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Modeling of Fault Alarm Monitoring System on IoT-Based Control Panel Alarm Annunciator

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Abstract

The existence of substation operators is essential for monitoring substation equipment and operating control rooms. In addition, substation operators also have other tasks, such as inspecting substation equipment in the switchyard or in-service inspection (Level 1 inspection). This condition is less than ideal because the operator cannot monitor the control room continuously while in the switchyard. The control panel at the substation is equipped with an alarm annunciator, which is auxiliary equipment that serves to provide warning signs to the operator regarding which protection functions are working. Therefore, it is necessary to have a monitoring system that can provide real-time information about the condition of the control panel alarm annunciator. This research models a fault alarm monitoring system that can provide notification messages according to the type of fault automatically through the Telegram application. The system test results show the average value of 100 test data on the five types of fault, resulting in an accuracy rate of 100%, a precision rate of 100%, a recall rate of 100%, an error rate of 0%, and an F1-score rate of 100%. This is because all test data on the five types of fault were detected correctly, and no test data from other types of fault was detected as the five types of fault. Based on these averages, it can be concluded that using a confusion matrix to measure the performance of the fault alarm monitoring system on the IoT-based control panel annunciator alarm shows excellent system performance results.

Keywords: Alarm Annunciator, Confusing Matrix, IoT, Monitoring, Substation Operator.

1. Introduction

In the era of rapid development of information technology, the Internet of Things (IoT) is one of the concepts that has a significant impact on various aspects of life [1]. One of the areas affected is the electric power system, especially in substations. Substations are power distribution and control centers that play a crucial role in maintaining a smooth supply of electricity to consumers [2]. Substations play an important role, providing switching, transforming, monitoring, metering and protection functions for the safe, efficient and reliable delivery of electrical power to consumers, controlling and directing the flow of electrical power and ensuring system safety through a series of control and protection mechanisms. Substations are an important part of the chain of interdependencies for many critical infrastructures [3]. The existence of substation operators is essential for monitoring substation equipment and operating control rooms [4].

One of the tasks performed by substation operators is to monitor the amount of electricity in each bay in the substation, such as transformer bays and conductor bays, then record each estimated peak load. In addition, substation operators also have other duties, namely inspecting substation equipment in the switchyard, which can also be called in-service inspection (Level 1 inspection). This condition is less than ideal because the operator cannot monitor the control room continuously [5].

The Bay Control Unit (BCU) or control panel, is the core device of substation automation. The BCU scheme is arranged according to the bays of the substation's main equipment. The main functions of BCU include: measurement of electrical parameters of voltage, current, power, frequency of

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substation main equipment; receiving control commands of circuit breakers, isolators, transformer taps issued from the dispatch center or substation operator workstation; BCU also ensures operation control safety through logic control, such as interlock. At present, in the substation automation system, the BCU is set according to the substation bay and mainly includes the types of line BCU, main transformer BCU, and busbar BCU [6].

The control panel at the substation is equipped with an alarm annunciator, which is auxiliary equipment that functions to provide a warning sign to the substation operator regarding which protection function is working [7]. Annunciators are usually in the form of written instructions that, under normal conditions, have no designation; if an abnormality occurs, the lights in the indicator light up according to the condition of the system at that time [8]. Failures or faults in the control panel can cause serious disruptions in the electricity supply. Therefore, it is necessary to have a monitoring system that can provide real-time information about the condition of the control panel.

