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# Industrial Internet of Things for Condition-based Maintenance of an Induction Motor

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**Abstract.** Condition-based Maintenance is a type of maintenance based on collected information through monitoring of the machine condition. This system uses Node-RED in Raspberry Pi to read the parameter value in the PLC Siemens S7-1200. The parameter being read is the motor vibration, the motor temperature, and the motor load factor (only simulated). This system monitors the motor parameter, sends a notification to users, keeps the parameter value to the database, and gives the average parameter value on that day. The measured parameter enables the system to analyze the possible causes of the increasing parameter values. Based on the testing results, PLC succeeds in sending the data to the Node-RED, monitoring the online dashboard, performing condition-based maintenance process, storing the motor parameter to the database, and sending the alarm notification through an email or SMS for users who are connected to the internet. We perform the experiments using PLC's simulated inputs and outputs, as the sensor reading of motor data still cannot be done accurately.



## INTRODUCTION

All physical things in a factory (such as tools, machines, motors) need maintenance. Factories expect all tools work optimally beyond the tool maintenance schedule since sudden tool damage can cause a production loss and reduce the tool efficiency and productivity in manufacturing factories. Knowing abnormalities in tools earlier can prevent greater damage to the machine [1]. There are three types of maintenance [2]:

a. Reactive maintenance, where maintenance is done when the machine is broken and can not be operated anymore.
b. Preventive Maintenance, where maintenance is done based on schedule made by considering how long a machine has operated
c. Predictive Maintenance (PdM), where maintenance is done based on optimal condition estimation of a machine

Many industries still apply reactive maintenance. This seems to be more economical because there is no cost spent on the tool maintenance. However, in the long run, this way will be more wasteful because when the machine breaks suddenly, the production efficiency will decrease, and it wastes industrial operational costs without making the products. Preventive maintenance is better than the previous one. However, it assumes all machines' conditions as equal. This may lead to an over-maintenance or under-maintenance situation of a machine.

There are two types of PdM. The first one is Condition-based maintenance (CbM), which detects a physical change on the machine (a sign of failure) so that maintenance can be done to maximize the working hours of the machine

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without increasing the risk of tool damage. In CbM, a condition or threshold is used to determine whether it is already the time or not to do machine maintenance. For example, maintenance should be done when there is a mechanical vibration that exceeds the threshold that has been set previously in the CbM algorithm. CbM consists of three main steps: data acquisition step, data processing step, and maintenance decision making step [3].

The key insight of CbM is condition monitoring, where continuous monitoring is done using sensors or other indicators, so maintenance only will be done when a machine is nearly broken [4]. All machines always suffer from particular symptoms or specific conditions [5]. In the case of a motor, some important conditions/parameters to be monitored are vibration, sound, lubrication oil [6], and other indicators such as temperature, physical condition, resistance, and conductivity [7].

The second type of PdM is one that uses a machine learning algorithm to predict when it is the best time to do maintenance. In this case, if there is more data, the prediction from PdM will also be more accurate. Unfortunately, sometimes those datasets do not exist in a factory, so PdM cannot be performed. In this paper, we propose CbM based on the Industrial Internet of Things (IIoT), so technicians can perform maintenance right before the tool breaks down. We use Node-RED as a suitable platform to integrate various components of an IoT system [8].

## DESIGN SYSTEM

This research aims to implement the concept of CbM to a 3-phase induction motor. Some sensors are used to read the parameter values from the motor. The sensors being used are, among others, sensor vibration to measure the motor vibration, temperature sensor to measure the motor temperature, and inverter to measure the power usage when the motor is operating. The value from all the parameters will be inputted into PLC, which then will be sent to the Node-RED in Raspberry Pi and stored into the MySQL database. They also can be monitored with a Node-RED dashboard. Node-RED is event-driven and ideal to be implemented by using hardware like Raspberry Pi to produce notification alarm output.

The general system design is shown in Fig. 1. The PLC would function to run the CbM algorithm from the ladder diagram and take the motor parameter values (vibration, temperature, and load factor) from the sensors that had been connected to the PLC analog inputs. Raspberry Pi was used to keep the parameter values sent by the PLC into the database, showing them on a dashboard display, and sending alarm notifications to the client.



