Engineering model development using Fuzzy Logic for wireless protective devices

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Abstract. Operationally, the distribution of electricity faces various technical limitations and environmental conditions during operations, on the other hand, it also bears the increasing need for electrical energy. Therefore, the system is required to provide high service by considering various disturbances that occur. Thus, an electric power system requires a protection system that is reliable and sensitive to various types of disturbances, and it has a fast response. In this work, the study is aimed to develop conventional protection devices by implementing intelligent systems based on fuzzy logic. The use of fuzzy is intended to support decision making by considering the voltage, current and temperature of the cable. The results show that the device developed can react quickly and cut off electricity. In addition, it can also respond to the types of interruptions that exist. Moreover, it also avoids damage devices installed on the network.

1. Introduction
In general, electrical system disturbances are caused by faults and overloads [1–3]. Furthermore, short circuits are some of the disturbances which can be caused by many things, including insulation failure due to excessive heat or humidity. In addition, this condition can also be caused by mechanical damage to electrical distribution equipment, and equipment failure, as a result of overload or other faults [4–6]. In these cases, mechanical characteristics are very important to be defined. Therefore, the electric power system (EPS) must be kept in good condition during operation from various disturbances that may occur. It means that the EPS must be stood for all types of disturbances and it must have stayed in high reliability. Technically, short circuits can occur between two-phase conductors, between all phases of a poly-phase system, or between one or more phases and ground conductors. To overcome this disturbance, the EPS needs a protection system (PS) that is able to keep the system operating normally or recover quickly after a disturbance occurs, either direct or indirect faults. The isolation of faults and abnormalities on the EPS requires the application of protective equipment that senses properly when an abnormal current flow exists and then removes the affected portion from the system [7–10].

In particular, the PS is used to protect the EPS and it is also used to isolate damaged parts or disturbing sections with healthy or normal parts so that the system can still function satisfactorily without experiencing severe damage due to current faults or other fault effects. Technically, the device used for the PS can be arranged with various interrelated equipment to support its function. This
Combination can be intended for currents and faults [11–13]. By coordinating with other parts, the PS has more power to cover disturbances. In principle, the PS is functioned to provide protection to the EPS, so that it does not suffer for the excessive damage due to faults and propagate effects.

Conventionally, the protective equipment widely uses relays that works based on the principle of mechanical strength. This principle is developed based on relay contact operation in response to trig, which results in mechanical forces generated through the flow of currents in one or more turns in the core or magnetic core. In a further development, protective equipment has been converted into a solid-state relay. The main difference from this type lies in its function which is similar to an electromechanical relay but has no moving components for increasing long-term reliability. The design of protective equipment is based on the use of integrated linear and digital electronic devices [14–16].

Furthermore, the PS has been developed into a form of a digital protective relay controlled by a microcomputer. This technology has been developed by data acquisition using information transducers and turning it into the right form for using microcomputers. Once the developments in this work, which is emphasized to develop intelligent protection devices that can provide information about abnormal conditions due to a fault and can provide immediate action if abnormal conditions occur at dangerous levels as discussed in these works. In detail, the PS is facilitated using an intelligent protection system (IPS). The IPS is developed using fuzzy logic (FL) as a tool for supporting a decision system to make instructions based on the conditions of the input voltage, current, and temperature of the conductor based on predetermined rules.

2. Protection system

Basically, the PS is a branch of the EPS where the focus of the study is related to the protection of the EPS from faults through the removal of damaged parts from the rest of the electricity grid. The most basic application of the PS is intended to keep the power system stable by considering component problems while leaving as much network as possible [3,9,14,17,18]. In addition, a protective device is installed on electrical equipment or electrical systems to anticipate abnormal conditions. In these studies, the PS is organized as detailed in Figure 1.

![Figure 1. Protection system concept](image-url)
significantly to respond to the high demand for electricity which is in line with the energy needs in various load sectors as the endpoint of energy consumption. The increased need for this load will have an impact on the level of a short circuit in the transmission system and increase the amount of fault current, which can pass through the breaking capacity of the circuit breaker [23–25]. Therefore, to overcome the extreme fault currents in the EPS, the IPS scheme is very important to consider all operating aspects. In fact, the use of algorithms in protection and supervision is an alternative strategy to face conventional protection.