Research on monitoring systems at substations has been carried out in previous studies, such as in 2021 research conducted by Citra et al. [9] regarding monitoring the temperature of non-contact cable connections with 20 kV transformers at Ngagel substation based on IoT. In this research, an IoT-based automatic monitoring system is made for cable connection clamps with transformers. This system will use the MLX90614 sensor, which will monitor the temperature of the transformer connection clamps, and then the data read by the sensor will enter the Wemos D1 mini microcontroller, which is in charge of managing the entire system. Then the data will be sent to the server via the data transmission protocol, namely MQTT, and then the data will be displayed on the dashboard online. So that the condition of the transformer connection clamp temperature can be accessed from anywhere by the operator. In 2021, research was conducted by Bambang et al. [10] regarding online monitoring of leakage current of power transformer power cables based on Wemos-D1 microcontroller with database via thingspeak to optimize level-2 inspection at PLN substation. This study developed a tool for monitoring leakage currents in power transformer power cables online. This tool works by using the PZEM-004T current sensor input as its current detector and internet network input to display the current data value to thingspeak, and BLYNK and WEMOS-D1 as its microcontrollers to process current information from the current sensor. The result is a current parameter on the power cable that is displayed on thingspeak online or on the web and notification of the current value in the form of a color in the gauge in thingspeak. In 2022, research was conducted by Ahmad et al. [11] regarding designing an online transformer temperature monitoring system using the IoT-based whatsApp application case study at PLN 150 kV Mekarsari substation. This study designed an online transformer temperature monitoring system using the IoT-based whatsApp application at the PLN 150 kV Mekarsari substation using the Design Science Research (DSR) method. This system was created to provide input and recommendations for PLN company UPT Bekasi in monitoring transformer temperatures to make it more effective and efficient. In 2023, research was conducted by Arief et al. [2] regarding IoT-based 110 Volt DC voltage monitoring system at Kebonagung substation. This study designed a system to monitor the DC system in real time and get early warning if an anomaly occurs. Using a smartphone and via a web browser. In 2023, research was conducted by Rahman et al. [12] regarding notification of feeder faults in primary distribution. This study designed a prototype to provide notification when a disturbance occurs in real time using a current sensor using an ACS712 current sensor as a current reader and a PZEM-004T voltage sensor. Utilization of the ESP32 module serves to send notifications to operators via the telegram application.

Based on the background and relevant previous research, this research is a new innovation by integrating IoT technology with alarm annunciators in substations. The aim of this research is to implement IoT with alarm annunciators in substations to monitor fault alarms. Integration between IoT and alarm annunciators can provide benefits such as real-time monitoring, automatic notification when a fault is detected, and the ability to access information remotely. Thus, it is expected that the system created will have excellent performance and can improve the efficiency of supervision by substation operators.

2. Method

The research method is basically a scientific way to get data with specific purposes and uses [13]. To achieve these goals, a method that is relevant to the objectives to be achieved is needed. The research method used is an experimental research method. The data used is obtained from literature studies and

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observations in the field. This research was conducted PLN (Persero) Company Transmission Service Unit and Krian substation, and 150 kV West Surabaya Substation. Figure 1 shows the system design of modeling the fault alarm monitoring system on IoT-based control panel alarm annunciator.

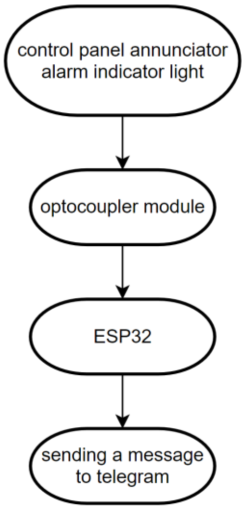

Figure 1. Flowchart of System Design

The system design in Figure 1 explains that the control panel annunciator alarm indicator light is used as a trigger that will be read by the optocoupler module. The type of fault indicator follows the alarm annunciator control panel bay 150/20 kV Transformer 2 in 150 kV West Surabaya Substation. The optocoupler module in this research is used as a DC circuit switching. Judging from its use, optocouplers are commonly used to isolate the common input circuit from the common output circuit. so that the voltage supply for each circuit is not overloaded and also to prevent damage to the control circuit (input circuit) [14]. The optocoupler circuit in this module is based on a photo transistor [15]. It will act like a typical transistor switch. In its working principle, this module uses a PC817 phototransistor-based optocoupler. The infrared LED will be controlled by a trigger from the control panel annunciator alarm indicator light. When a fault occurs, the fault indicator light will light up, and then it will provide a trigger to the optocoupler module. In this configuration, phototransistor-based optocouplers can be used with microcontrollers to detect pulses or interrupts. In this research, an 18-channel optocoupler module is used. ESP32 is used to process the data obtained from the optocoupler module and send it to the media used by the user, namely telegram. In this research, the telegram application is used as a medium for monitoring fault alarms on the control panel annunciator alarm by sending message notifications according to the type of fault to the telegram group.

