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Protection of Transformers with Fuzzy Logic

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Abstract: Power transformers are one of the most expensive and most important elements in the power system. Malfunctions in power transformers result in significant power cuts and, consequently, material damage. This important problem needs to be solved. Power transformers must be protected from various fault conditions and faults in the power system. In this study, power transformers are significantly protected from failures in power systems. While this process is provided by various protection relays, the differential protection relays are generally used. In this study, protection relays have been controlled by fuzzy logic and protection has been provided in power transformers. The fuzzy based relay algorithm has been composed of flux-differential current derivation curve, harmonic restriction and percentage differential characteristic curves. The fuzzy-based relay algorithm has been coded in Matlab software. The software has been tested on the power transformer control panels at the Erdemli Substation. The electrical and mechanical failures that occurred have been identified in a shorter time. Thus, damage to power transformers is prevented by controlling relays more effectively and faster. This has led to a significant reduction in maintenance and repair costs. It is understood that the study is successful.

Keywords: Transformer protection, power transformers, fuzzy logic.

1. Introduction

As one of the key elements of the economy and social development, electrical energy has become one of the today's indispensable energy sources. This energy source has become preferable because it is easy to use electric energy, easily transformed to other energy sources with high efficiency and does not harm the environment while consuming. However, the continuous, inexpensive and reliable energy is constantly increasing the demand for this resource. Parallel to economic and social development, electricity consumption is increasing. Considering the plant and operation costs for the generation, transmission and distribution of electrical energy, the protection of energy systems is given more importance every day in line with the principle of providing reliable and continuous energy [1,2]. It is very important for

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the consumers to have a very short downtime when the electrical energy is never cut or cut. It is important to consider the services that cannot be produced due to the power outage, the loss of the workforce and the costs for the repair of the system. It is intended to be able to estimate the faults before they occur. Both the repair costs of the hardware can be reduced and the disruption of the operation can be minimized due to the disabled equipment. Considering all this together, the necessity of good protection of energy systems is clearly seen. An ideal protection system must have the characteristics of reliability, selectivity, speed, simplicity and economy. While this process is provided by various protection relays, the differential protection relays are generally used. In this study, protection relays have been controlled by fuzzy logic and protection is provided in power transformers [3,4].

2. Digital Relaying for Power Transformer

In the case of power transformers, the area between the differential protection relay and the primary and secondary current transformers of the power transformer is maintained. In this way, the differential protection relays provide protection in a certain area before the limits. The relay is not activated outside these areas. Differential protection is based on the principle of current measurement. Differential protection of power transformers is shown in Figure 1.

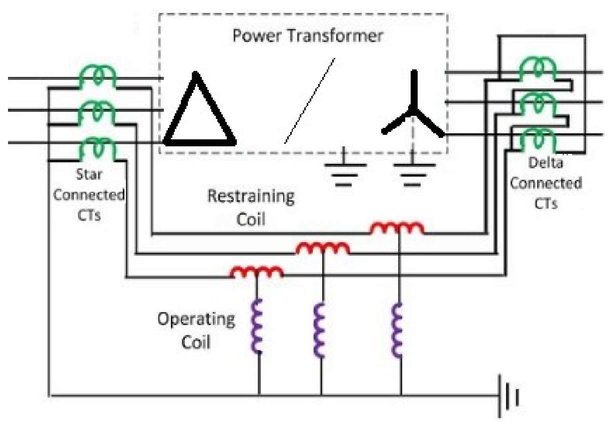

FIGURE 1. Differential protection of power transformers

Differential protection relay compares current values on both sides of the power transformer. In normal operating conditions, it is desirable that the current entering the relay is output in the same way from the other side. In other words, the residual current values entering the relay should be equal and the difference between them is 180 degrees. This is achieved by actual current transformers or by auxiliary current transformers as required. Under normal operating conditions, the same current value must pass through both sides of the power transformer. This current enters from a current transformer and exits from another current transformer. If the current transformer ratios are the same, the secondary windings of the current transformers of the power transformer are connected to form a closed circuit [5,6].

3. Fuzzy Logic Concept

Fuzzy logic is based on fuzzy set and sub set. In a classical approach, an entity is a member of the coop or is not. When expressed mathematically, "1" is the value when the element is a member of the conglomerate, and "0" when the element is not a member of the conglomerate. Fuzzy logic is the extension of classical cluster representation. Each entity in the fuzzy entity set has a membership level. Contrary to classical clusters, the membership grades of fuzzy clusters can change in infinite number of intervals (0,1). These are a whole bunch of grades of membership that are continuous and unbroken. Binary variables such as cold-warm, fast-slow, light-dark in sharp clusters are likened to the real world by being softened by flexible qualifiers such as a little cold, a little warm, a little darkness in the fuzzy logic. Once fuzzy variables are defined and membership functions are assigned to them. There are some rules that are used in defining fuzzy clusters. In principle, the number of fuzzy sets assigned to each variable is usually a single number. This provides the presence of a centre point to prevent numerical oscillation between adjacent values. Second, the number of fuzzy sets is usually between 3 and 9. To describe causal relations, we must be able to distinguish one subset from the other by the use of linguistic variables. The greater the number of sub-clusters, the more difficult it becomes. It is easy to distinguish between short, medium and long variable values. But with a lot of data, this situation becomes more difficult. The linguistic descriptions of the subclasses can be interpreted. At the same time, each fuzzy set must sum up the compound sets. This overlay provides a continuous control area for the fuzzy controller. Once the blur sets have been defined and assigned their membership functions, the rules must be written for each combination of the control variable. These rules will relate input variables to output variables using ‘If-Then’ expressions in decision-making. The condition ‘If’ is a prelude to the result of each rule. In general, each rule is shown in ‘If’ (prefix) ‘Then’ (result) style.

