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A Fault Detection and Protection Scheme for A 200 MVA Transformer Using Fuzzy Logic

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Abstract: *The paper elucidates a fault detection and protection scheme for a 200MVA transformer using Fuzzy logic. Fuzzy logic (FL) tool box in MATLAB/ SIMULINK software was utilized in the simulation system that diagnosed transformer faults and also monitors its operating conditions. Current and rate of change of current with time have been identified as the input variables, duly represented in the programme as "Error" and "Error-Dot". These variables have their universe of discourse from -1.5 to 1.5 and from -10 to 10 respectively. Fuzzy logic sensor is designed to monitor the current (i) conditions of the transformer at both ambient and full load. The results from the research show that whenever the output response is zero the current in transformer is normal. This is obtained when input values of [0] and [0] are injected into the system to produce a response of "6e-017" which is approximately zero. Whereas if the output response is greater than zero it implies that the transformer current is rising beyond normal and protection scheme should be alerted. This condition is achieved when input values of [-1.5] and [5] are used on the system to give a response of "+5". However, if the response is less than zero then the transformer current is below normal, hence the protection scheme should be alerted. To investigate this, input values of [1.5] and [-5] gives a response of "-5".*

Keywords: *Fault, detection, current, voltage, controller*

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I. Introduction

Transformers are static electromagnetic machines designed for transformation of one alternating voltage to another with different voltage and current characteristics [1]. Large power transformers belong to a class of very expensive and vital components in electrical power system. In practice, they are protected against internal short circuit and over-heating of which capacity percentage differential relays are universally adopted for internal short circuit protection [2].

A transformer can be single or multiphase depending on the primary and secondary windings. There are so many faults and losses which can occur in transformer both on load and off load. Most of the losses like eddy current and hysteresis in the core and the resistive power (I^2R) loss in the windings result to heat. This heat may culminate to other dangerous conditions like reduction of dielectric strength, earth fault and finally burning of the windings. To prevent undue temperature rise and guard against a final collapse, various system of cooling are adopted depending on the voltage level to dissipate such heat [3]. The coolants are mostly air and oil with accessories to increase its efficiency. Tests are carried out during commissioning and while in service to ensure reliability.

Transformers are designed such that as little energy as possible is wasted inside it, thus ensuring that its efficiency is as high as possible [3]. Hence:

(i) Low resistance copper coils are used so that internal energy (I^2R) losses in the windings are small.
(ii) Laminated core is used to reduce eddy current losses.
(iii) The core is made of soft magnetic materials in order to reduce the energy required to bring about magnetic reversal (hysteresis loss).
(iv) Efficient core design is adopted to ensure that all the primary flux is linked with secondary.

Despite all engineering design and constructional efforts, an ideal transformer called "lossless transformer" cannot be practically obtained because of the inherent and unavoidable losses and faults. Sequel to this, detection schemes are devised to monitor and sieve out the occurrence of such faults. The inception of the faults introduces abrupt changes of amplitude and phase in voltage and current signals. Faults allow abnormal large currents to flow, resulting in over heating of power system components. If the fault is typically a short circuit, it can exist as an electrical arc in a fluid (such as air). The extremely high temperature in arcs will vaporize any known substances causing equipment destruction and fire [4]. Faults can cause three-phase system voltages to rise above their acceptable ranges or to be unbalanced causing three-phase equipment to operate improperly. They can cause the system to become unstable and loose synchronism. There are conventional fault detection schemes which include typical electrical sensors, which are of bimetal-strip, switch or thermostat type or thermocouple, thermo-resistor detectors and thermistor [5]. Non electrical sensors are of gas or fluid filled type. Other constructional features are employed for the detection such as bulchholz relay and transformer breather with desiccant [5].