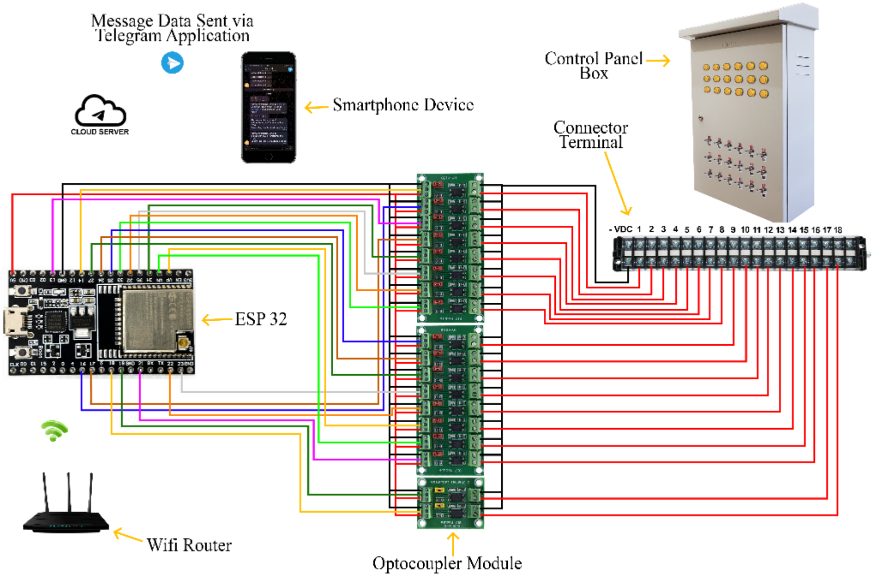

Figure 2. Circuit Schematic

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In Figure 2, it is explained that in the panel box there are 18 pilot lamps and toggle switches, each adjusting the number of types of fault. This panel box uses a 110 Volt DC power supply as its source, following the operating voltage as in the control panel at 150 kV West Surabaya Substation. Terminal blocks are used to connect each fault indicator light with the optocoupler module. The red wire indicates a voltage of +110 Volt DC as well as input for optocouplers for 18 types of fault. The black wire indicates a voltage of -110 Volt DC as well as the GND input to the optocoupler module. The types of fault can be explained in the following Table 1. Table 1 shows the types of fault indicators that exist in the transformer bay control panel [16]. The output of the optocoupler module can be explained in the following Table 2. The optocoupler module output requires a 5 Volt VCC, which is jumpered on all optocoupler module outputs and connected to the 5 Volt VCC pin on the ESP32, as well as a GND, which is jumpered on all optocoupler module outputs and connected to the GND pin on the ESP32.

Table 1. Type of Fault Used

Indicator Light	Type of Fault
1	Primary CB trouble (P52F)
2	2'ry CB trouble (S52F)
3	Over current ground protection (NS51GT)
4	20KV bus abnormal voltage (F84)
5	Different protection (T87)
6	Fan trouble (88FT)
7	B'Holz/pressure relief device (96)
8	Primary CB trip coil supervision (74)
9	Over current protection (TP51)
10	Over current protection (TS51)
11	Breakdown voltage pressure relief device transformer
12	Ground phase detecting protection (F64Ø)
13	Control source under voltage (LR27)
14	Over current ground protection (NP51GT)
15	Over voltage ground protection (F64V)
16	Oil level low (33QT)
17	Winding/oil temperature (26T)
18	Transformer trip (T86)

Table 2. Optocoupler Module Output and ESP32 Input Pins

Optocoupler Module Output (Cable Color)	ESP32 Input Pins
Red cable (Jumpered at each optocoupler module output)	VCC 5 V pin
Black cable (Jumpered at each optocoupler module output)	GND pin
Yellow cable	14 pin/GPIO 14
Blue cable	16 pin/GPIO 16
Purple cable	13 pin/GPIO 13
Brown cable	17 pin/GPIO 17
Dark green cable	34 pin/GPIO 34
Gray cable	35 pin/GPIO 35
Orange cable	32 pin/GPIO 32
Green cable	33 pin/GPIO 33
Blue cable	25 pin/GPIO 25
Brown cable	26 pin/GPIO 26
Dark green cable	27 pin/GPIO 27
Gray cable	23 pin/GPIO 23