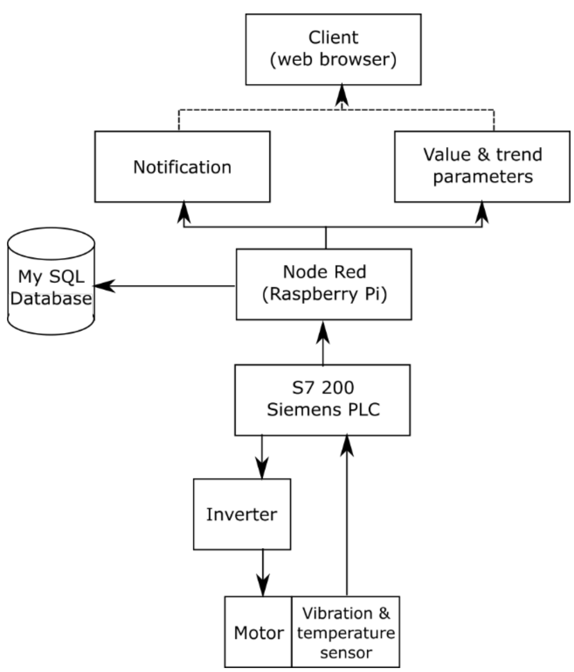



**FIGURE 1.** Outline of the System Design

Hardware network topology can be seen in Fig. 2. There was a router connected to the Wide Area Network (WAN) for internet connection. This router was also used to set the IP address and Subnet Mask so that the PC and Raspberry Pi could communicate with the PLC. PC was used to do the ladder diagram programming on PLC Siemens with TIA Portal 14 application. All devices are connected via ethernet.

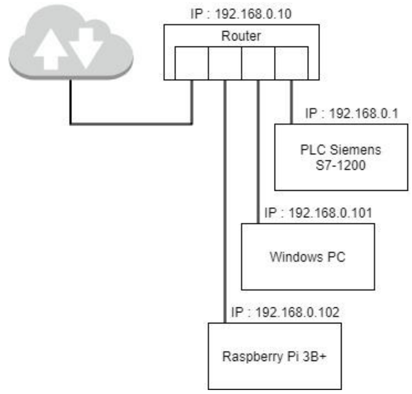



**FIGURE 2.** Network topology of hardware system

## The System Mechanism

Our CbM mechanism is described in Fig. 3. This mechanism happens in S7 1200 PLC as a low-level controller and RaspberryPi (NodeRed) as Human Machine Interface (HMI) that can be accessed from the internet.

The system works parallelly for every parameter. When a parameter exceeds the first threshold (high or abnormal), the abnormal parameter indicator will be shown on the dashboard in the form of a text display and LED indicator. When the parameter value exceeds the second threshold (high-high or emergency), the dashboard will show an emergency indicator and send a notification to the technicians or users.

For vibration parameter, there is a variable to measure the motor vibration called Velocity (V) with mm/s unit. The velocity itself is a value change from Displacement (D), while Displacement means the distance among peaks in the vibration wave in mm (millimeter) unit. In the normal condition, the vibration produced by the motor is below the threshold high (around 2.8 mm/s). In comparison, the emergency condition is when the vibration is above the threshold high high (around 4.5 mm/s). The standard of both thresholds is taken from ISO 10816-3 [9].

We then explain the selection of temperature parameters. We used an AC 3-phase motor with insulation class F, which has a maximum temperature of 155 Celcius. The high high threshold is around 145, and the high threshold is above 135 Celsius [10]. The normal condition is achieved when the temperature is below the threshold high. If the motor is still operating at a temperature exceeding 145 Celcius, the motor bearing will be damaged quickly. When the motor temperature exceeds the insulation class motor, the insulation motor can melt and cause a short circuit.

The parameter load factor is based on the power usage of the motor. The load factor is a value comparison of motor power divided by the rated full load current or the power when the full load is based on the specification of the motor. The maximum motor efficiency is achieved when the load factor is around 60% to 80% [11]. When the load factor is above 100%, it means the motor needs more power than that from the motor design. This can happen because there is a problem with the supply voltage that causes the motor to need more power to keep its torsion. Another possibility is that there is a short circuit due to the motor insulation degradation. Too much load or dirty motor bearing also causes the motor to need more power to get enough torsion.

There is a CbM output analysis that will be displayed on the dashboard to help users in doing the troubleshooting when maintaining the motor. The analysis output can predict the causes of motor damage based on any parameter observing the value abnormality. If three parameters are used, there will be eight possible combinations. Fig. 4 visualizes all possibilities of parameter combination on the normal or high value. The analysis output will be shown in the section of Testing and Results.