4. Digital Relay Control with Fuzzy Logic

The purpose of protection relays and relay systems is to remove the part of the fault from the system as soon as possible by ensuring that appropriate breakers are opened in order to minimize the damage when faults occur. It is ideal for protection systems to prevent the malfunction and prevent it from failing [7,8]. In this study, the control of the power transformer protection relays is based on fuzzy logic. Fuzzy system for digital relay control is given in Figure 2.

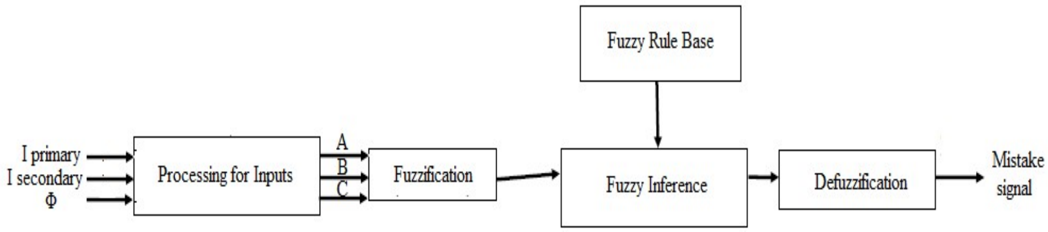

FIGURE 2. Fuzzy System for Digital Relay Control

'A' represent Flux-differential current slope (dΦ/di) which consist from 'little', 'middle' and 'big'. 'B' represent second harmonic of differential current which consist from 'little' and 'big'. 'C' represent the ratio between the value of restraint current to the value of operation current consist from 'little', 'middle' and 'big'. The output consist from 'no mistake' and 'mistake'. If the value of the output is greater or equal to 3, then the case is 'mistake', and if the value is smaller than 3, then the case is 'no mistake'. 'A' fuzzy membership functions is given in Figure 3.

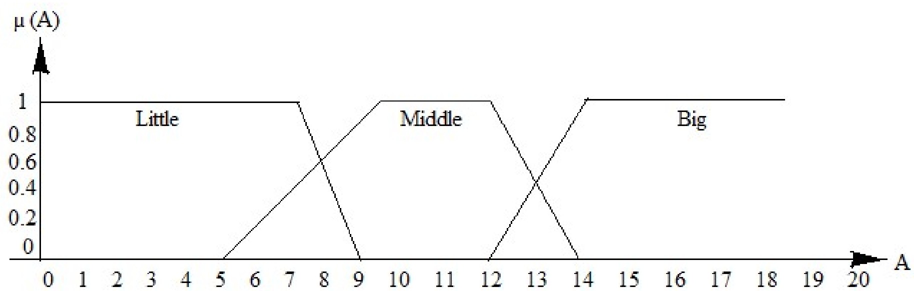

FIGURE 3. A fuzzy membership functions

'B' fuzzy membership functions is given in Figure 4.

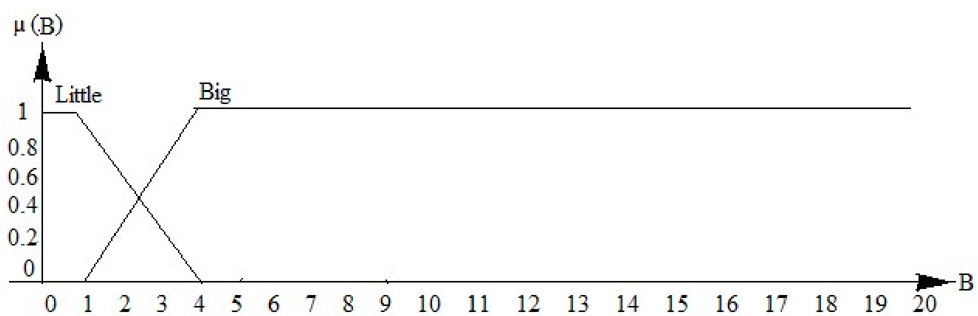

FIGURE 4. B fuzzy membership functions

'C' fuzzy membership functions is given in Figure 5. Fuzzy rule base of 'A-B' is shown in Table 1. Fuzzy rule base of 'A-C' is given in Table 2. Fuzzy rule base of 'B-C' is shown in Table 3.