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Optocoupler Module Output (Cable Color)	ESP32 Input Pins
Orange cable	22 pin/GPIO 22
Yellow cable	VP pin/GPIO 36
Green cable	VN pin/GPIO 39
Purple cable	21 pin/GPIO 21
Dark green cable	19 pin/GPIO 19
Yellow cable	18 pin/GPIO 18

Figure 3, there is a workflow diagram of the system, starting with the start as the beginning of the program and system. The fault indicator light is used as an input or trigger; if there is fault, then the indicator light will light up and provide a trigger to the optocoupler module. The optocoupler module will perform a voltage reading process if the optocoupler module reads a significant voltage (logic 1) and if there is no significant voltage (logic 0). Furthermore, the digital signal output from the optocoupler module will become a digital pin input on the ESP32, which is already connected to the internet network. ESP32 will process the data received from the optocoupler module, and then the data will be sent to the Telegram application media used by the user. The data sent to the Telegram application is in the form of a warning notification according to the type of fault. An example of the content of a notification message for one type of fault can be shown in Table 3.

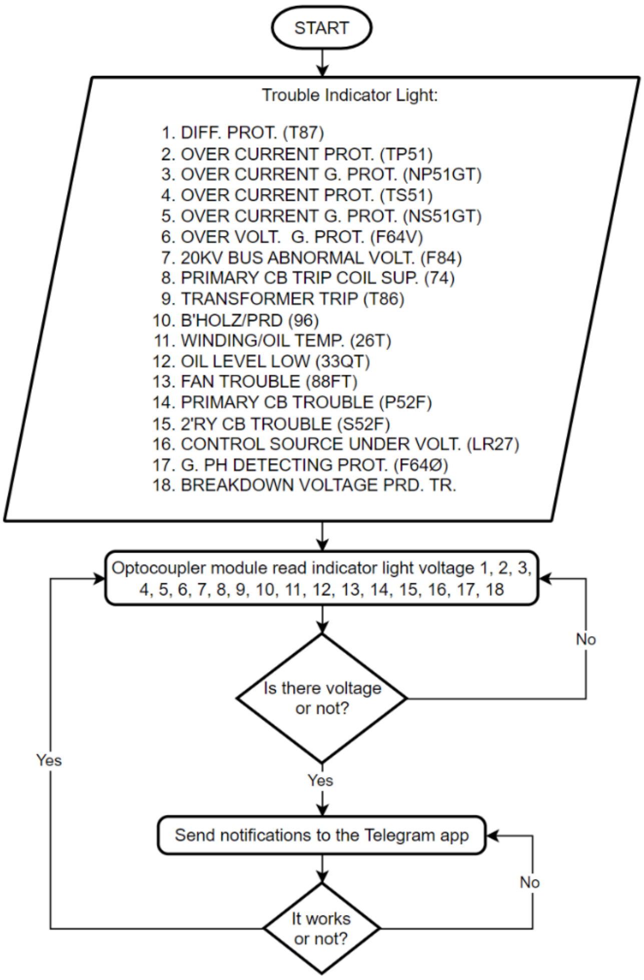

Figure 3. System Workflow

In analyzing the data in this study, there is data taken to analyze in order to determine the ability of the tools that have been designed and made. Researchers apply the confusion matrix method to analyze the performance of the system that has been made. The confusion matrix is an important

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performance evaluation tool in data mining classification, providing a comprehensive overview of the model's prediction results [17], [18], as shown in Table 4.

Table 3. Notification Message Content

Notification Message Content
"Bay transformer 2 150/20kV annunciator alarm on!!! Fault indication transformer trip (T86) Go immediately and check the control room"

Table 4. Confusion Matrix

		Observed	
		True	False
Predicted class	True	True positive (TP)	False positive (FP)
	False	False negative (FN)	True negative (TN)

Where :

TP : True Positive, which is the amount of positive data that is correctly classified by the system.
TN : True Negative, which is the amount of negative data that is correctly classified by the system.
FN : False Negative, which is the amount of negative data but misclassified by the system.
FP : False Positive, which is the amount of positive data but misclassified by the system.