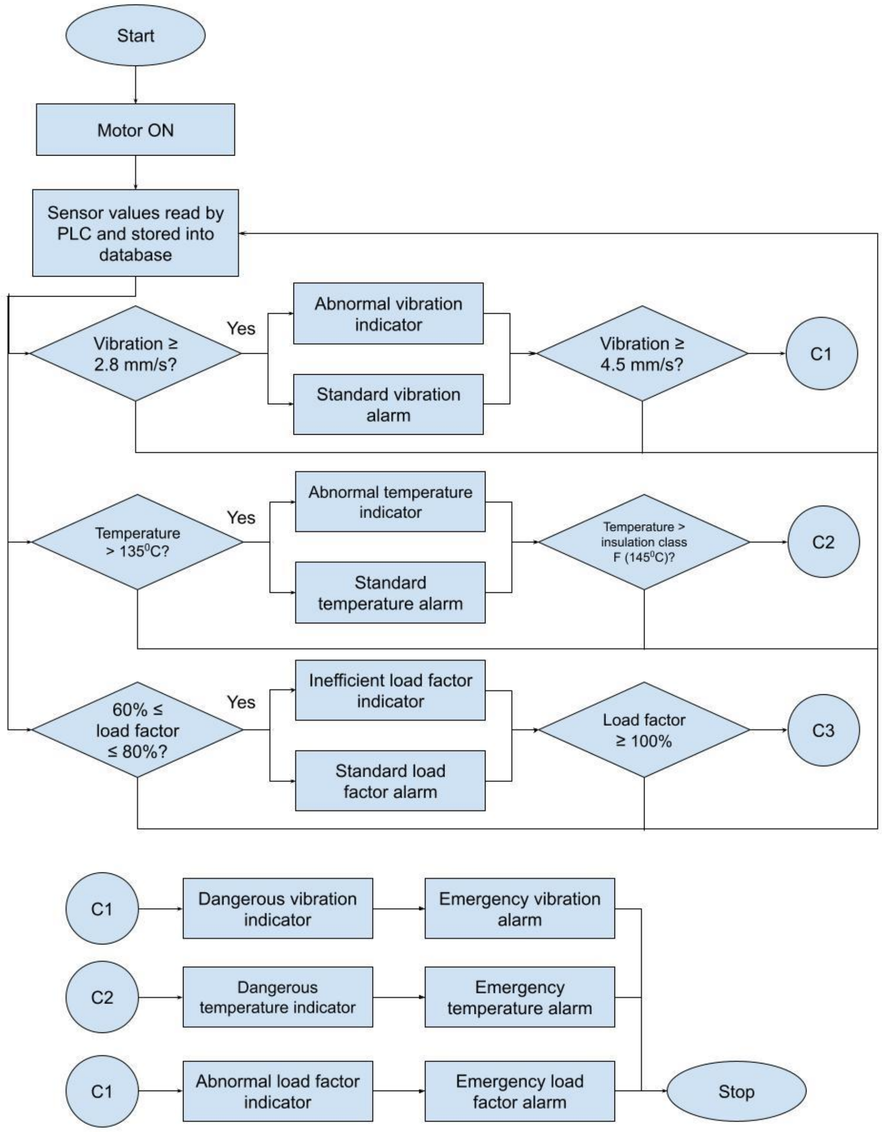
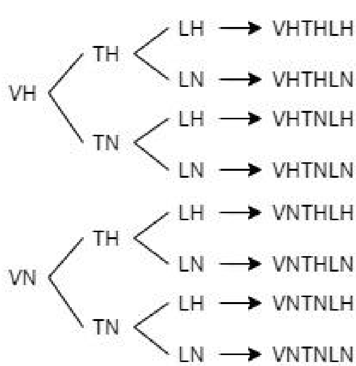



**FIGURE 3.** System mechanism




Note:
V: Vibration
T: Temperature
L: Load factor
N: Normal
H: High

**FIGURE 4.** All possible parameter combinations

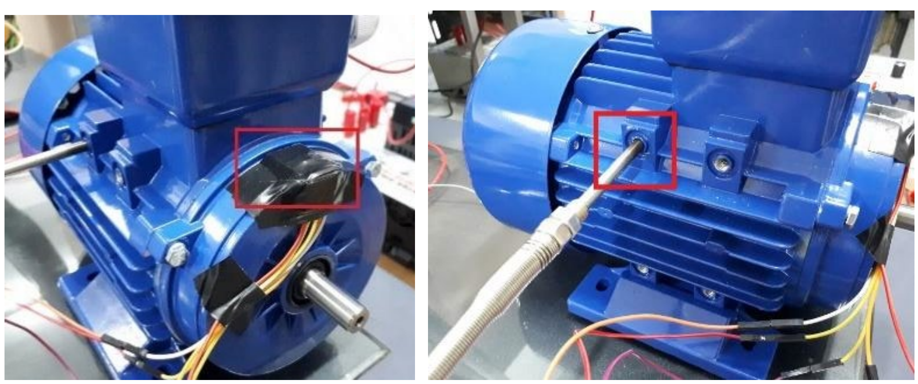
## Hardware Configuration

There are two AC 3-phase 4-pole motors of ADK type GL-632-4. One of the motors (Motor A) is new and in its optimal condition, and the other motor (Motor B) is conditioned to have a technical problem and need maintenance (see Fig. 5). The conditioning on Motor B is done by breaking its ball bearing that functions to keep the position of balls inside the bearing and by filling the gap among the balls inside the bearing. The broken ball bearing means that the motor is damaged, which often occurs and has a significant impact on the increase of motor vibration and temperature.