A fuzzy logic as an alternative method of fault detection and protection on power transformer has been adopted for this paper research. Soft computing has been proposed as a method to solve real-world problems, which defy conventional approaches. In fact, even when expert knowledge is available, it is often more easily stated in descriptive form that is, as statement like "IF a sign of certain type appears THEN one or more faults must be present"[6].

Fuzzy logic incorporates a simple rule-base if "X AND Y THEN Z" approach to solving problems rather than attempting to model a system used which rely on the operator and experience rather than technical understanding of the system. Design of a fuzzy logic sensor needs qualitative knowledge about the system under consideration.

Unlike most conventional and modern detection schemes, fuzzy logic sensors are capable of tolerating uncertainties and imprecision to a greater extent. Hence they produce better results under changing operating conditions and uncertainties or imprecision in system parameters.

II. Faults In Transformer

Though transformer is a static device, protected by the main circuit breaker thus there is almost no possibility of external fault to it other than internal faults like; open circuit fault, overheating fault or rise in transformer temperature, winding short circuit fault, change in oil quality, earth fault, change in oil level, abnormal noise and damage to bushing insulators. .inherently, transformers have losses, such losses include.

(i). **Eddy current loss:** As electromotive force (e.m.f) is induced on a transformer core, it generates current in the core in the same way as it does in a conductor. This current is called eddy current and would cause a large loss of power and excessive heating [7].

If the core is made of laminations insulated from one another, the eddy current is confined to their respective sheets and it is reduced. If the core is split into three as shown above, an emf per lamination is only a third of that generated in the solid core and the cross sectional area per path is also reduced to about a third. With reduced area, resistance is increased so that resistance per path is roughly three times that of the solid core. Consequently, the current is about $1/9^{th}$ of that in solid core.

Hence ,

$$= \frac{I2R\ loss\ per\ lamination}{I2R\ loss\ in\ solid\ core} \tag{1}$$

$= \quad (1/9)^2 \times 3 = I^2 \times 3 = 1/27$

Since there are three laminations

Then:

$$= \frac{Total\ Eddy\text{-}current\ loss\ in\ lamination\ core}{Total\ Eddy\text{-}current\ loss\ in\ solid\ core} \tag{2}$$

$= \quad 3/27 = (1/3)^2$

It follows that the eddy-current loss is approximately proportional to the square of the thickness of the lamination. Hence the eddy current loss can be reduced to any desired value not less than 0.4 mm for economic justification. It can still be reduced considerably by the use of silicon-iron alloy, usually about 4% silicon. The resistivity of this alloy is much higher than that of ordinary iron. Therefore thin and high resistivity laminations effectively reduce the eddy current loss to small proportions. The induce emf is proportional to FB_m (since $4.44FNØ_m$) this causes the flow of eddy current.

$$Ie = \frac{emf}{Impedance\ of\ core\ path} \tag{3}$$

So $\quad \mathbf{p_e = KF^2 B_m^2\ watts/m^3}$ **(4)**

Where k = constant

F = frequency of magnetic flux.

B_m = maximum flux density in tesla.

III. Methodology

This paper presents a complete circuit diagram of improved fault detection and protection for a transformer using fuzzy logic fault detector is shown in Figure 1.

At HV side of the transformer, current $I_1 = \dfrac{MVA}{\sqrt{3}\ MV}$ or $\dfrac{KVA}{\sqrt{3}\,KV}$

$$\frac{I_1}{I_2} = \frac{N_2}{N_1} \tag{5}$$

$$I_2 = I_1 \times \frac{N_1}{N_2} = input\ \boldsymbol{current(error)} \tag{6}$$

R, Y and B represent the voltage lines from both side of the power transformer while CTs is the cu transformer on both sides of the power transformer

T = Transformer Protected.

During differential, at time t, our second input I_3 now becomes

$$dI_2/dt = error - dot \tag{7}$$

Note that; I_2 which is the output current from the transformer becomes the input current "Error" to the fuzzy detector, while dI_2/dt which is the output current at time t, becomes the second input current error-dot to the fuzzy detector.

