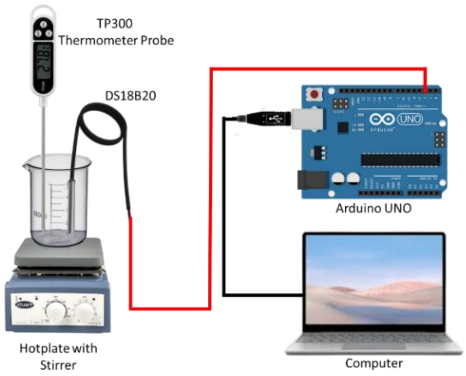

Figure 1: Experimental setup of transformer oil temperature detection.

Figure 2 shows the flowchart of the experimental setup. The workflow starts with preparing the experimental setup to measure and monitor the transformer oil temperature. By using the refractometer, measure the refractive index of the utilizing water as a reference and a few degraded transformer oils with RI values of 1.4732, 1.4782, and 1.4786. Record the value for analysing purposes.

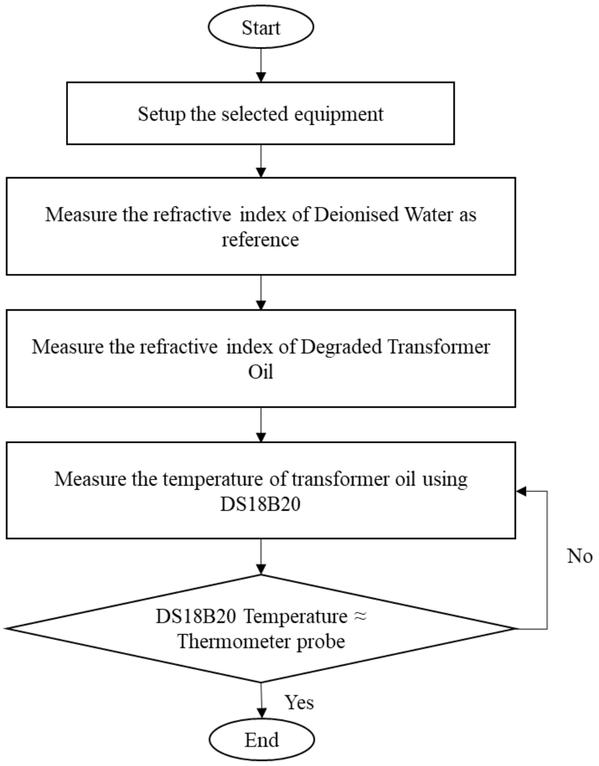

Figure 2: Flowchart of the experimental setup.

2.2 Software Developments

Figure 3 shows the input and output of the system with Arduino UNO as the main microcontroller. The input consists of the component sensor (DS18B20), power supply and Arduino IDE program code. While the output consists of LED, Buzzer, LCD Display and Relay. With the aid of the block diagram, it will be easier to design a complete system using the Proteus 8 Professional software.

Figure 4 shows the schematic diagram of the system in Proteus 8. It consists of Arduino UNO as the main microcontroller, LCD display, DS18B20 temperature sensor, 5V relay and many more. The simulation works as desired output presented by the block diagram.

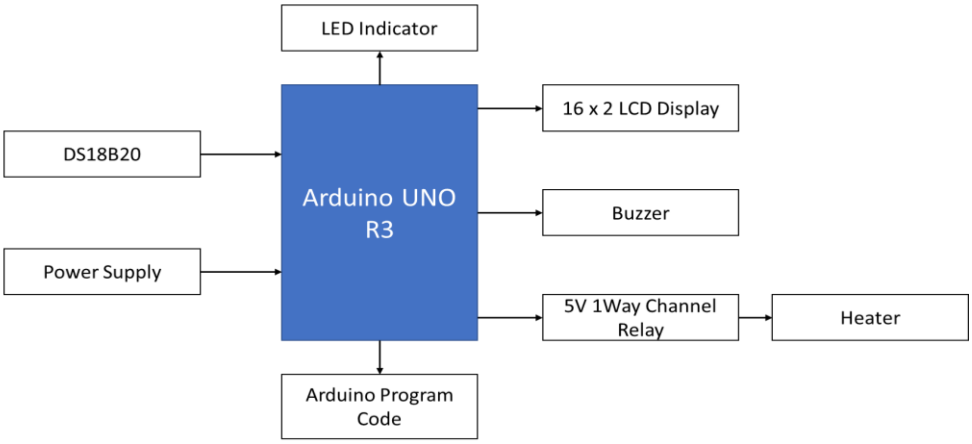

Figure 3: System block diagram.