**FIGURE 5.** New motor condition and opened broken motor

The vibration sensor is developed using the ADXL335 accelerometer, while PT100 is utilized as the temperature sensor. The sensor readings are processed by an Arduino, and then fed to S7 1200 Siemens PLC via Modbus TCP/IP protocol. Arduino behaves as the master, and PLC will behave as the slave. SINAMIC G120C PN is an inverter used to control the induction motor. It communicates with PLC via PROFINET. The motor used here has 0.18 kW capacity, while the inverter has 0.55 kW capacity. Vibration sensor ADXL335 is located on the upper side of the motor body (see Fig. 6a). In contrast, Pt100 is located on the particular side of the motor body (see Fig. 6b).





(a) (b)

**FIGURE 6.** Location of vibration and temperature sensors

Unfortunately, the vibration sensor reading is not accurate enough to be applied in the CbM system. Apparently, the motor rotations create magnetic fields that distort the accelerometer reading result. To replace the sensors, we use two potentiometers connected to PLC's analog inputs. Fig. 7 shows the PLC wiring with simulated inputs and outputs.

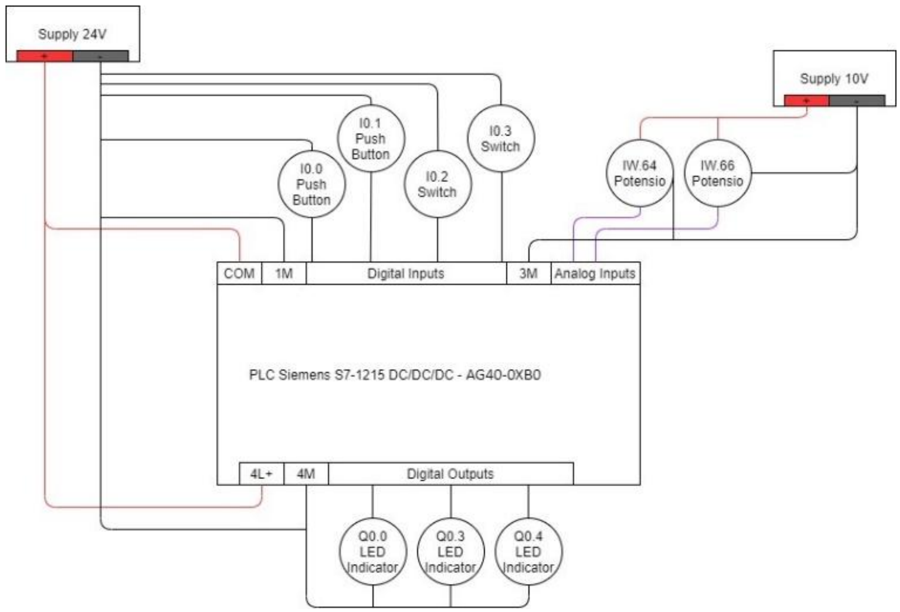



**FIGURE 7.** The PLC wiring diagram

## Software Configuration

The ladder diagram is used as the PLC programming language. A part of the ladder diagram that moves the value from an address to the one that suits Node-RED is shown in Fig. 8. For instance, the vibration parameter is kept in address %MD12, which then is converted into %MW102. However, the vibration parameter in the Node-RED is configured to be kept in address %QW20. Thus, %MD12 is inputted into the function block CONV to be converted into integer %MW102, whose address is then moved to %QW20 applying the block MOVE function. This also applies to the other parameter like temperature in the address %MD17 to %QW5 and load factor in the address %MD37 to %QW15.

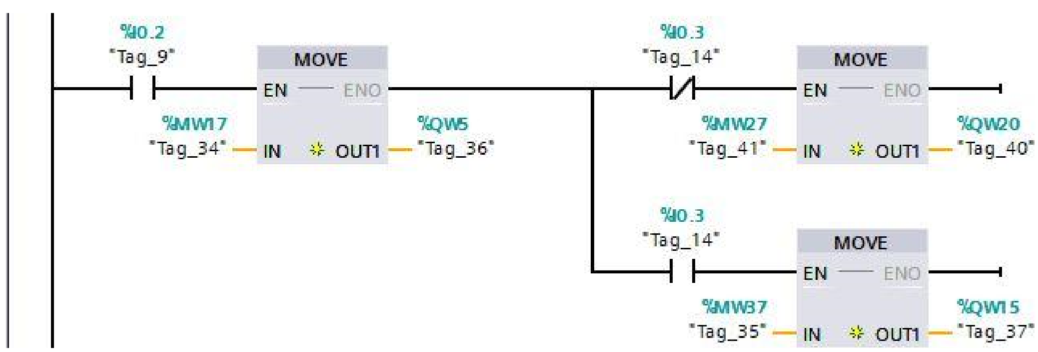



**FIGURE 8.** Part of the ladder diagram

The parameter value simulation is done by using a potentiometer with a voltage supply of 0 - 10 volts, in which the potentiometer goes into the address %IW64 and %IW66. The maximum potentiometer value that goes into both addresses is around 26500 when the value of the potentiometer is 10 volts. If scaling on each parameter is done where the vibration achieves the maximum value of 8 after being divided by 10 in the function node, the temperature is maximum 160, and the load factor is maximum 110. Thus, for every 1-volt increase on the analog PLC input, the parameter vibration will rise 0,8 mm/s; the parameter temperature will rise 16 °C, and the parameter load factor will rise 11%. The flow for the sending function of the parameter value from PLC to the Node-RED and MySQL database can be seen on Fig. 9.

