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ADVANCED GAS DETECTION IN TRANSFORMER OIL USING MICROCONTROLLERS: A CUTTING-EDGE APPROACH

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Article Info

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Abstract

The growing significance of electricity in modern society, driven by rapid technological advancements, has amplified the need for a reliable electrical energy distribution system. Transformers, integral components of this system, facilitate the transmission of electrical energy between circuits using magnetic-electric induction. Within transformers, transformer oil plays a critical role as an insulating medium and coolant in the central region. This oil acts as a cooling agent, crucial in regulating the temperature rise within the transformer. However, excessive temperature fluctuations can damage the paper insulation on the coil, leading to potential insulation failure.

The variation in temperature load or ambient temperature in the power transformer can negatively impact the insulation, and rising transformer windings' temperature can further exacerbate the situation, altering the composition and properties of the transformer oil. Such changes can significantly reduce the insulating value of the oil, posing a risk of insulation breakdown. Therefore, it becomes essential to monitor the working capacity of the insulation used to prevent potential failure.

The insulating ability of the transformer oil can also be compromised by excessive loading, causing the oil to expand and emit gases dissolved within it. This contamination of the oil with gases can further diminish its insulating properties. Moreover, different loading levels lead to the generation of dissolved gases in the transformer oil, some of which are combustible. If these gases exceed the solubility limit, they can interfere with the transformer's operation.

Given these challenges, there is a pressing need to develop effective methods for assessing and maintaining the quality of transformer oil to ensure the seamless operation of power transformers. This research aims to investigate the impact of temperature variations and loading levels on transformer oil's insulation capacity and the presence of dissolved gases. By understanding these factors, strategies can be

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devised to optimize transformer performance and prevent undesirable consequences.

1. Introduction

The rapid development of technological advances has increased the importance of electricity in people's lives. With advances in household and industrial equipment technology that uses electrical energy as a power source, the need for the availability of electrical energy is increasing, so it is necessary to develop a reliable system to distribute electrical energy from power plants to consumers. A transformer is one of the essential equipment in the electric power system that is used to transmit electrical energy from one circuit to another that operates using magnetic-electric induction [1].

Inside the transformer, there is transformer oil which functions as an insulating medium and coolant in the central part of the transformer. Transformer oil is a cooling medium that anticipates the temperature rise in the transformer. The existence of an excessive temperature rise can damage the paper insulation on the coil (coil) inside the transformer. Damage to the insulation of transformer oil is caused by a change in temperature load or ambient temperature (ambient temperature) in the power transformer. Heating the transformer windings can damage the insulation, and an increase in oil temperature will change the composition and properties of the transformer oil. If this change is allowed, it can cause the insulating value of the oil to decrease [2].

The heat generated by the conductor can cause the insulation temperature to rise above its maximum temperature. If this heating condition continues, the insulation can deteriorate and cause insulation failure, which can cause insulation breakdown. The content in the transformer oil can cause this condition to be contaminated with particles and moisture. In a transformer, to avoid insulation failure, it is necessary to know the working capacity of the insulation used [3].

Excessive loading can cause the transformer oil to expand and emit gases dissolved in the oil. These gases will then precipitate and become contaminated with oil, thereby reducing the insulating ability of the oil. Transformer conditions can be maintained or improved by knowing the quality of transformer oil. Different loading levels can result in the emergence of dissolved gases in the transformer oil. Some of the gases that arise are flammable (combustible). If these gases exceed the solubility limit in transformer oil, it will cause interference with the operating transformer [4].

2. Literature Review

2.1. Transformer

A transformer is a static electromagnetic device used to transfer/change electrical energy from one electrical circuit to another. Transformer reliability must be respected to maintain high performance. In addition to its important role, the transformer is also said to be the most expensive asset in the distribution of electric power, so that regular maintenance of the transformer is considered more effective and efficient from an economic point of view compared to replacing the transformer [5].

Transformers are used with much precision, both in the fields of electric power and electronics. In the case of using a transformer power system, every need can be met with an appropriate and economical voltage for each need, such as when distributing electric power over long distances. It is important to note that alternating current is often used for the generation and distribution of electric power, so that in the use of a simple and reliable transformer it is possible to choose the appropriate and economical voltage for each need [6].