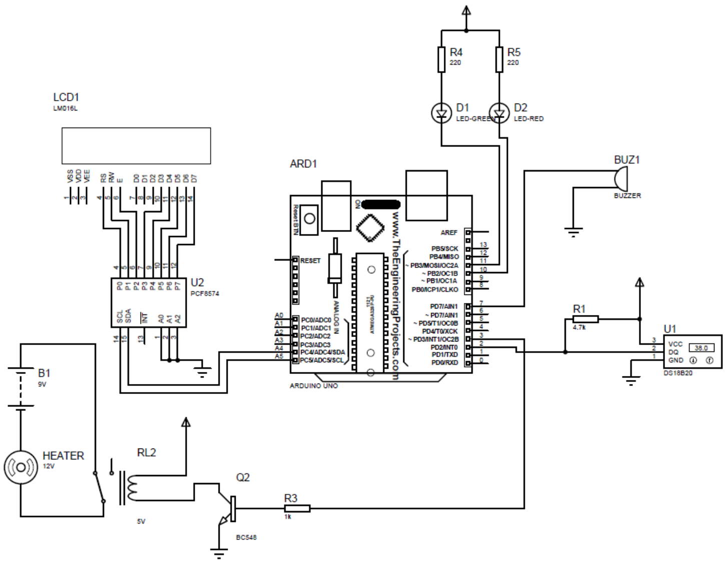

Figure 4: **The schematic diagram in Proteus 8.**

3. Results and Discussion

The results and discussion section presents data output analysis on monitoring the temperature of the transformer oil using a Proteus Professional 8 and an actual experimental setup in the laboratory. The experimental setup, the purpose of it was to find out the accuracy of the electronic sensor (DS18B20) in measuring transformer oil temperature. Three samples of degraded transformer oil were used in the experimental setup to analyse the performance of the temperature sensor in measuring temperature with a different value of the refractive index.

3.1 Simulation Results

Based on the Proteus 8 Software Simulation design, a few outputs can be observed during the simulation process. The output is the LED indicator, Buzzer, Relay, and 16 X 2 LCD. There were three conditions of output which are set up, normal, and critical condition. The critical condition is referring to a value of temperature more than 80°C. The simulation output is presented in the form of a table in Table 2.

Table 2: Simulation output during Set up, Normal, and Critical conditions.

Item	Output	Condition		
		Set up	Normal	Critical
1	Led-RED	OFF	OFF	ON
2	Led-Green	ON	ON	OFF
3	Buzzer	OFF	OFF	ON
4	Relay	OFF	OFF	ON
5	Heater	ON	ON	OFF
6	16X2 LCD	"Transformer Oil Temp. Monitoring"	"Oil Temperature: __℃ __°F"	"!CAUTION! HIGH TEMPERATURE"

3.2 Experimental Results

The experimental results present the output of the temperature sensor in measuring temperature value for three samples of transformer oil with different refractive index values. The first sample is the new transformer oil with a refractive index of 1.4732. While the other two are the degraded transformer oil with a refractive index value of 1.4782 and 1.4786 respectively. The data collected for every transformer oil sample are the input voltage, voltage data, measured temperature, reference temperature, and calculated percentage error.

The objective of this experimental setup is to determine the performance of the component sensor DS18B20 in measuring the temperature of transformer oil. Based on the collected data, the voltage data against sensor temperature for every refractive index has been plotted to obtain the sensitivity of the sensor. The output graph for three samples plotted the same pattern which is linearly increased. The output graph for the three samples is shown in Figures 5, 6, and 7 respectively. When the temperature increases, the voltage data increases. The sensitivity of the sensor is based on the gradient of the plotted graph. Furthermore, the linearity of the sensor is based on the R-squared value in the graph. The performance of the sensor is tabulated in Table 3. The output voltage was converted to temperature value by utilizing the linear regression method [4]. The mathematical formulation is stated in Equation (1).

