Application of Fuzzy Logic to Electrical Protection Devices

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Abstract. The amount of electricity used is followed by the magnitude of the risk of disasters caused by power disruptions. In general, PLN as the manager of electricity distribution has provided standard protection for users, but it has not provided good protection from disasters due to disturbances, because in general the protection is specific to one type of disturbance, and the cause of the disturbance cannot be known through protection devices provided. Therefore we need a smarter electrical protection device by applying fuzzy logic to the protection device. Fuzzy on this protection device aims as a decision support system to show the condition of the electricity network based on the parameters of voltage, current, and temperature of the cable. The results of fuzzy logic in the form of a hazard level with a range of 1-10 which is divided into 3 status states, namely safe, alert, and hazardous, which in danger conditions the protective device will cut off the electricity so as not to damage electronic devices. Besides that, from the results of fuzzification, the parameters measured can be known to cause interference.

1. Introduction

Based on 2017 statistical data on electric power, currently, electricity users in Indonesia reached 68 million with the largest user being the household sector which reaches 91% [1,2]. The amount of use of electrical energy is inseparable from the magnitude of the risk of disasters due to electrical disturbances. To prevent this disaster, electricity service providers have provided standard electricity protection to protect each customer. However, this protection is not enough to protect users from electrical disturbances. Based on the news of the compass, 70% of fires in Jakarta are caused by an electrical short circuit. Of course, the disaster caused huge losses to the loss of human lives. In addition, by using standard protection, officers who analyze the disturbance will find it difficult to find out the cause of the disturbances [3–6].

Therefore this study developed an intelligent protection device that can provide information on abnormal conditions due to interference and can provide immediate action if the abnormal conditions occur at a dangerous level [7,8]. This intelligent protection system was developed using fuzzy logic as a decision support system to make decisions based on conditions for input voltage, current and conductor temperature on the basis of rules that have been determined. The output of fuzzy logic is the level of danger from the measured conditions [9–11]. If the condition has reached the danger level, the
solid-state relay actuator will cut off the current to prevent damage to electrical devices on the network protected by this system.

2. Study of literature

2.1. Electrical disturbances
Disruption is defined as a physical condition caused by the failure of a device, component or an element to work in accordance with its function [12–14]. If an electrical disturbance occurs and is not immediately handled or localized it will cause damage to the electrical equipment. Based on the abnormal conditions caused by the disturbance are as follows:

- Overload disruption is interference caused by increasing load requirements so that the power supply continues to increase.
- Short term interruption, can occur between phases (3 phases or 2 phases) or between 1 phase to the ground and can be temporary (non-persistent) or permanent (persistent).
- Overvoltage disturbance, a system disturbance that causes the voltage flowing on the grid to increase.
- Power outages are disturbances caused by interruption of generating units, short circuits, interference with distribution or transmission components.
- Interference instability is interference that occurs after other disturbances that cause swing power or power swing.

2.2. Electrical protection
Electric power system protection is a protection system that is installed on electrical equipment or electrical systems to anticipate abnormal conditions [14–17]. With the existence of electrical protection, it can prevent damage to electrical equipment due to interference. The requirements that must be met to make electrical protection devices are as follows.

- Avoid or reduce damage to electrical equipment due to interference.
- Quickly localize the area of disturbance becomes smaller.
- It has high reliability.
- Able to protect humans from the dangers of electricity.

For example, electrical protection is a Mini Circuit Breaker (MCB) that protects from overload and short circuit conditions which results in rising conductor temperatures and damage to electrical equipment. The working principle of the MCB is to cut off the electric current if the value of the current through it exceeds the nominal limit [18–20].

2.3. Fuzzy logic
Fuzzy logic is a decision-making process based on a rule base that has been created and has several ambiguous and gray parameters. Fuzzy logic is determined by logical equations rather than complex differential equations and is derived from thoughts that identify and take advantage of the grayness between two extremes. The fuzzy logic system consists of fuzzy sets and fuzzy rules [9,10,21,22]. The fuzzy methods known today are Mamdani, Sugeno, and Tsukamoto. Each method of fuzzy logic consists of 3 processes, namely fuzzification, rule evaluation, and defuzzification. Fuzzy logic components are as follows.

- The membership function is the stage of changing the parameter input to the value of the membership degree. The degree of membership can be expressed in the form of certain mathematical equations. The general form of membership is the trapezoid expressed in mathematical equations with four parameters \([a, b, c, d]\).
- The fuzzy logic system, there are 4 main components, namely fuzzification, the knowledge base in the form of database and rule base, decision making logic and defuzzification unit. The fuzzification process is used to change data enter explicitly in the form of degrees of membership. The knowledge base is used to connect the input set with the output set. The logic of decision making is used to combine the rules contained in the rule base into a set of fuzzy outputs. Defuzzification is a step to change the results of the inference engine that is expressed in the form of fuzzy sets to a real number.
• The logic of decision making or commonly called fuzzy inference (fuzzy inference) is the application of fuzzy rules at the input which then evaluates each rule. The principle of fuzzy logic is to apply if-then rules to every fuzzy rule.