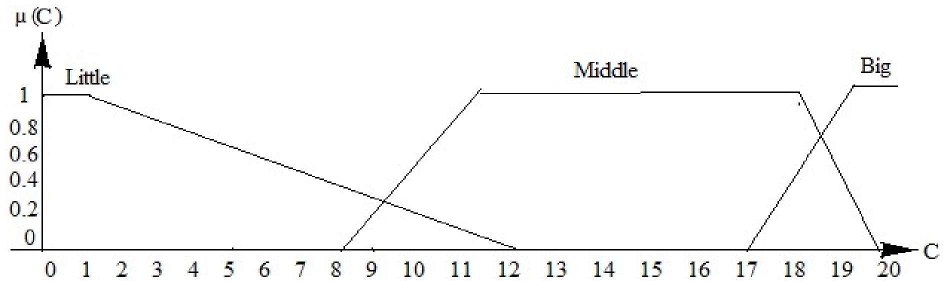

FIGURE 5. C fuzzy membership functions

TABLE 1. Fuzzy Rule Base of A-B

A **B**	**Little**	**Middle**	**Big**
Little	No Mistake	No Mistake	No Mistake
Big	Mistake	Mistake	Mistake

TABLE 2. Fuzzy Rule Base of A-C

A **C**	**Little**	**Middle**	**Big**
Little	Mistake	Mistake	No Mistake
Middle	No Mistake	No Mistake	No Mistake
Big	No Mistake	No Mistake	No Mistake

TABLE 3. Fuzzy Rule Base of B-C

B **C**	**Little**	**Big**
Little	Mistake	Mistake
Big	No Mistake	Mistake
Big	No Mistake	Mistake

Fuzzy logic software in Matlab Program is given in Table 4.

TABLE 4. Fuzzy logic software

```
» if A is Little and B is Little then Output is No Mistake else
» if A is Middle and B is Little then Output is No Mistake else
» if A is Big and B is Little then Output is No Mistake else
» if A is Little and B is Big then Output is Mistake else
» if A is Middle and B is Big then Output is Mistake else
» if A is Big and B is Big then Output is Mistake else
» if A is Little and C is Little then Output is Mistake else
» if A is Middle and C is Little then Output is Mistake else
» if A is Big and C is Little then Output is No Mistake else
» if A is Little and C is Middle then Output is No Mistake else
» if A is Middle and C is Middle then Output is No Mistake else
» if A is Big and C is Middle then Output is No Mistake else
» if A is Little and C is Big then Output is No Mistake else
» if A is Middle and C is Big then Output is No Mistake else
» if A is Big and C is Big then Output is No Mistake else
» if B is Little and C is Little then Output is Mistake else
» if B is Big and C is Little then Output is Mistake else
» if B is Little and C is Big then Output is No Mistake else
» if B is Big and C is Big then Output is Mistake
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Audit input information from the system has been converted into symbolic values, which are linguistic qualifiers. Using the membership function, fuzzy clusters and membership degrees were determined to which the login information belongs. Linguistic variable values were assigned to numerical values. The value ranges that the input variables can take are determined. Performance evaluation was made, which converted the ratio of input variables. Membership functions have been converted to appropriate verbal variables. Thus, fuzzy data was prepared. Rules and system variables that define the relationship between the entry and exit of the system and used in decision making are created. The fuzzy inference process was carried out by the rules defined among the linguistic expressions. Knowledge base and decision making logic are used. The blurry data from the extraction process has been converted to real values so that it can be used in the real system, the blur has been removed. The provisions of the rule sentences created by the membership functions of the fuzzy system have been transformed into a single form of expression by rinsing. In the rinsing process, membership interval values were found for each rule. Thus, exit membership values were determined.

5. Conclusions

The main task of power systems is to provide energy to the end user in the most economical way, at an acceptable level of reliability and quality. The reliability of the system also depends on the reliability of the elements that make up the system. The most basic and important hardware in power systems are power transformers. It is very important in energy systems to prevent malfunctions and to operate the transformers in good operating conditions. It is important to establish assets for the secure system infrastructure by making investments in the energy system. In addition, it is very important to manage these resulting assets effectively and efficiently. Power transformers are the most valuable place in these assets. Compared to other assets, both their functions and their economic values constitute the largest price. In an ideal protection system, reliability, selectivity, speed, simplicity and economic features should be present. These protection operations are provided by various protection relays.

In this study, protection in the power transformer where the malfunction occurred was determined by determining the place where the malfunction occurred and by separating this part from the system as soon as possible. In this disconnection, differential protection relays are used. These protection relays are controlled with fuzzy logic. The fault in the transformer was quickly detected. Thus, it is possible to quickly remove the defective part from the system. Relay control software was created in Matlab program with fuzzy logic. These relays used in the protection of power transformers have been effectively and quickly controlled. This software was tested on the protection relays in Erdemli Transformer Substation. With this software, malfunctions in the power transformer were determined in a short time. The defective part was provided to leave the system in a short time. Thus, malfunctions in power transformers are prevented from causing significant damage to the power transformer. This has led to a significant reduction in breakdown costs in power transformers.

Authorship contribution statement

Zile Mehmet: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation, Visualization, Investigation, Writing Reviewing and Editing.

Declaration of competing interest

The author declares that there is no competing financial interests or personal relationships that influence the work in this paper.

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