To bring the IPS for replacing the conventional protection, this study is illustrated in Figure 2. Technically, the concept of development is carried out in several stages, which include the development of the data collection process, the data conversion process, the optimization process, and the decision making process. The data collection process is carried out with various sensors that are needed according to the type of data parameters. Data communication is also done using a wireless system for information paths to the data conversion process. In this works, the FL is used to make a decision-making process based on a rule set that has been created and has several ambiguous and parameters. Moreover, the FL is determined by logical equations rather than complex differential equations and it is derived to identify and take advantage of the grayness between two extremes [26–28]. The FL consists of fuzzy sets and fuzzy rules which are used to optimize the system. The optimization is very important during the operation as part of the economic side management [29–32]. This method is consists of 3 processes, namely fuzzification, rule evaluation, and defuzzification. In particular, the determination of device specifications is defined based on system requirements in hardware or software. As the PS by taking into account the voltage, current and temperature parameters of the cable, it is needed a sensor device that is able to measure quantities accurately, as presented in Figure 2. Moreover, Figure 2 shows the process of decision support systems based on the results of the FL. The system is designed in accordance with the functions of its parts, in order to be able to provide decisions related to the conditions that occur. This fuzzy section is composed of several processes which include fuzzification, inference, and defuzzification.

3. Developing Procedures
As illustrated in Figure 1 and Figure 2, the main subjects are covered for the operating equipment for capturing data and the data process is used to provided information optimized using the FL to meet a decision in these steps. The selection of device specifications is determined based on the desired system requirements for hardware or software. The EPS is developed by taking into account the voltage, current and temperature parameters of the cable using a sensor device [7,9,17,33]. In addition, a voltage sensor consists of current transformers and signal conditioners. The current sensor is closed to sensors that are able to measure the amount of current. Moreover, a temperature sensor is presented to measure ambient temperature with high resolution. Specifically, the data acquisition process in this development is a process where the system collects, retrieves and prepares data that is then processed.
In this work, the system will obtain data based on the amount measured during operating conditions. In the measurement, voltage and current parameters are carried out periodically in accordance with the measured electrical frequency. Furthermore, temperature measurements of the cable are also carried out continuously at regular intervals for the real data as detailed in Figure 3.

Figure 3. Sequencing data acquisition

Figure 4. Controlling action status
The further step is covered in a status decision that is oriented for the PS to present automatically as the IPS. The system will perform a calculation process to convert the analog value of the microcontroller into units of measurement according to the parameters measured. In addition, the sensor does not need to change the value because the value obtained is an appropriate unit of measurement. Moreover, the controlling section is used to maintain from the danger level obtained from the FL as given in Figure 4. Figure 4 shows the procedure to decide the final status as long as the system responsible for determining an instruction to the installed mechanical parts at the EPS.

4. Result
By considering all processes and procedures as detailed in the previous section, the results are performed in several indicators to inform the status. In addition, the system hardware is also designed for determining technical results, where this design is implemented and arranged into a protection device that is tested with input parameters simultaneously. Physically, the output is displayed on a monitor to inform the results of the process. In this section, the system is tested to measure parameters in real terms and compared to measuring devices that have been calibrated to determine the accuracy of the sensor. As the operating performances, the results are given in the following figures.

![Figure 5. Voltage performances](image1)

![Figure 6. Current performances](image2)
Figure 7. Temperature performances

Figure 5 and Figure 6 show the operating performances covered for voltage and current data. From this figure, it can be seen that the system has run on a stable voltage relatively between the designed device and calibrated device to keep a voltage condition. Contrasted to other results, current performances, the IPS has worked on fluctuated loads as shown in Figure 6 with increasing current capacity during all periods of the data collection. Moreover, these results show good equipment with high precision measurement for the sensor and calibrated tool of the operating current. In particular, temperature performances are given in Figure 7. This figure illustrates the current flow during the operation of the EPS. Based on the IPS, the temperature is increased gradually in line with current performances as detailed in Figure 6.

From the above performances, it is known that the condition is able to measure parameters with a different value under permitted deviations in the optimization process. The system is also tested to ensure that the FL which implemented is run well. In this test, the system is given input with the 212-volt input voltage, 4.2 amperes, 24 Celcius degree for the cable temperature, and around 25 Celcius degrees for the environment temperature. The contribution of these parameters is described in Figure 5, Figure 6, and Figure 7.

5. Conclusion
Electrical disturbances that occur in the power system can cause problems and it can also cause damage, therefore, it needs a protection device. This equipment can measure parameters and provide information about conditions for safe, alert or dangerous status. The developed device has capable to measure electrical parameters and provides operating data from fuzzy algorithms. For further research, it can be developed on variations of fuzzy input and decreasing iteration achievements.

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