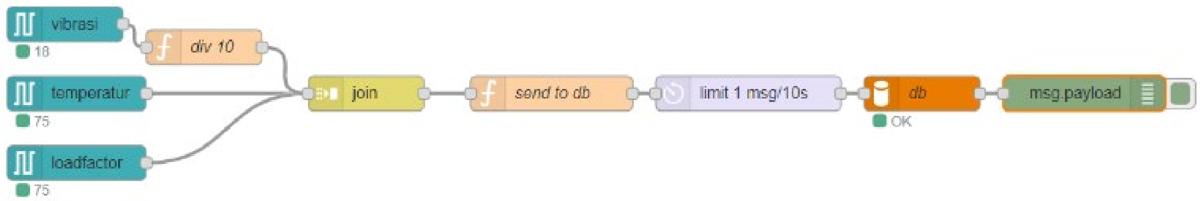



**FIGURE 9.** The flow of PLC value stored into the database

There are nodes that need to be configured before the Node-RED can be connected to the MySQL database and PLC. To connect with MySQL, a MySQL database should be created first in the PHPMyAdmin. After the database and table have been made, the nodes need to be set in "db". Then, the PLC node setting will be adjusted to the variable being used on the ladder diagram. Fig. 10 below shows node properties for MySQL and PLC address variables whose value will be taken to the Node-RED.

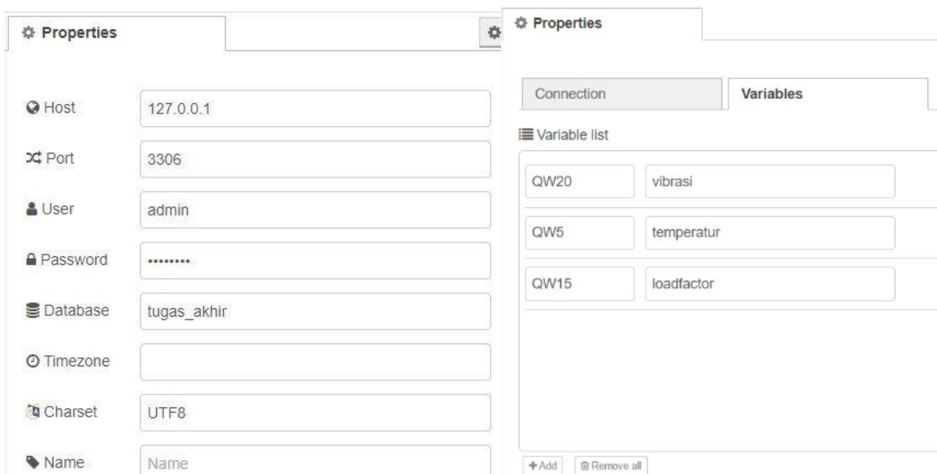



**FIGURE 10.** My SQL and PLC Nodes Properties



## RESULTS AND DISCUSSION

On this section, some testing to know the functionality of the system will be conducted, namely monitoring from the dashboard, notification, and CbM algorithm output testing. Furthermore, testing is also conducted to know the duration of the parameter sending from the PLC to Node-RED and the notification duration from the alarm to email and SMS sent to the users.

### Dashboard Results

The dashboard page to display the Parameter Overview can be seen in Fig. 11. The page to display the trend, average, status, and recommendation on temperature parameters can be seen in Fig. 12. We also created similar pages for vibration and load factors. The database shown in the table in the dashboard can be seen in Fig. 13.