The accuracy value is the ratio between the correctly classified data and the total data. The precision value represents the number of correctly classified positive category data divided by the total correctly classified data. The recall value shows the percentage of positive category data that is correctly classified by the system. The error value is the case that is identified incorrectly in a number of data, so that it can be seen how much the error rate is in the system used. F1-Score is the harmonic mean of recall and precision, which gives a balanced picture between the two metrics. This is useful when there is a need to minimize False Positive and False Negative equally [19], [20]. The accuracy value can be obtained from equation 1. The precision value can be obtained from equation 2. The recall value can be obtained from equation 3. The percentage error can be calculated using equation 4. The F1-score can be calculated using equation 5. The macro F1-score can be calculated using equation 6. The weighted F1-score can be calculated using equation 7.

$$\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}} \tag{1}$$

$$\text{Precision} = \frac{\text{TP}}{\text{TP+FP}} \tag{2}$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP+FN}} \tag{3}$$

$$\text{Error Rate} = \frac{\text{FP+FN}}{\text{TP+TN+FP+FN}} \tag{4}$$

$$\text{F1 – Score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision+Recall}} \tag{5}$$

$$\text{Macro F1 – Score} = \frac{\text{F1−Score (class 1)} + \dots + \text{F1−Score (class…n)}}{\text{overall number of classes}} \tag{6}$$

$$\text{Weighted F1 – Score} = \frac{\text{overall class 1} \times \text{F1−Score class 1} + \dots + \text{overall class n} \times \text{F1−Score class n}}{\text{overall class 1} + \dots + \text{overall class n}} \tag{7}$$

3. Result and Discussion

In this research, there are 5 types of fault that are tested in real time, such as over voltage ground protection (F64V), over current ground protection (NP51GT), widing/oil temperature (26T), oil level low (33QT), and transformer trip (T86). This test is carried out to measure or validate the results of the performance of the fault alarm monitoring system on the IoT-based control panel annunciator alarm using the confusion matrix method. The confusion matrix method is used to calculate the accuracy value, precision value, error value, and F1-score of the system.

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3.1 Over Voltage Ground Protection (F64V) Testing

The over voltage ground protection (F64V) uses an INA219 sensor to measure if there is overvoltage with the help of a DC power supply. The voltage limit is 5 Volt DC. So if the voltage set from the DC power supply exceeds 5 Volt DC, the sensor will detect and be used as input to the ESP32, and then the ESP32 will instruct the DC relay, which functions as a switch, to turn on the indicator light on the panel box and send an input signal to the optocoupler module to send a fault notification to the telegram application. Based on Table 5, the test results of over voltage ground protection (F64V) for 20 tests show that when given a different voltage input, each test (>5 Volts DC) with the help of a DC power supply successfully turned on the fault indicator light on the control panel box and successfully sent a notification to the telegram according to the type of fault, namely over voltage ground protection (F64V).

Table 5. Over Voltage Ground Protection (F64V) Testing Results

Testing	Input Voltage (DC Power Supply) (Volt)	Panel Indicator Light	Telegram Notifications
1	5.4	On	Sent
2	6.0	On	Sent
3	6.5	On	Sent
4	6.9	On	Sent
5	7.0	On	Sent
6	7.3	On	Sent
7	7.5	On	Sent
8	7.7	On	Sent
9	8.0	On	Sent
10	8.5	On	Sent
11	8.6	On	Sent
12	8.8	On	Sent
13	9.0	On	Sent
14	9.2	On	Sent
15	9.6	On	Sent
16	9.9	On	Sent
17	10.0	On	Sent
18	10.1	On	Sent
19	10.3	On	Sent
20	10.5	On	Sent

3.2 Over Current Ground Protection (NP51GT) Testing

The over current ground protection (NP51GT) uses an INA219 sensor to measure if there is more current with the help of a DC power supply and DC motor. So by adjusting the voltage from the DC power supply with a DC motor load, the current will automatically increase until it exceeds 0.15 A, the sensor will detect and be used as input to the ESP32, and then the ESP32 will instruct the DC relay, which functions as a switch, to turn on the indicator light on the panel box and send an input signal to the optocoupler module to send a fault notification to the telegram application. Based on Table 6, the test results of over current ground protection (NP51GT) for 20 tests show that when given a different current, each test (>0.15 A) with the help of a DC power supply and a DC motor successfully turned on the fault indicator light on the control panel box and successfully sent a notification to the telegram according to the type of fault, namely over current ground protection (NP51GT).