The working principle of the transformer is based on Ampere's law and the law Faraday, who stated that magnets can attract electricity and vice versa. If the coil on the transformer has alternating current, the number of magnetic lines of force will change. As a result, on the primary side, induction occurs. The secondary side gets a magnetic force line from the primary side which is also quite a lot. So on the secondary side there is also induction, as a result there is a voltage difference between the two ends and the equation obtained can be seen in equation 1 below:[6]

$$\frac{Vp}{Vs} = \frac{Np}{Ns} = \frac{Is}{Ip} \quad (1)$$

The type of oil that is often used as insulating oil at PLN is mineral oil, mineral oil is oil made from petroleum processing, namely between the diesel and turbine oil fractions which have a very complex chemical structure. This insulating oil resulting from distillation still has to be modified so that it has high insulation resistance, good heat stability, and meets other technical requirements. Dielectric strength is a measure of a material's ability to withstand high stresses without causing dielectric failure. Based on data obtained on 9 January 2021 from the Ministry of Energy and Mineral Resources of the Republic of Indonesia, it is stated that oil reserves in Indonesia will be exhausted within 9.5 years assuming no new reserves are discovered in the future. Various efforts have been made to reduce the use of mineral oil, where its availability is very limited, non-renewable also has weaknesses including not being degraded so that it can cause environmental pollution[7].

2.2. Transformer Oil

Transformer oil is a liquid insulating material used as insulation and cooler on the transformer. Most of the insulating material oil must have the ability to withstand breakdown voltage, whereas as transformer oil cooler should able to dissipate that heat generated[8]. The increase in temperature at excessive loading on the transformer will result in a heating effect. Any increase in temperature above the limit of 6ºC causes the life of the transformer to age. In Indonesia, based on SPLN, transformers can only operate at temperatures below 40ºC with an average daily and annual temperature of around 30ºC. According to the IEC (International Electrotechnical Commission) the life of the transformer is only around 20 years[2].

Insulation failure can occur due to several main factors, including aging insulation, decreased dielectric strength, and overvoltage on the insulation. In addition, other factors that can cause insulation failure are the distance between the electrodes, the area of the electrodes, and the cooling system[9].

Good insulating oil has a good dielectric value and breakdown voltage value. Breakdown voltage is an electric voltage when an insulator cannot face the electric field pressure on an electrode that has a potential difference so that the insulator is no longer able to isolate or can turn into a conductor. When the value of the breakdown voltage is small then there is interference. The disturbance that occurs in the insulating oil of the transformer can be influenced by several things, one of which is due to the presence of contaminants in the insulating oil. These contaminants are usually in the form of liquid contaminants, the presence of water in the insulating oil is caused by several external and internal factors such as, when it rains, the water can enter the transformer, and when the temperature inside the transformer is high while the temperature around the transformer is lower or otherwise it will result in the presence of water vapor[10]. The requirements for transformer oil as insulation are as follows[11]:

1. Low viscosity to facilitate circulation
2. High flash point to prevent fire
3. Acid free to prevent rust of copper and damage to windings.
4. Not corrosive
5. Resistant to oxidation
6. Has a high dielectric strength (breakdown voltage).
7. Does not contain sediment (P3B, 2003)

2.3. Dissolved Gas Analysis (DGA)

Dissolved Gas Analysis (DGA) is one of the tests on the oil transformer that aims to Find out the dissolved gases in the oil transformers are generally gas such could not be detected on the test oil characteristics. Gas monitoring dissolved aims to determine the type failure of transformer oil, and prevent the transformer from burning due to flammable gases. Test result DGA in the form of hydrogen gas, methane, carbon monoxide, carbon dioxide, acetylene, ethane, and ethylene will rise with the resulting transformer temperature increases transformer overload and loss. This heat can trigger the acceleration of the reaction hydrocarbons in transformer oil especially rising ethane and ethylene gases which is usually caused by hot metal. According to (IEEE Std C57.104-1991), there is some methods that need to be done in interpret and analyze data based on the test results of the DGA obtained, namely TDCG (Total Dissolved Combustible Gas), Key Gas, Roger's Ratio, and Duval's Triangle[12].

2.4. Arduino Uno

The ubiquitous use of microcontrollers in automobiles, robotics, and industrial systems has made their research important. An Arduino board includes a microcontroller and other features that make programming and debugging simple . An engineer only needs to install the

Arduino IDE, which is available online at www.arduino.cc, on his computer, write the program, compile it, and load it into the board . There is no need for an additional programmer. Its functions are simple to grasp, which makes it ideal for inventor prototyping. The C programming language is used by Arduino[13].