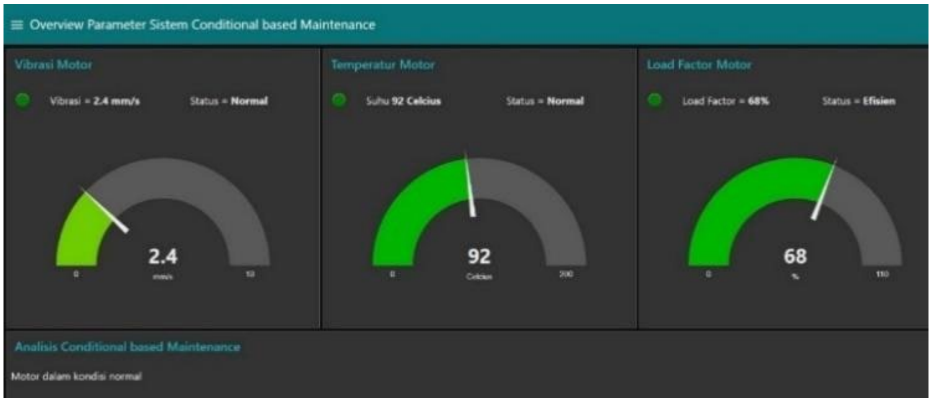



**FIGURE 11.** The Parameter Overview Dashboard

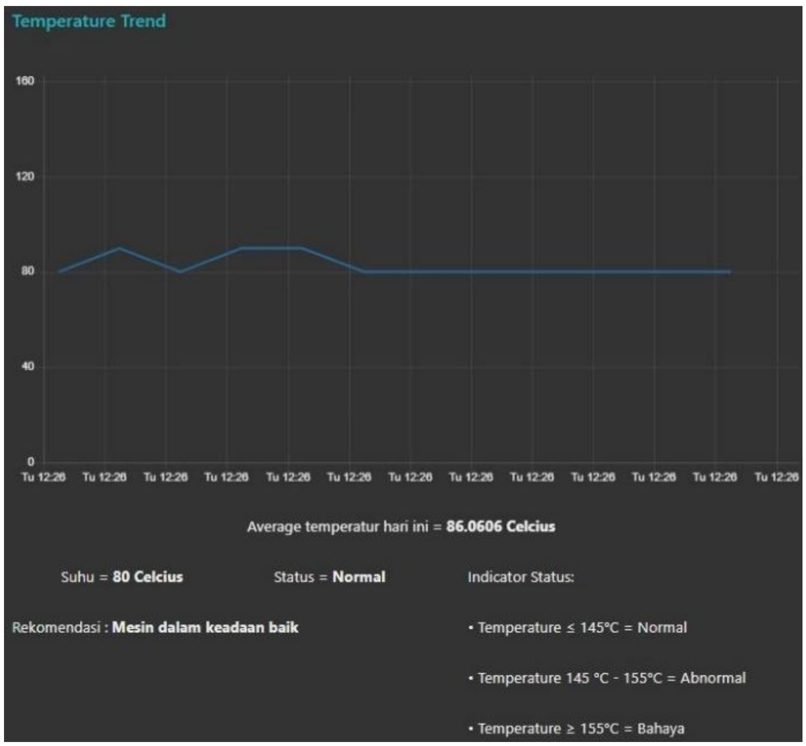
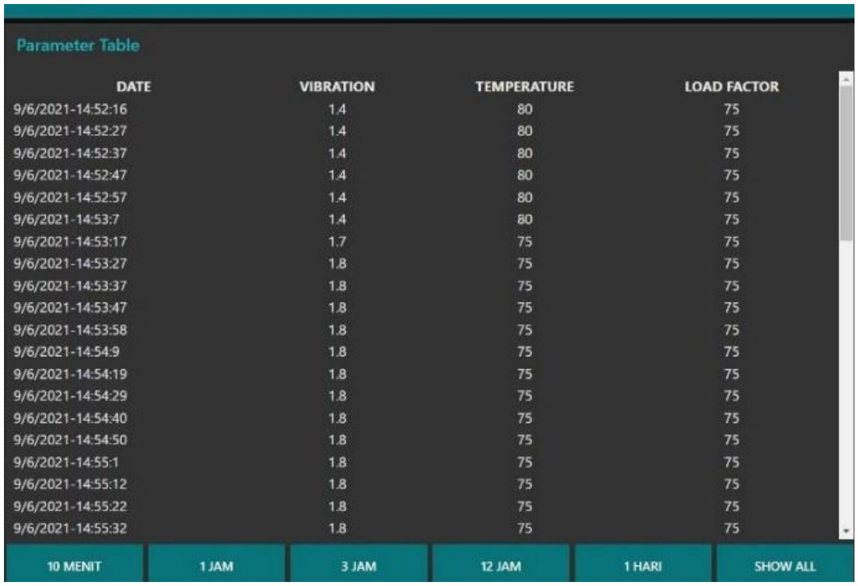



**FIGURE 12.** The temperature parameter dashboard

## Notification and SMS System Testing

This experiment was carried out to know whether the notification system worked out or not. The notification aims to be an alarm for the users. For the notification system to work, it must be made sure that the Raspberry Pi has been connected to the internet. The parameter value was simulated by using a potentiometer connected to PLC's analog input. Fig. 14 shows the email notification results, while Fig. 15 shows the SMS notification results.