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Table 6. Over Current Ground Protection (NP51GT) Testing Results

Testing	Current (DC Power Supply and DC Motor) (Ampere)	Panel Indicator Light	Telegram Notifications
1	0.17	On	Sent
2	0.19	On	Sent
3	0.21	On	Sent
4	0.23	On	Sent
5	0.25	On	Sent
6	0.27	On	Sent
7	0.29	On	Sent
8	0.31	On	Sent
9	0.33	On	Sent
10	0.35	On	Sent
11	0.37	On	Sent
12	0.39	On	Sent
13	0.41	On	Sent
14	0.43	On	Sent
15	0.45	On	Sent
16	0.47	On	Sent
17	0.49	On	Sent
18	0.51	On	Sent
19	0.53	On	Sent
20	0.55	On	Sent

3.3 Widing/Oil Temperature (26T) Testing

The widing/oil temperature (26T) uses a DS18B20 temperature sensor to measure if the water temperature exceeds the limit of 70 ºC with the help of an electric water heater. So if the water temperature has reached or exceeded 70 ºC, the sensor will detect and be used as input to the ESP32, and then the ESP32 will instruct the DC relay, which functions as a switch, to turn on the indicator light on the panel box and send an input signal to the optocoupler module to send a fault notification to the telegram application. Based on Table 7, the test results of widing/oil temperature (26T) for 20 tests show that when the water is heated to a different temperature, each test (>70 ºC) with the help of an electric water heater successfully turns on the fault indicator light on the control panel box and successfully sends a notification to the telegram according to the type of fault, namely widing/oil temperature (26T).

Table 7. Widing/Oil Temperature (26T)Testing Results

Testing	Water Temperature (Electric Water Heater) (ºC)	Panel Indicator Light	Telegram Notifications
1	76.06	On	Sent
2	81.94	On	Sent
3	85.81	On	Sent
4	88.44	On	Sent
5	90.31	On	Sent
6	91.75	On	Sent
7	92.69	On	Sent
8	92.69	On	Sent
9	93.44	On	Sent
10	94.00	On	Sent
11	94.00	On	Sent
12	94.44	On	Sent
13	94.75	On	Sent
14	95.00	On	Sent

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Testing	Water Temperature (Electric Water Heater) (ºC)	Panel Indicator Light	Telegram Notifications
15	94.75	On	Sent
16	95.00	On	Sent
17	95.31	On	Sent
18	95.44	On	Sent
19	95.31	On	Sent
20	95.44	On	Sent

3.4 Oil Level Low (33QT) Testing

The oil level low (33QT) uses a water level sensor to measure if there is a decrease in the water level with the help of a measuring cup that has been modified with an additional water tap to reduce the amount of water. The water level limit is 120 ml. So if the water is reduced and is already at the limit or below the 120 ml limit, the sensor will detect and be used as input to the ESP32, and then the ESP32 will instruct the DC relay, which functions as a switch, to turn on the indicator light on the panel box and send an input signal to the optocoupler module to send a fault notification to the telegram application. Based on Table 8, the test results of oil level low (33QT) for 20 tests show that when the water has decreased and is already at the limit or below the limit of each different test (<120 ml), with the help of a measuring cup, successfully turned on the fault indicator light on the control panel box and successfully sent a notification to the telegram according to the type of fault, namely oil level low (33QT).