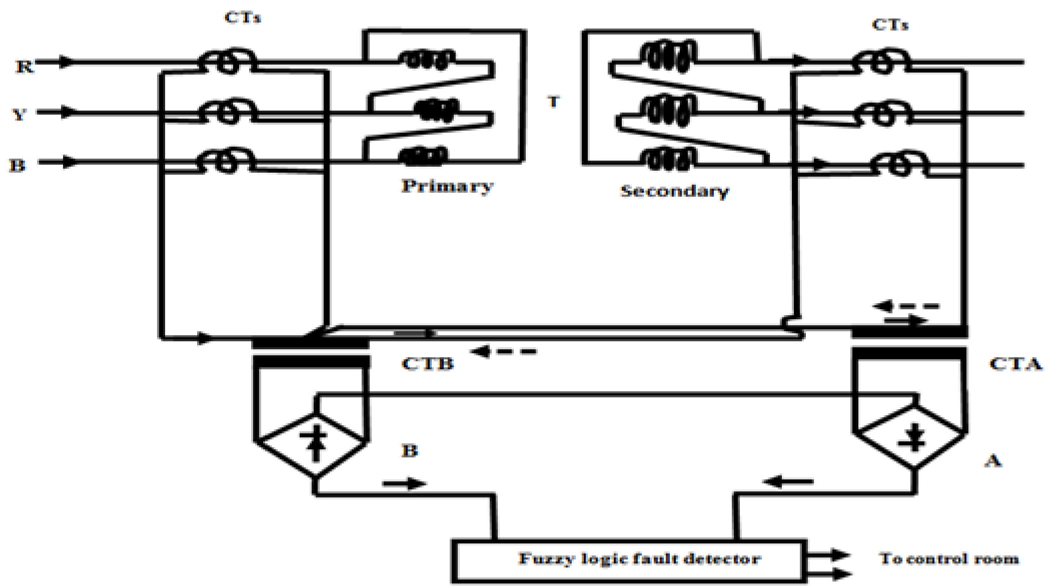

Figure 1: Circuit diagram of a Fuzzy fault detector

CTA = Auxiliary current transformer at operating side.
CTB = Auxiliary current transformer at restraining side.
IA = Operating current.
IB = Restraining current.

The circuit of Figure 1 shows the circulating-current scheme for the protection of a 3-phase delta/delta power transformer against current. Note that the CTs on the two sides of the transformer are connected in star. These compensate for the phase difference between the power transformer primary and secondary. The fuzzy logic fault detector is connected to the current transformer on the power transformer to be protected. Differential relay is equally connected. The currents at both sides of the transformer are compared by the differential circuit. An auxiliary CTA and CTB are connected in the operating and restraining current circuits respectively. The secondary of these auxiliary CTs are connected to the rectifier bridge comparator. The output of the operating auxiliaries CTA and CTB is given to Rectifier Bridge A and B respectively, whose output values give forward currents to the fuzzy logic detector as input1 and input 2.

These input values undergo the process of fuzzification according to the rule structure one after the other. The initial results from each input values are feedback into the system and back to the controller through the rectifier as seen in Figure 1.. Similarly, depending on the number of possible fuzzy rules as, these input values are fuzzified logically to produce output response values, which are combined to produce a crisp output via the controller (fuzzy logic fault detector). The fuzzy logic fault detector will detector the fault and tries to rectify the fault within a pre-set time, but if the fault persist an alarm as well as signal will be send to the control room before the system trips off.

This paper investigates the feasibility of using fuzzy logic method to predict and detect faults at early stage in distribution transformer. The fuzzy logic based detector has been developed to monitor and predict faults at an early stage on particular section of the transformer. The detector for this early warning faults detection device only requires external measurement taken from the input and output nodes of the transformer as shown in Figure 1.

The measurement taken from the transformer will be processed by the fuzzy logic controller available in MATLAB Tool Box.