$$Voltage\ (mV) = 0.021(Temperature\ ℃) + 0.1\mu \quad Eq.1$$

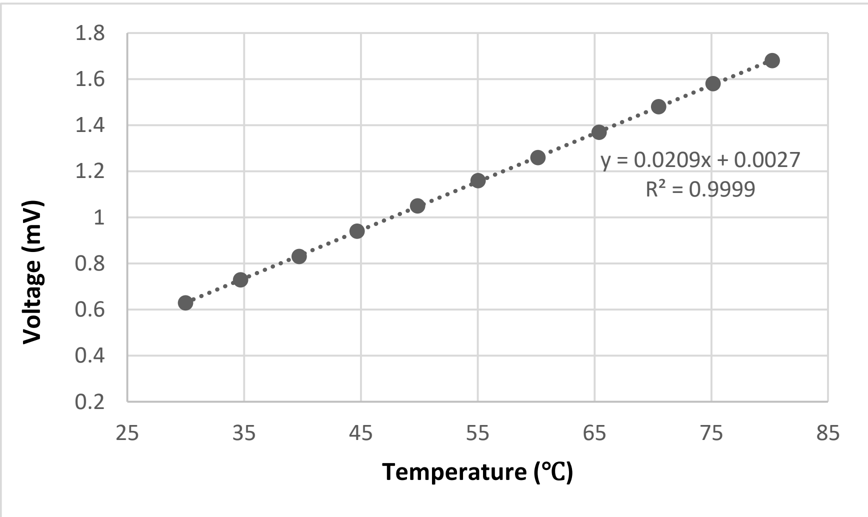

Figure 5: Temperature against DS18B20 sensor output voltage (RI=1.4732).

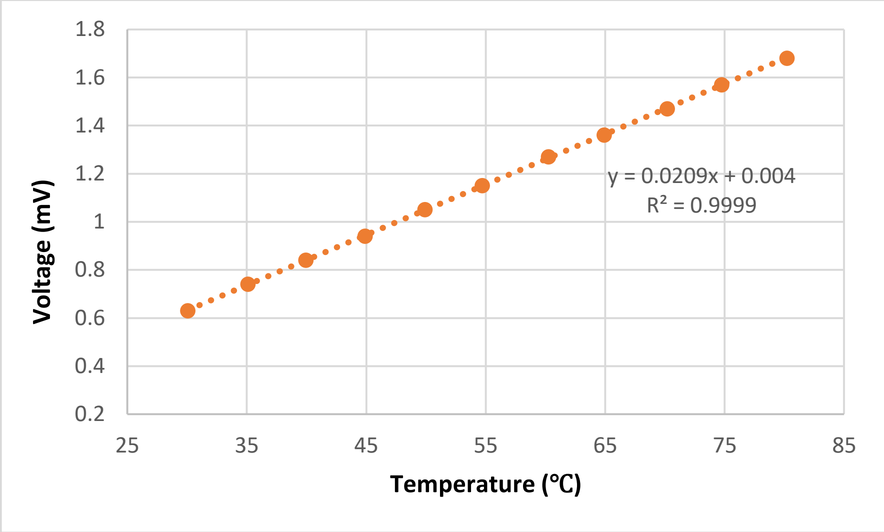

Figure 6: Temperature against DS18B20 sensor output voltage (RI=1.4782).

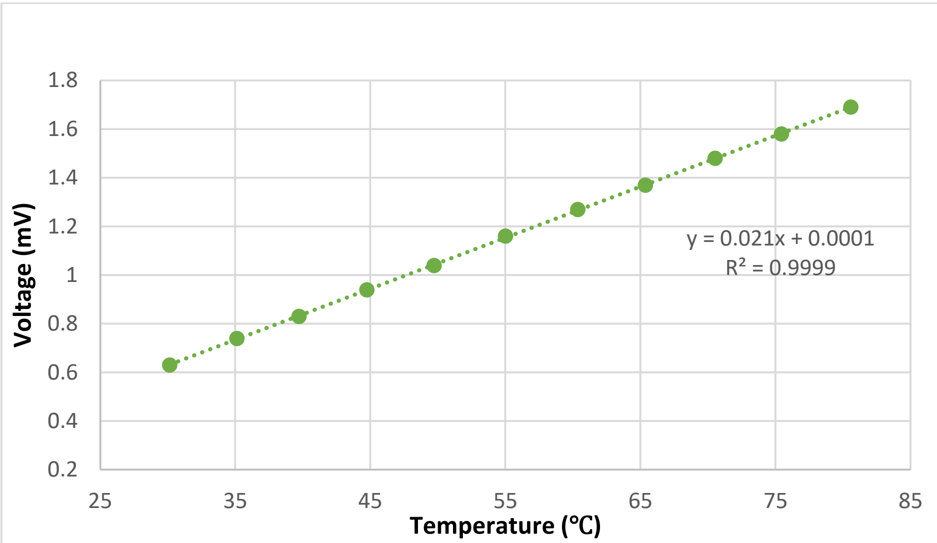

Figure 7: Temperature against DS18B20 sensor output voltage (RI=1.4786).