Table 8. Oil Level Low (33QT) Testing Results

Testing	Water Level (Measuring Cup with Water Tap) (ml)	Panel Indicator Light	Telegram Notifications
1	110	On	Sent
2	110	On	Sent
3	100	On	Sent
4	100	On	Sent
5	90	On	Sent
6	90	On	Sent
7	80	On	Sent
8	80	On	Sent
9	70	On	Sent
10	70	On	Sent
11	60	On	Sent
12	60	On	Sent
13	50	On	Sent
14	50	On	Sent
15	40	On	Sent
16	40	On	Sent
17	30	On	Sent
18	30	On	Sent
19	20	On	Sent
20	20	On	Sent

3.5 Transformer Trip (T86) Testing

The transformer trip (T86) uses the MCB as a safety and detector in the event of a short circuit connected to 220 Volt AC in the test. So if a short circuit occurs, the MCB will secure and detect the fault used as input to the AC relay coil, which functions as a switch, to turn on the indicator light on the panel box and send an input signal to the optocoupler module to send an fault notification to the telegram

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application. Based on Table 9, the test results of transformer trip (T86) for 20 tests show that when a short circuit occurs, the MCB will secure and detect an fault used as input to the AC relay coil, which functions as a switch, to turn on the indicator light on the panel box. This test successfully turned on the fault indicator light on the control panel box and successfully sent a notification to the telegram according to the type of fault, namely transformer trip (T86).

Table 9. Transformer Trip (T86) Testing Results

Testing Short Circuit (Push Button ON-OFF and MCB)	Panel Indicator Light	Telegram Notifications
1	On	Sent
2	On	Sent
3	On	Sent
4	On	Sent
5	On	Sent
6	On	Sent
7	On	Sent
8	On	Sent
9	On	Sent
10	On	Sent
11	On	Sent
12	On	Sent
13	On	Sent
14	On	Sent
15	On	Sent
16	On	Sent
17	On	Sent
18	On	Sent
19	On	Sent
20	On	Sent

3.6 *Confusion Matrix*

Table 10 above is a table of the system confusion matrix. Based on Table 11 of the test results in the table above, it can be seen that the accuracy, precision, recall, and F1-score values of over voltage ground Protection (F64V), over current ground protection (NP51GT), widing/oil temperature (26T), oil level low (33QT), and transformer trip (T86) reached 100% and the error rate reached 0%. This situation is because all test data on the five types of faults is detected correctly, and no test data from other types of faults is detected as one of the five types of faults.

Table 10. Confusion Matrix Results

		Actual					
		(F64V)	(NP51GT)	(26T)	(33QT)	(T86)	Total
Predicted	(F64V)	20	0	0	0	0	20
	(NP51GT)	0	20	0	0	0	20
	(26T)	0	0	20	0	0	20
	(33QT)	0	0	0	20	0	20
	(T86)	0	0	0	0	20	20
	Total	20	20	20	20	20	100

Where :
(F64V) : Over voltage G. prot. (F64V)
(NP51GT) : Over current G. prot. (NP51GT)
(26T) : Widing/oil temperature. (26T)

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(33QT) : Oil level temperature (33QT)
(T86) : Transformer trip (T86)

Table 11. Testing Results

	(F64V)	(NP51GT)	(26T)	(33QT)	(T86)	Average (%)
Accuracy (%)	100	100	100	100	100	100
Precision (%)	100	100	100	100	100	100
Recall (%)	100	100	100	100	100	100
Error rate (%)	0	0	0	0	0	0
F1 – score (%)	100	100	100	100	100	100
Macro F1 – score (%)	100					
Weighted F1 – score (%)	100					

4. Conclusion

The average value of system testing with the confusion matrix method from 100 test data on the five types of fault, resulted in an accuracy rate of 100%, a precision rate of 100%, a recall rate of 100%, an error rate of 0%, and an F1-score rate of 100%. This is because all test data on the five types of fault were detected correctly, and no test data from other types of fault was detected as the five types of fault. Based on the results of this study, the theoretical and practical implications can be stated that using the confusion matrix method to measure the performance of the fault alarm monitoring system on the IoT-based control panel annunciator alarm shows excellent system performance results and the results of this study are used as input for substation operators who can provide benefits, such as real-time monitoring, automatic notification when a fault is detected, and the ability to access information remotely.

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