Generally, fault detection and protection of high voltage transformer using fuzzy logic consist of the following steps.

(i) Identification of input and output variable
(ii) Construction of control rules
(iii) Fuzzification and fuzzy membership functions
(iv) Selection of composition rule of inference
(v) Defuzzification method [8].

The simulation software used in this research is simulink MATLAB. This can be achieved by building the system using the graphical user interface (GUI) tools provided by fuzzy logic tool box.

The five primary graphical user interface GUI tools for building, editing and observing fuzzy inference systems in fuzzy logic tool box in is shown in Figure 2

The fuzzy Inference System Editor (FIS Editor): Handles the high level issues for the system: How many input and output variables? What are their names?

Membership Function Editor: Used to define the shapes of the membership functions associated with each variable.

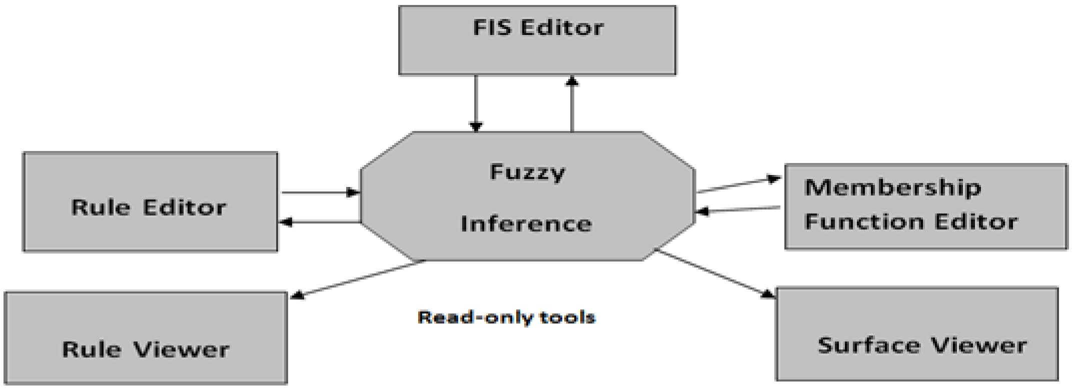

Figure 2: Building Systems with Fuzzy Logic Toolbox

Rule Editor: For editing the list of rules that defines the behaviour of the system.

Rule Viewer and the surface Viewer: Used for looking at, as opposed to editing, the FIS. They are strictly read-only tools. It can show (for example) which rules are active, or how individual membership function shapes are influencing the results. The Surface Viewer is used to display the dependency of one of the outputs on any one or two of the inputs that is, it generates and plots an output surface map for the system. Though it is possible to use fuzzy logic tool box by working strictly from the command line, in general it is much easier to build a system graphically. There are five primary GUI tools for building, editing, and observing fuzzy inference systems in fuzzy logic tool box.

(i) Fuzzify the inputs
(ii) Application of fuzzy operator
(iii) Application of an implication operation
(iv) Aggregate the outputs
(v) Defuzzify the output

IV. Fuzzification

Input variable are assigned degree of membership (u) confidence (CF) or degree of fulfillment in various classes. The fuzzy output sets are aggregated to form a single fuzzy output set.

V. Defuzzification

The output fuzzy set is defuzzified to find the crisp output current, output = centroid (control, aggregation). If ordinary analysis is used instead of the simulation procedure, which is used in this research work, the centre –of-max method should be applied. Here each fuzzy output is taken as the strength or weight at y axis position of the corresponding output membership function. During de-fuzzifciation, each fuzzy output is multiplied by its corresponding maxima of the output membership functions. The sum of these products is divided by the sum of all fuzzy output to obtain the x-axis position [8].