Fg 1. Arduino Pin Configuration **2.4.**

Arduino IDE

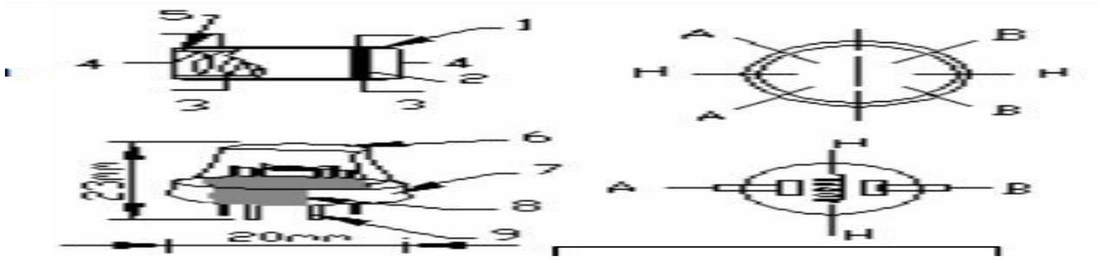
The Arduino integrated development environment (IDE) is software that allows you to create programs on a computer and upload them to the Arduino physical board. To demonstrate the design, the program began with the Arduino IDE software. The Arduino IDE simplifies the process of writing and uploading code to the Arduino Uno. The Arduino IDE software includes a program editor, compiler, and uploader[14].

1. Program editor : a window that functions to write and edit programs.
2. Compiler : functions to check whether there are error's or not in the program code that has been made.
3. Uploader : functions to upload (upload) the program results made to the Arduino board.

Fg 2. Display of the Arduino IDE Software

2.4. MG-811 Sensor

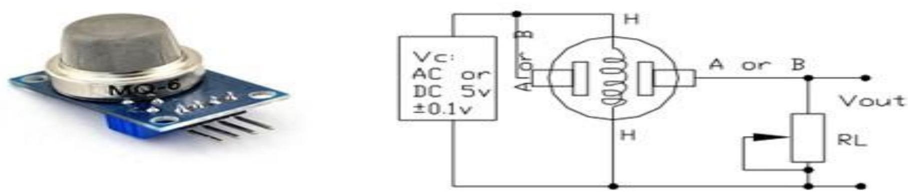
The MG-811 sensor is a sensor that can detect carbon dioxide (CO_2) gas with high sensitivity in a room. This sensor can detect effective concentrations of CO_2 gas at concentrations of 350-10000 ppm. MG-811 can perform detection at temperatures of -20-50ºC. This sensor will be active when a voltage is applied to the vcc pin of 6V either at AC or DC voltage. This sensor also has a heater or heater that requires a voltage of 6V to work[15].



Fg 3. MG-811 Sensor Structure **2.4.**

MQ-6 Sensor

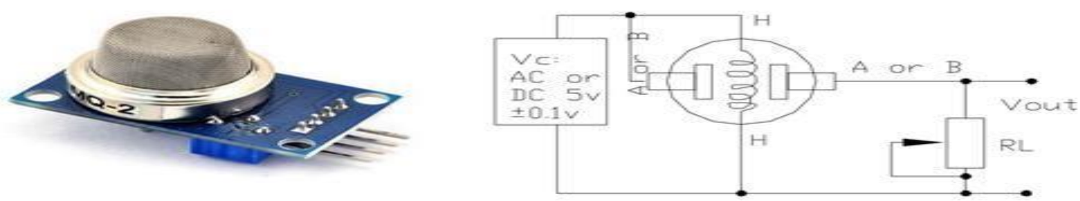
The MQ-6 sensor is a gas sensor that is commonly used to detect LPG (Liquefied Petroleum Gas) gas. This sensor can also detect ethane gas, because LPG contains 40% ethane gas[16]. The sensitive material of the MQ-6 sensor is SnO_2, which has a lower conductivity in clean air. When flammable gas is present, the sensor conductivity is higher with increasing gas concentration. This sensor can detect concentrations on sensors of 200-10000 ppm. MQ-6 can perform detection at a temperature of 20ºC with a tolerance limit of ± 2ºC[17].