• Defuzzification is resistant to changing fuzzy sets that contain fuzzy rules into a certain crisp value. There are several defuzzification methods in Mamdani rules, including the Center of Area (COA) which takes the midpoint of the fuzzy area to determine crisp solutions, Mean of Maximum (MOM) determines crisp solutions by taking the average domain that has a maximum membership value, Largest of Maximum (LOM) determines the crisp solution by taking the largest value from the maximum membership value, Smallest of Maximum (SOM) determines the crisp solution by taking the smallest value from the domain that has the maximum membership value, and the bisector determines the crisp solution by taking the value in the fuzzy domain that has the membership value is half of the total membership value in the fuzzy area.

2.4. Decision Support System
Decision Support System (DSS) is a system used to provide information, guide, provide predictions for users to make decisions appropriately [23,24]. The SPK characteristics are as follows.

• Designed to assist in decision making in solving structured or non-structured problems by adding human wisdom and computerized information.

• The processing process combines analytical models with conventional data entry techniques and information search or checking functions.

• It can be used or operated easily by people who do not have high computer operating capability.

• Designed with an emphasis on aspects of flexibility and high adaptability so that it is easily adapted to share changes in the environment that occur and user needs.

3. METHODOLOGY
In the study of the Application of Fuzzy Logic to this Electrical Protection Tool researchers used the following research design.

3.1. Determination of Specifications
The determination of device specifications is determined based on system requirements in hardware or software. As an electrical protection system by taking into account the voltage, current and temperature parameters of the cable, it is needed a sensor device that is able to measure these quantities accurately.

In addition to sensors, the system also requires a processing device that is able to execute quickly, has sufficient storage and has good reliability, because in this system the process of calculating the value of sensors is needed, run the fuzzy logic algorithm and provide action on each condition as optimal
and fast [27]. Therefore, researchers determine the processing device used is Xtensa LX06 integrated into the ESP32 module.

Furthermore, to provide information to users, the system is equipped with a 16x2 Alphabetic LCD display device that can be programmed so that it displays parameter information, system conditions and protection conditions based on fuzzy logic. As an electrical protection system that is able to cut off electricity in hazard conditions, the system must have a circuit breaker. The circuit breaker used is a Solid State Relay (SSR) which is an electronic switch that is able to disconnect and flow the current based on a given trigger. In a closed switch the device is capable of carrying an electric current up to 40Ampere.

3.2. Hardware Planning
The hardware design of this study discusses the effectiveness of each component to build a protection system. In general, the relationship of each component is as follows.

![Figure 2. Diagram Block Hardware](image)

From Figure 2 it is known that the ZMPT101b voltage sensor and ACS712 current sensor need to be added to the signal conditioning device before connecting to the ESP32 module via the ADC pin. This signal conditioning device is used to reduce the maximum voltage range of the sensor from 5Volt to 2.5Volt using the output voltage distribution from the sensor. This needs to be done because the maximum voltage that is able to be measured by the ESP32 module is 3.3Volt. Other sensor devices such as the LM35 temperature sensor and the MLX-90614 temperature sensor do not need to do signal conditioning because on the LM35 temperature sensor the maximum output sensor voltage does not exceed 3.3Volt, while the MLX90614 temperature sensor uses an I2C interface with the ESP32 module.

3.3. Software Design
This discussion focuses on the design of data acquisition methods, the design of fuzzy logic used and control actions.

3.3.1. Data Acquisition. The process of data acquisition is the process by which the system collects, retrieves and prepares data which is then processed [9]. In this process, the system will acquire data based on the measured amount. In the measurement of electrical parameters such as voltage and current measurements are carried out periodically in accordance with the measured AC electrical frequency. In electricity, in Indonesia, the frequency used is 50Hz so that measurements are made once every 20 milliseconds by measuring the amplitude value of the electrical signal in 1 period. Furthermore, measurements of the ambient temperature and the temperature of the cable are carried out continuously.
Initialization

Read ADC value and read received I2C data

Every 20 milliseconds convert data from ADC to every units

Save to variable have been declare

Figure 3. Data Acquisition Flowchart

After the data retrieval process, the system will then perform a calculation process to convert the 12bit analog value of the microcontroller into units of measurement according to the parameters measured. In changing the value, there are several methods used such as inputting the ADC reading into the equation obtained from the graph approximation method, and information from the component datasheet. In addition, the sensor with the I2C interface does not need to change the value because the value obtained is an appropriate unit of measurement.

3.3.2. Fuzzy Logic Design. As a decision support system based on the results of calculations from fuzzy logic, the system needs to be designed well in order to be able to give a decision that is in accordance with the conditions that occur. The design of the fuzzy logic design is based on the following block diagram.

From the block diagram above it is known that the fuzzy algorithm, in general, is the process of fuzzification, inference, and defuzzification. In the fuzzification process, the system will change the crisp value of the input variable into a membership function in the fuzzy domain. The change process is determined from the membership function equation that can be represented in the graph as follows.

Figure 4. Diagram Block Fuzzy Logic

In the voltage parameter, the measured value is the difference in voltage measured by the sensor with a nominal value of 220V. The difference is then classified into 4 membership functions, namely, Negative Big, Negative Small, Normal, and Positive Big.