VI. Result Analysis

In this paper the result and simulations are presented as follows:
The fuzzy parameter of Current (error) is modified by the adjectives negative big (nb), negative small (ns), zero (z), positive small (ps) and positive big (pb). This is done by the source code. Error = [-1.5 1.5]. The simulation result of input error (current) is shown in Figure. 3.

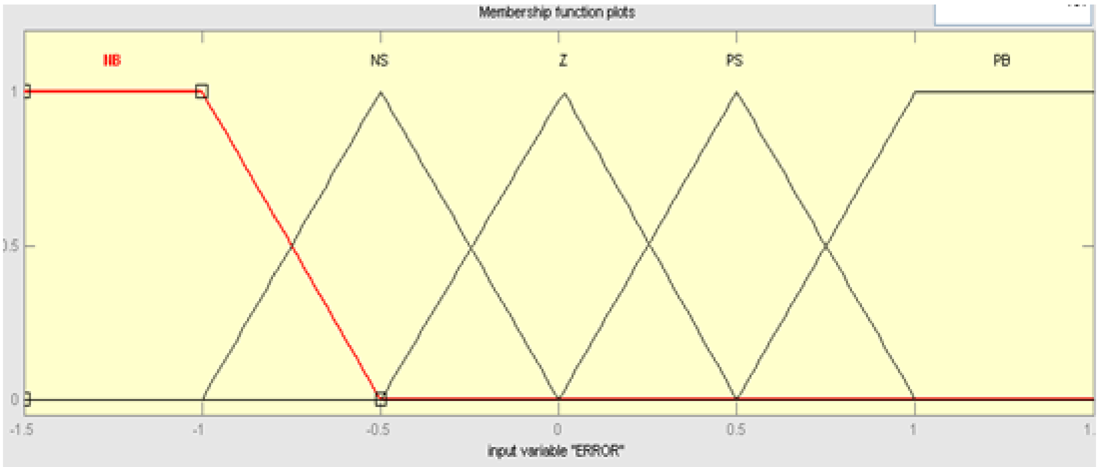

Figure 3: Error Membership Function

The second fuzzy input parameter of the rate of change of error (dele-error) is modified by the linguistic variables positive (p), zero (ze) and negative (n).
Del- error = [-10, 10]
The simulation result of rate of change of current Error-dot is shown in Figure 4.

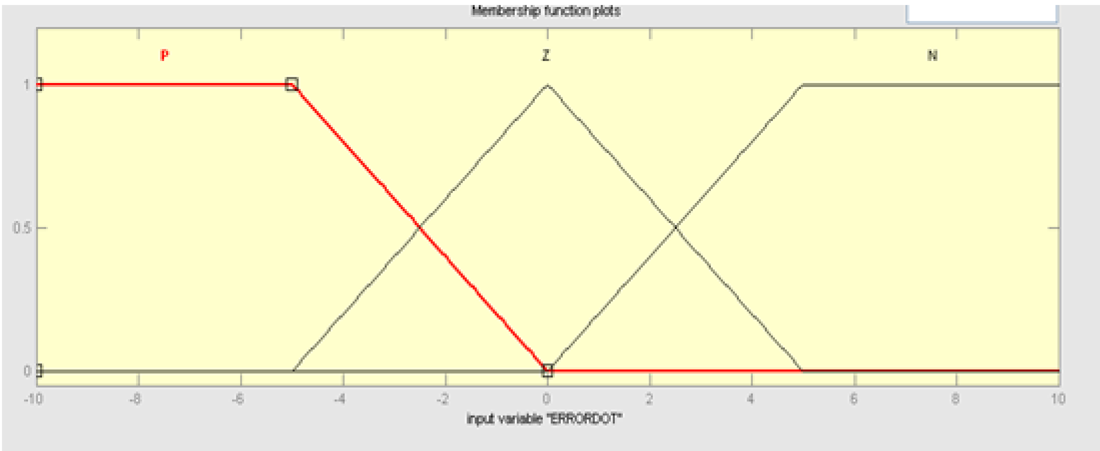

Figure 4: Error-Dot membership functions

The fuzzy Output (‘control current’) is modified by the linguistic variables;
“H” = “High” Output response.
“ NC” = “No change” to current output.
“L” = “Low” Output response.
The simulation result of the consequent of the degree of membership with which the antecedents Error and Error-dot were calculated is shown in Figure 5.