Fg 4. MQ-6 Sensor Module

2.5. MQ-2 Sensor

The MQ-2 sensor is a gas sensor that is commonly used to detect LPG (Liquefied Petroleum Gas) gas. This sensor can also detect ethylene gas, because LPG contains 10% ethylene gas[16]. MQ-2 resistance value is different for various types and various gas concentrations. When using this component, sensitivity adjustment is necessary. Calibrate the detector for 1000 ppm liquefied petroleum gas. When measuring accurately, the proper alarm point for the gas detector must be determined after considering the influence of temperature and humidity[18].

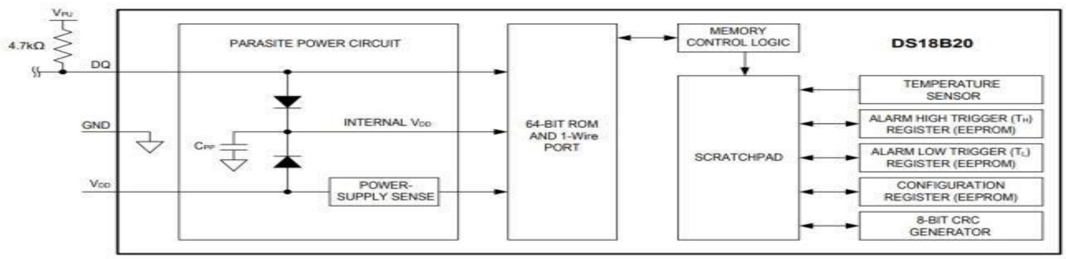


Fg 5. MQ-2 Sensor Module **2.6.**

DS18B20 Sensor

The DS18B20 sensor is the latest digital temperature sensor in the Maxim IC series. This sensor can read temperatures with 9-bit to 12-bit accuracy in the range of -55oC to 125oC (+/-0.5oC). Each sensor produced has a unique 64-bit code embedded on each chip, enabling the use of a large number of sensors via a single wire (single wire data bus/1-wire protocol). Fg 6, a) displays the physical form of the DS18B20 sensor and b) block diagram of the DS18B20 sensor[19].

(a)



(b)

Fg 6. Physical Form and DS18B20 Sensor Block Diagram

2.7. LCD (Liquid Crystal Display)

LCD (Liquid Cristal Display) is an important component because the LCD can display commands that must be executed. The LCD screen uses two polarizing weight sheets and a liquid crystal between the two sheets. LCD is widely used in designing a system using a microcontroller. The 16x2 LCD has 16 PINs, where each pin has a symbol and also its functions. This 16x2 LCD operates on a +5V power supply but can also run a +3V depower supply. This 16x2 LCD has two important parts: the backlight, which is useful when used at night, and the contrast, which serves to sharpen the display. Here is a picture of a 16x2 LCD[20].

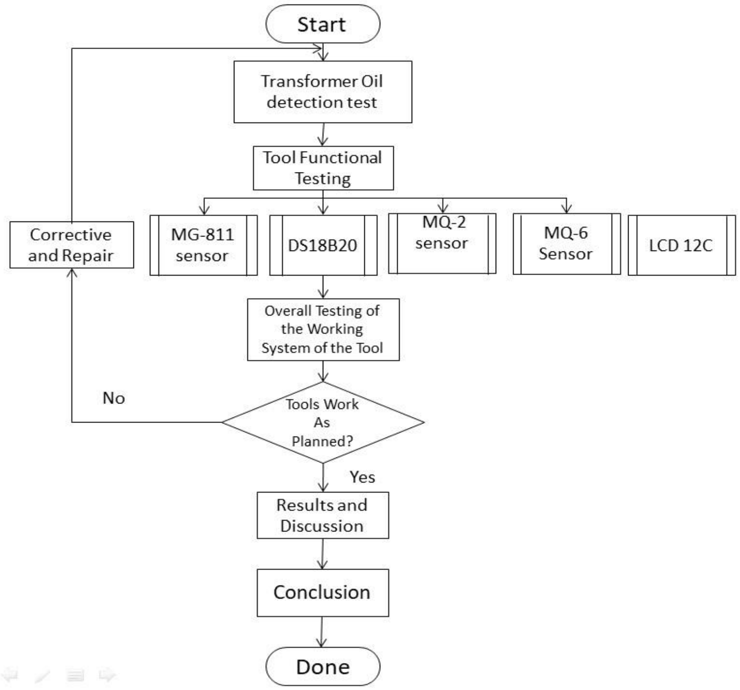
Fg 7. LCD I2C size 16x2

3. Method

In this study the authors used a gradual research method consisting of certain steps, procedures and techniques. Some of the initial stages in carrying out this research are as follows.