Parameter Table

| DATE | VIBRATION | TEMPERATURE | LOAD FACTOR |
|---|---|---|---|
| 9/6/2021-14:52:16 | 1.4 | 80 | 75 |
| 9/6/2021-14:52:27 | 1.4 | 80 | 75 |
| 9/6/2021-14:52:37 | 1.4 | 80 | 75 |
| 9/6/2021-14:52:47 | 1.4 | 80 | 75 |
| 9/6/2021-14:52:57 | 1.4 | 80 | 75 |
| 9/6/2021-14:53:7 | 1.4 | 80 | 75 |
| 9/6/2021-14:53:17 | 1.7 | 75 | 75 |
| 9/6/2021-14:53:27 | 1.8 | 75 | 75 |
| 9/6/2021-14:53:37 | 1.8 | 75 | 75 |
| 9/6/2021-14:53:47 | 1.8 | 75 | 75 |
| 9/6/2021-14:53:58 | 1.8 | 75 | 75 |
| 9/6/2021-14:54:9 | 1.8 | 75 | 75 |
| 9/6/2021-14:54:19 | 1.8 | 75 | 75 |
| 9/6/2021-14:54:29 | 1.8 | 75 | 75 |
| 9/6/2021-14:54:40 | 1.8 | 75 | 75 |
| 9/6/2021-14:54:50 | 1.8 | 75 | 75 |
| 9/6/2021-14:55:1 | 1.8 | 75 | 75 |
| 9/6/2021-14:55:12 | 1.8 | 75 | 75 |
| 9/6/2021-14:55:22 | 1.8 | 75 | 75 |
| 9/6/2021-14:55:32 | 1.8 | 75 | 75 |

10 MENIT | 1 JAM | 3 JAM | 12 JAM | 1 HARI | SHOW ALL

**FIGURE 13.** The dashboard to display the *database*


**FIGURE 14.** The email notification result

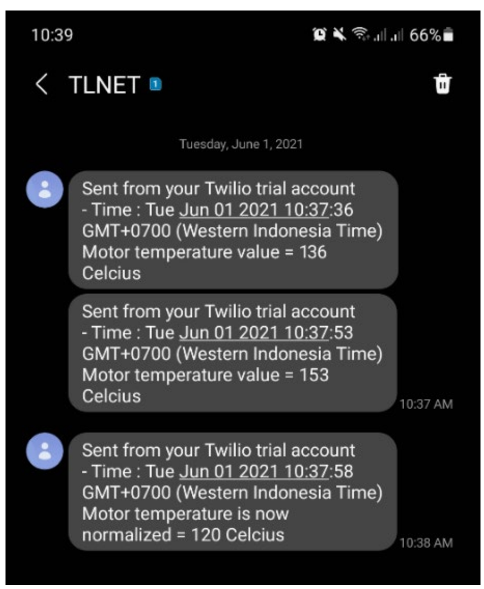



**FIGURE 15.** The SMS notification result

Table 1 shows the results of sending the alarms, accompanied by the time gap from the first time the alarm was on (known from the debug nodes) to the notification sent as an SMS and email. The time is acquired when the SMS and email came in.

**TABLE 1.** The alarm notification experiment results

| Jenis Alarm | | Notification Type | | Amount of time | |
|---|---|---|---|---|---|
| | | SMS | Email | SMS (seconds) | Email (seconds) |
| Vibration | Abnormal | Successful | Successful | 1 | 2 |
| | Emergency | Successful | Successful | 2 | 1 |
| | Normalized | Successful | Successful | 1 | 1 |
| Temperature | Abnormal | Successful | Successful | 1 | 1 |
| | Emergency | Successful | Successful | 2 | 2 |
| | Normalized | Successful | Successful | 1 | 1 |
| Load Factor | Abnormal | Successful | Successful | 1 | 1 |
| | Emergency | Successful | Successful | 1 | 3 |
| | Normalized | Successful | Successful | 1 | 1 |
| Average time | | | | 1,22 | 1,44 |

## CbM Algorithm Experiment

The result of all possible causes of motor damage based on the values of each parameter is shown in Table 2 (based on our private communication with the expert in the induction motor field [12]). The results are shown on the dashboard on "Analysis of Condition-Based Maintenance." The note on the condition has been shown in Fig. 4.

**TABLE 2.** Possible Analysis of Condition-Based CbM

| Condition type | CbM Analysis Output |
|---|---|
| VNTNLN | Motor in normal condition |
| VHTNLN | 1. The motor bearing is broken or dirty<br>2. The motor base is not rigid<br>3. There is a loose machine part inside the motor structure<br>4. The motor bearing is not placed tightly |
| VNTHLN | 1. Overheat happens because of errors in the motor ventilation or fan<br>2. The motor has been operating for too long<br>3. The room temperature is too hot |
| VNTNLH | 1. The motor is overloaded, it may cause the bending of the motor shaft if it happens for a long time |
| VHTHLN | 1. The motor bearing is broken or dirty, so it causes excessive friction and heat |
| VHTNLH | 1. The motor is overloaded, which may cause the bending of the motor shaft<br>2. The Motor bearing is broken or dirty, or the rotor scratch the stator, so it causes excessive vibration |
| VNTHLH | 1. The motor is overheated because of overload, which may cause the bending of the motor shaft |
| VHTHLH | 1. The motor bearing is broken or dirty, so it causes excessive friction and heat<br>2. The bent motor shaft or asymmetrical motor bearing causes uneven air gap, so friction happens between stator & rotor that causes heat |

Fig. 16 is one of the samples of the dashboard at condition 1, namely the vibration parameter that exceeds the normal value. While Fig. 17 is another sample of the dashboard at condition 7, namely when the three parameters exceed the normal value.