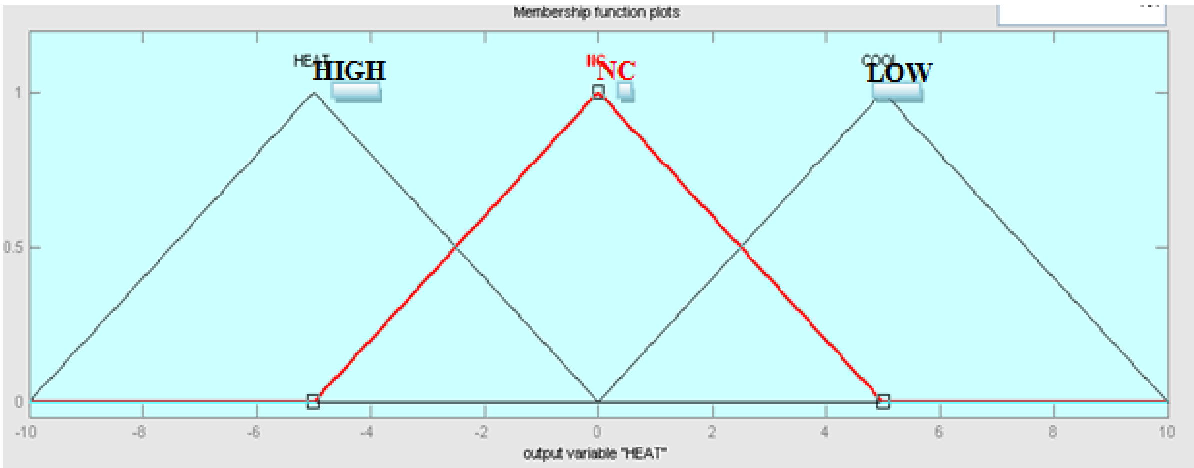

Figure 5: Consequent of Fuzzy rules

The aggregation of fuzzy rule outputs and the crisp output value for current is shown in Figures 6a, 6b and 6c.