3.1. Gas Detector Working System

This design presents a variety of data in the form of numbers. Before making the program, the working order of the tool and all components are needed to be connected to form a system of gas detection devices in transformer oil. The system flow chart for the transformer oil gas detector is as follows:



Fg 8. Tool Working Diagram

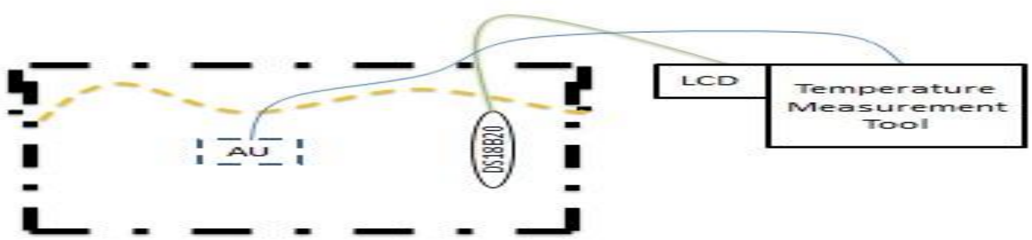
The flow chart above uses the tool starting from taking transformer oil samples. At this stage there is a sensor circuit that functions as a voltage value detector. Furthermore, these values will detect gas contained in the transformer oil. The voltage value will be processed on Arduino, and the results of the detection will be displayed on the LCD on this device.

3.2. Testing of Gas Detectors in Transformer Oil

Tests carried out in this study include functional testing and overall system performance. Functional testing is divided into 3, namely testing the DS18B20 sensor, CO2 sensor, C2H6 sensor and C2H4 sensor.

- DS18B20 Temperature Sensor Testing

  Testing of the DS18B20 sensor is carried out by uploading a special program for voltage and creating a test circuit.



Fg 9. DS18B20 Temperature Sensor Testing

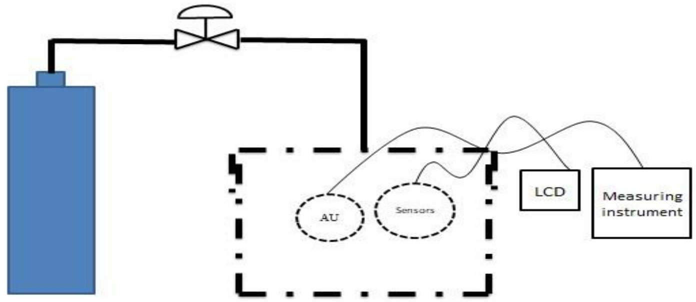
- CO2 Sensor Testing

  The CO2 sensor test aims to measure the gas content of carbon dioxide contained in transformer oil.
- C2H6 Sensor Testing

  The C2H6 sensor test aims to measure the gas content in ethane contained in transformer oil.
- C2H4 Sensor Testing

  C2H4 sensor testing was carried out to measure the levels of ethylene gas contained in transformer oil.
- Overall Testing

  Testing the overall performance of the gas level detector in transformer oil is running the entire system both input, process and output. Testing the overall performance of the gas level detector in transformer oil is carried out to determine the performance of the tool. This test tends to pay more attention to the output results displayed on the I2C LCD.



Fg 10. Overall Testing

4. Result and Discussion

The tool for detecting levels of carbon dioxide, ethane and ethylene gas that has been designed and built and carried out in the testing phase. The testing phase is carried out first by conducting functional tests and performance tests on the entire system to determine the level of success and accuracy of the gas level detector in the transformer oil.

4.1. DS18B20 Sensor Test Results

The results of the test design that has been carried out aim to see the level of accuracy of the sensor in measuring temperature whether it works well or not.

Table 1. DS18B20 Sensor Test Results

No	Thermometer temperature reading (°C)	DS18B20 temperature reading (°C)	Error%
1	35 °C	35,31 °C	0,00857
2	40 °C	40,20 °C	0,005
3	45 °C	45,32 °C	0,00711
4	50 °C	50,00 °C	0
5	55 °C	55,43 °C	0,00781
6	60 °C	60,23 °C	0,00383
7	65 °C	65,56 °C	0,00861
Average			0.04123
SD Value			0.00315

It can be seen that changes in temperature in the table have an average value of 0.03853%, for the standard deviation value on the DS18B20 sensor it has a value of 0.00315°C. The DS18B20 sensor test was carried out 7 times. From the results of the output temperature value obtained on the sensor of 30.94°C.