Table 3: Performance of DS18B20 temperature sensor.

Item	Parameter	Refractive Index (RI)		
		1.4732	1.4782	1.4786
1	Sensitivity	0.0209 mV/°C	0.0209 mV/°C	0.0210 mV/°C
2	Linear Range	30°C - 80°C	30°C - 80°C	30°C - 80°C
3	Linearity	0.99	0.99	0.99

Figure 8 shows the percentage error of the DS18B20 temperature sensor when measuring the temperature of three sample transformer oils. The graph shows that transformer oil with a refractive index value of 1.4732 has the highest percentage of error which is 0.9% at 35°C. While the lowest percentage of error is 0.036% for transformer oil with a refractive index of 1.4732 and 1.4786 at 55ºC. The lower percentage of error value, the more accurate value sensed by the sensor system.

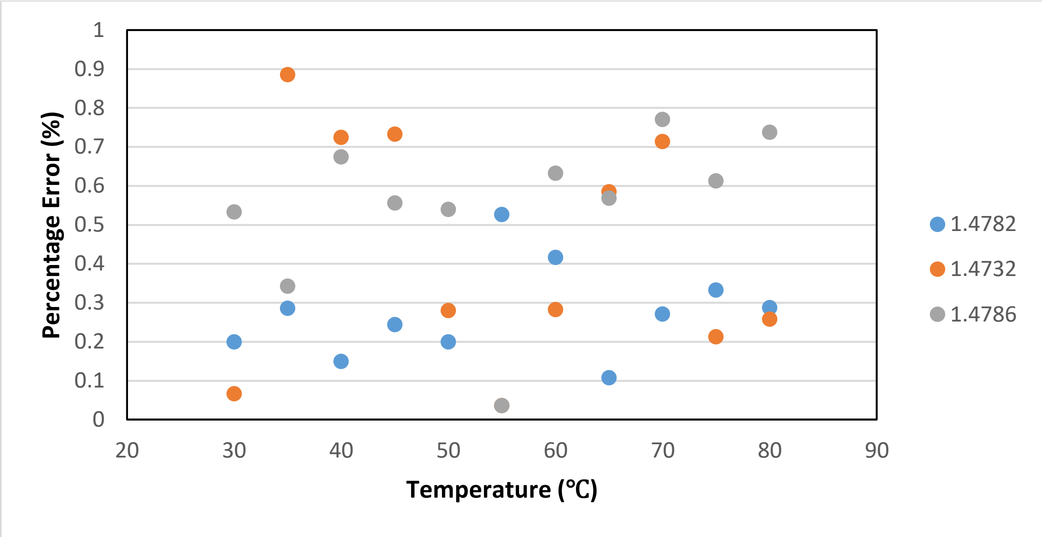

Figure 8: Temperature against percentage error for each transformer oil.

The percentage error of the sensor increases during the starting time of the temperature which is at 30°C. This is due to the sudden temperature increase and affected the sensor's accuracy during temperature measuring. It can clearly be seen that during the temperature value of 55°C, the sensor has picked up a value that is almost identical to the actual value with a percentage error of less than 0.1%. The pattern of the graph shows that when the temperature rises, the percentage error starts to decrease significantly. Thus, it produces more accurate results as a consequence of the sensor accuracy increase. The percentage error was calculated using Equation (2) formula [7].

$$Percentage\ Error = \frac{|Actual| - |Expected|}{Expected} \times 100\% \qquad Eq. 2$$

4. Conclusion

The objective was to design and develop a thermal resistor-based transformer oil temperature detection successfully developed using the Proteus 8 Professional. The complete system has been modelled and simulated successfully. Moreover, the functionality of the system has been tested and acquired validation. Next, the performance of the component sensor DS18B20 in measuring the temperature of the transformer oil has been successfully tested. . The percentage error rate influences the accuracy of the sensor. The sensor has a very low percentage of error for degraded oil sample with 1.4732 and 1.4782 at temperature value of 55°C. The maximum percentage of error is 0.9%, hence indicating the sensor accuracy of 99% has been achieved. The sensitivity of the sensor achieved based on testing was equal to 0.209 mV/°C with a linearity of greater than 99%. Finally, the workability of the system was successfully tested for degraded transformer oil and achieves a promising value in terms of sensitivity and accuracy.

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through GPPS (Vot Q243).

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