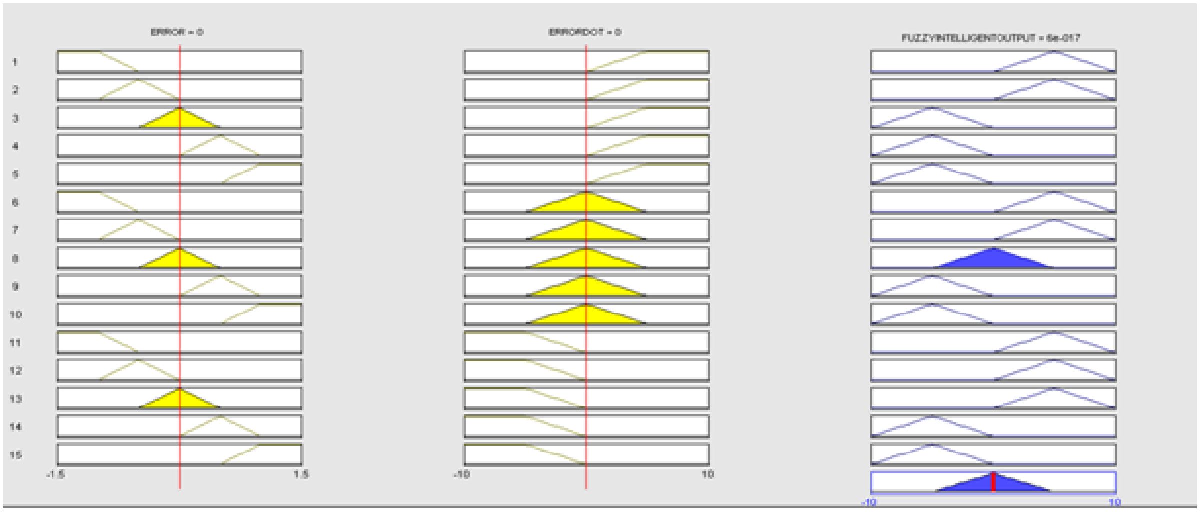

Figure 6a: Aggregate of Fuzzy for “NO CHANGE” Output Response

At input “Error” of [0] and “Error-Dot” of [0], the fuzzy output sets are aggregated to form a single fuzzy output set. These conditions of error and error-dot occur when the Current of the transformer is within the tolerable limit; hence, the system sees no input data and thereby works with zero as input data. The output fuzzy set is defuzzified under this condition to find the crisp output value for the transformer Current to be “6e^{-017}”, which implies that the system is calling for “NO CHANGE” Output response; hence the system is running at a normal current level.
If there is change between the error membership and error-dot membership, then, there exists change at output as shown in Figure 6b.

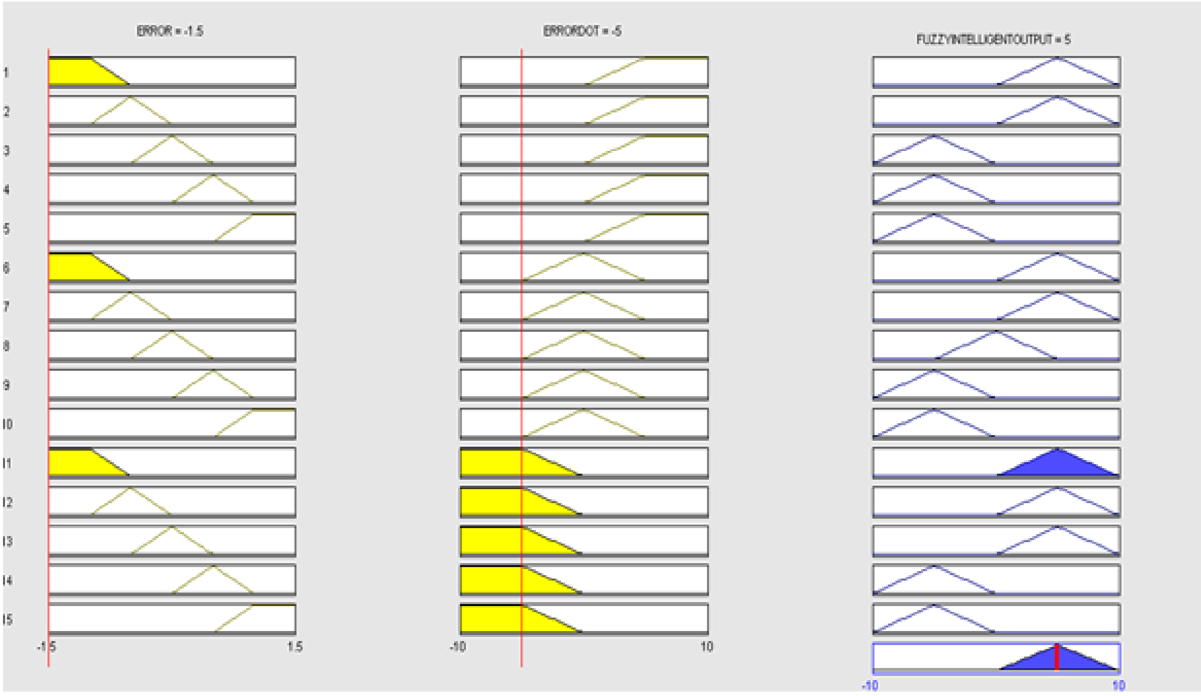

Figure 6b: Aggregate of Fuzzy for "High Current" Output Response

In this result analysis, input "error" = [-1.5] and "error-dot"= [5], after defuzzification, we have a crisp output = "5", which implies that the system is alerting the protection scheme since the Current may be too high.