4.2. CO_2 Sensor Test Results

This test was carried out in a closed room. The source of carbon dioxide (CO_2) used for testing came from paper smoke that was burned in a closed room, the test was carried out 5 times. Observation of the test results with the CO_2 sensor is seen in the results table.

Table 2. CO_2 Sensor Test Results

No	Testing Stage	Condition	Sensor Value
1	Testing 1	No Gas	0
2	Testing 2		0
3	Testing 3		3
4	Testing 4		0
5	Testing 5		1
6	Testing 1	There's Gas	1222
7	Testing 2		1432
8	Testing 3		1552
9	Testing 4		26
10	Testing 5		10

The CO2 sensor detects carbon dioxide values in the range > 1000 ppm, in test 4 and test 5 it is considered an incorrect (invalid) detection from the sensor, this is indicated by a drastic decrease in value.

4.3. C_2H_6 Sensor Test Results

Testing the C2H6 sensor to detect ethane gas was carried out 5 times in the absence of gas and gas, the test results can be seen in the following table of results.

Table 3. C_2H_6 Sensor Test Results

NO	Testing Stage	Condition	Sensor Value
1	Testing 1	No Gas	0
2	Testing 2		0
3	Testing 3		0
4	Testing 4		0
5	Testing 5		0
6	Testing 1	There's Gas	1905
7	Testing 2		2048
8	Testing 3		3500
9	Testing 4		3762
10	Testing 5		3931

The sensor test was successful in detecting it in ppm units and showing the correct number for each test that has been carried out.

4.4. C_2H_4 Sensor Test Results

Testing the C2H4 sensor to detect ethylene gas was carried out 5 times in the absence of gas and gas, the test results can be seen in the following table of results.

Table 4. C_2H_4 Sensor Test Results

NO	Testing Stage	Condition	Sensor Value
1	Testing 1	No Gas	0
2	Testing 2		0
3	Testing 3		0
4	Testing 4		0
5	Testing 5		0
6	Testing 1	There's Gas	1552
7	Testing 2		2368
8	Testing 3		1402
9	Testing 4		2168
10	Testing 5		268

The test results on the C2H4 sensor succeeded in detecting ethylene gas contained in LPG gas. The sensor test succeeded in detecting the gas value in ppm units and showing the correct number in tests 1 to 4 in testing with LPG gas, but in test 5 the gas value suddenly dropped dramatically and was considered an incorrect value (invalid) from the sensor the.

4.5. Overall Test Results

The test is carried out using transformer oil that has been preheated with a heater. The results obtained on the MG-811, MQ-2, MQ-6 and DS18B20 sensors will be processed to display output on the I2C LCD. each part in this planning system works according to their respective controls. Tests were carried out on transformer oil to determine the output results on the control panel LCD. The output of the LCD results will display the gas levels of carbon dioxide (CO2), ethane (C2H6), ethylene (C2H4) and DS18B20 temperature.

Table 5. Overral Testing

Testing	MG-811	MQ-6	MQ-2	DS18B20 (°C)

1	328	28	21	30
2	345	33	23	35
3	361	34	25	40
4	412	36	28	45
5	467	39	29	50
6	489	41	32	55

Based on the test results table, it was possible to read the gas parameters carbon dioxide, ethane, ethylene and temperature. The levels of carbon dioxide gas in transformer oil read from 328 ppm to 489 ppm, ethane gas from 28 ppm to 41 ppm, ethylene gas from 21 ppm to 32 ppm. Based on the overall test results table, the gas content in transformer oil continues to increase continuously.

5. Conclusion

Based on the results of testing and discussion on the design of the detectors for carbon dioxide (CO2), ethane (C2H6), and ethylene (C2H6) gas levels in transformer oil that have been made, conclusions can be drawn, namely:

1. At the time of testing, the temperature of the transformer oil increased which resulted in the gas content in the transformer oil also increasing.
2. According to key gas analysis, ethylene gas can cause overheating of oil if the gas content in ethylene is 63%, ethane is 20%.
3. In the study using prototype sensors to detect ethane and ethylene gases. The sensor is not a sensor specifically for detecting the two gases. Researchers took the percentage value of each gas detected for LPG gas which is the main function of the two sensors, in LPG gas there is 40% ethane gas and 10% ethylene gas.

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