Figure 5. Voltage Membership Function
In the current parameter, the measured value is the measured current value by the sensor which is divided based on the load level of 1200VA electricity. So that the membership function is normal, large and more.

The parameter values that are measured are the difference in the temperature of the cable and the ambient temperature so that a large difference in temperature is obtained which indicates changes in the temperature of the cable due to internal factors. Furthermore, the difference results are divided into 3 membership functions, including normal, warm and hot.

After the fuzzification process, enter the next variable fuzzy rule formation. The determination of the fuzzy rule base is based on the researcher's knowledge. In order to obtain the rules as presented in table 1.

| Temperature | Voltage | Current       |
|-------------|---------|---------------|
|             |         | normal | big | over |
| Normal      | NB      | danger      | danger | danger |
|             | NS      | safe      | safe  | danger |
|             | PB      | danger     | danger | danger |
| Warm        | NB      | danger     | danger | danger |
|             | NS      | safe      | alert | danger |
|             | PB      | danger     | danger | danger |
| Hot         | NB      | danger     | danger | danger |
|             | NS      | alert     | alert | danger |
|             | PB      | danger     | danger | danger |

In this process, the system uses the MIN-MAX inference model so that the fuzzy output composition is obtained. Furthermore, the results of the composition are defuzzification. One method of defuzzification in Mamdani's fuzzy logic is centroid. This method looks for the midpoint value of the composition based on the moment and area of the composition, or can be formulated into mathematical functions:

\[ Z^* = \frac{\int \mu_x(z)z \, dz}{\int \mu_x(z) \, dz} \]  

By using equation (1) the system can find out the value of crisp from the results of fuzzy logic. The crisp value is a representation of the hazard level in the condition measured by the sensor. Furthermore, from the results of determining the level of danger, the system will take action in accordance with the conditions.
3.3.3. **Control.** From the danger level obtained from fuzzy logic, the system will give an action in the form of current termination when the hazard condition is at level 8.

![Control Action Flowchart](image)

**Figure 8.** Control Action Flowchart

Termination of the electric current is carried out by the SSR actuator so that the hazard condition does not last long and can protect other electronic devices.

4. **RESULT**

From the results of designing the system hardware, then built and arranged to become a protection device with the following results.

![Tool design looks outside](image)

**Figure 9.** Tool design looks outside

On the outside there is visible 16x2 LCD to inform the user, then there are 4 push-buttons that are used to select the menu contained on the LCD. Then at the bottom of the device, there is a terminal block that is used to connect electrical conductor cables from the source and the load. Furthermore, the system will be tested to measure parameters in real and compared with measuring devices that have been calibrated to determine the accuracy of the sensor. From the test, results have been obtained as the following data on the Figure 10, Figure 11, Figure 12, and Figure 13, respectively.

![ZMPT101 voltage sensor testing](image)

**Figure 10.** ZMPT101 voltage sensor testing

![Testing the ACS712 current sensor](image)

**Figure 11.** Testing the ACS712 current sensor
From the data above, it is known that in the real condition tool is able to measure parameters with a difference in value that can still be tolerated. Then the system will be tested to ensure that the fuzzy algorithm that is implemented runs well and gives the appropriate results. In this test, the system is given by an input condition input voltage: 212 V, input current: 4.2 A, cable temperature: 24 °C, and ambient temperature: 25 °C. From the conditions of the input values above then, the fuzzification process is carried out to convert the crisp value into the fuzzy domain. The safe conditions are performed in Figure 14 and Figure 15. Moreover, the reversible conditions are illustrated in Figure 16 and Figure 17.

From the inference process between the rules above, the next step is the formation of the composition between the rules. At this stage, it is done by finding the maximum value of each predicate. The results of the composition between the rules are as depicted in Figure 18.
From Figure 18, it is known that the crisp value of the fuzzy logic test is 4.02 so that it can be seen that the conditions resulting from the application of fuzzy logic are "alert". The calculation results are then compared with the results of calculations by the program embedded in the device which is embedded in the serial monitor.

From the above results, it is known that the system has worked and performed calculations well so that the results of the system calculations are the same as the results of manual calculations. From the above results, it is also known that the time spent in fuzzy algorithm execution in one calculation is 2 milliseconds. Then the tool response can be seen based on the time of data acquisition to produce a decision is 22 milliseconds. With this response time, this tool has a response time faster than the MCB 6A, which on average can provide a 0.7-second response to interference.

5. Summary

Electrical disruptions can cause problems ranging from damage to electronic equipment to lead to disasters such as a fire. Therefore we need electrical protection devices that can measure parameters and provide information on safe, alert or hazard conditions. From the results of this research, it is known that the tools made in this study are able to measure electrical parameters and conductors in a curative manner and can provide information on the conditions of the results of the fuzzy algorithm. The results of these decisions can be used as a warning in case of danger and can cut off electricity so that electrical disruptions do not damage electronic equipment. For technicians, the results of the fuzzy algorithm can be information about the cause of the disturbance.

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