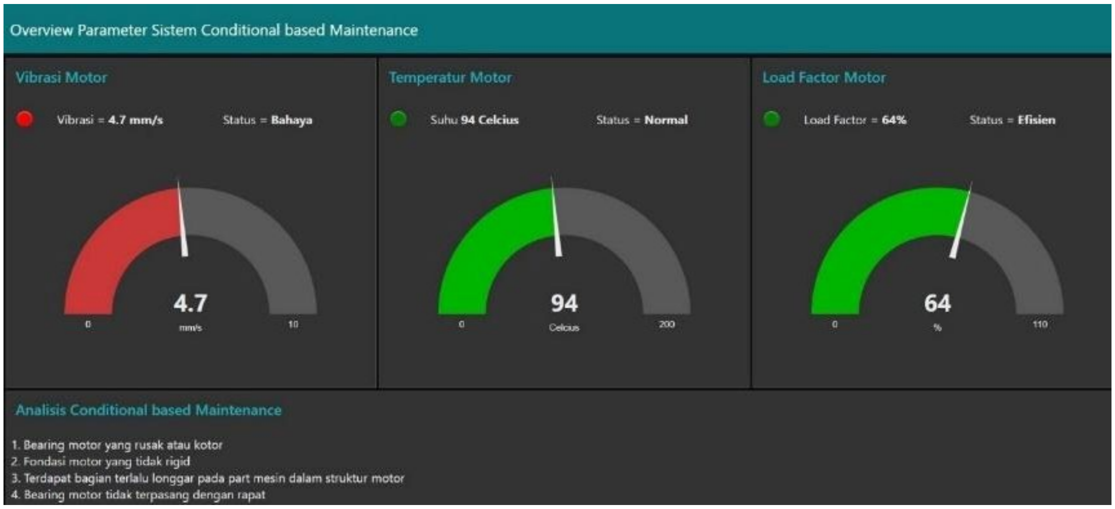



**FIGURE 16.** Dashboard Display at Condition 1

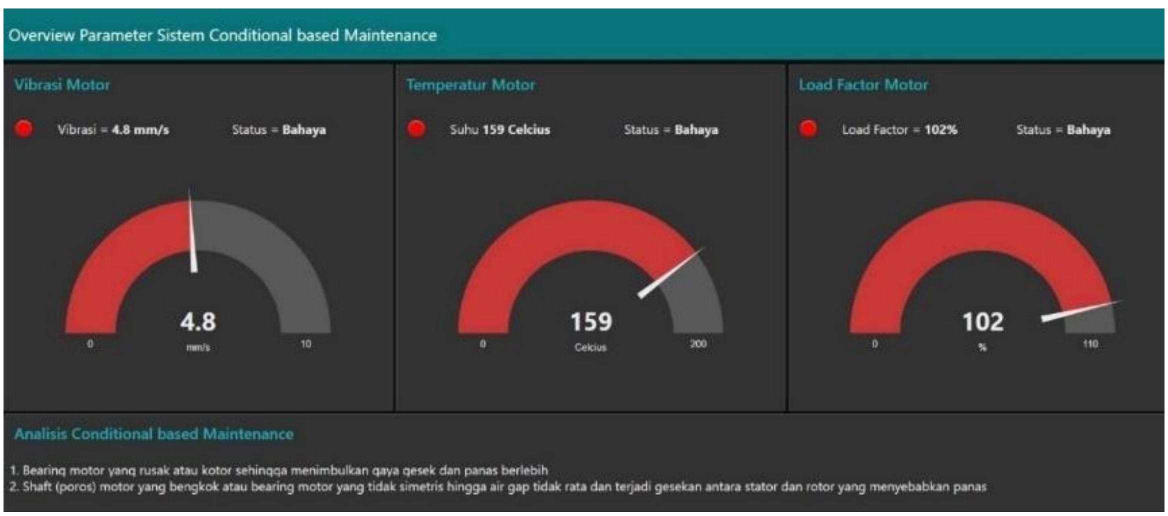



**FIGURE 17.** Dashboard Display at Condition 7

## CONCLUSION

There are some conclusions to be made in this research:

1. Raspberry Pi communication with PLC Siemens S7-1200 has been successfully connected. Values monitoring has been successfully displayed on the Node-RED dashboard and stored in MySQL Database.

2. The system has been connected to the internet. It can send an email and SMS notification when the alarm turns on, with the average time of SMS 1.22 seconds and of email 1.44 seconds.

3. The CbM algorithm to read and compare the parameter value with the threshold being read proves to be successful. Furthermore, there is an additional analysis feature on the possible damage on the motor based on the parameter values that influence each other from the interview with experts and from the referred journals.

## ACKNOWLEDGMENTS

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