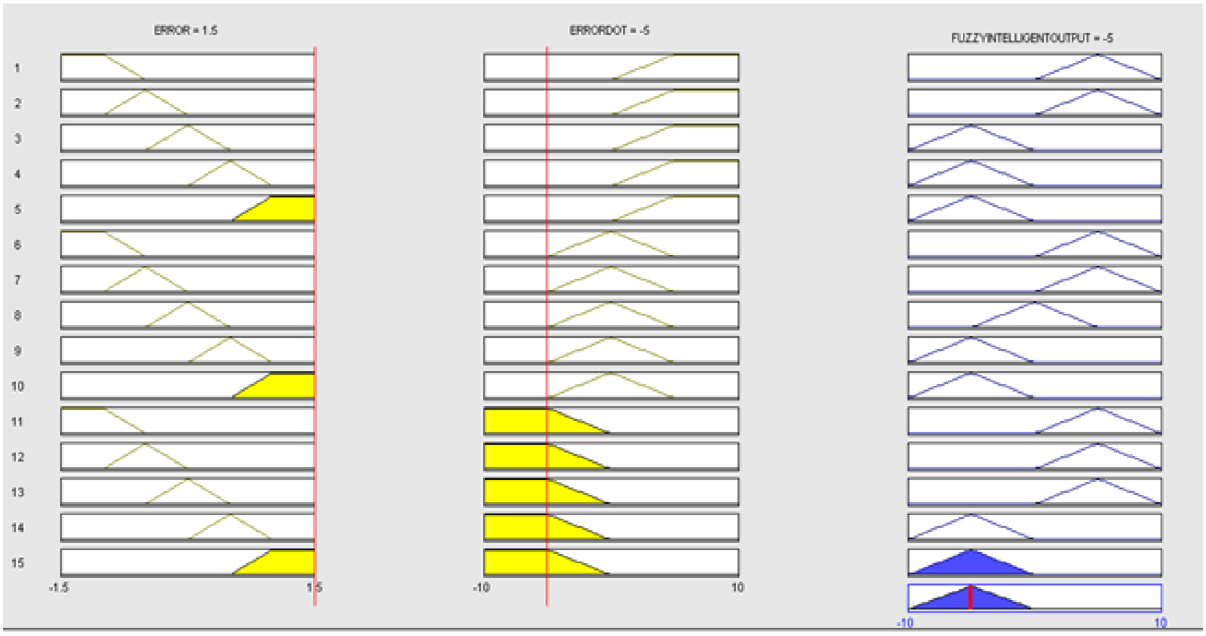

Figure 6c: Aggregate of Fuzzy for "Low Current" Output Response

The simulation result of the input data "1.5" and "-5" from the analysis = "-5", which implies that the transformer is having low current; hence the detector is just notifying the control engineer that the current in the system is low**.**

VII. Conclusion

A fuzzy logic on transformer fault diagnostic system has been designed with two inputs and a single output variable, each having three membership function detector. The accuracy of the fuzzy logic fault detector and protection can also be improved by choosing the appropriate defuzzification scheme for a given problem. The two basic requirement that must be fulfilled by a protection scheme which include rapid and automatic disconnection of the faulty equipment and minimizing the disconnection of the healthy section of the system are inherent in fuzzy scheme, therefore this scheme adds prolonged life to the power system, equipment, and a subsequent reduction in the cost of maintenance. The flexibility offered by the rule paradigm for formalizing thinking is very greater. The comparison between the fuzzy detector and the conventional method reveals the superiority of fuzzy. The fuzzy detector is more sensitive to equipment and the system parameters.

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