Power Transformer Protection by Using Fuzzy Logic

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Abstract

Power transformer protective relay should block the tripping during magnetizing inrush and rapidly operate the tripping during internal faults. Recently, the frequency environment of power system has been made more complicated and the quantity of 2nd frequency component in inrush state has been decreased because of the improvement of core steel. And then, traditional approaches will likely be maloperated in the case of magnetizing inrush with low second harmonic component and internal faults with high second harmonic component. This paper proposes a new relaying algorithm to enhance the fault detection sensitivities of conventional techniques by using a fuzzy logic approach. The proposed fuzzy-based relaying algorithm consists of flux-differential current derivative curve, harmonic restraint, and percentage differential characteristic curve. The proposed relaying was tested with MATLAB simulation software and showed a fast and accurate trip operation.

Keywords — flux-differential current, fuzzy logic, internal faults, magnetizing inrush, power transformer, protective relay.

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الخلاصه

عند حماية محولات القدره, يجب التمييز بين تيار التدفق وتيار الفشل. في الاونه الاخيره تم تطوير امحولات مما ادى الى تقليل التوافقيه الثانيه في تيار التدفق بشكل كبير من خلال التطور الحاصل بالقلب الحديدي. أدى هذا التطور الى الخلط بين قيمة هذه التوافقيه في حالة الفشل وحالة التدفق مما صعب الفصل بين الحالتين. يتناول هذا البحث خوارزميه جديده لتحسين حساسية الكشف عن الخطأ الداخلي للمحوله من خلال المنطق المضبب. تحتوي خوارزمية المرحل المقترح على فيض فرق التيار والتوافقيه الثانيه لفرق التيار ومميزات منحني فرق التيار. تم فحص المحول بأستخدام برامجيات MAT LAB ووجد ان أستجابة المرحل المقترح تكون سريعه.

I. Introduction

The function of power system protective relaying is to initiate the prompt removal of abnormal conditions from service of elements of power system. Since the appearance of microprocessor in the mid-1970s, digital protective relaying has attracted much attention [1]. The power transformer is one of the important elements in power system. Electrical protective relaying of power transformer is based on a percentage differential relaying technique in which transient magnetizing inrush and internal fault must be distinguished [2]. Harmonic-restrained differential relay is based on the fact that the magnetizing inrush current has a large second harmonic component, and nowadays the above technique is widely applied. But this technique must be modified because harmonics occur in a normal state of power system and the quantity of second frequency component in inrush state has been decreased because of the improvement in core steel or the ability to produce EHV under ground cable which increase the capacity of the system [1][6]. There are cases in which the presence of differential currents cannot make a clear distinction between fault and inrush. New relaying technique with high reliability is required for flexibility in spite of change of condition in power system. In the last decade,in order to advance the conventional approaches, several new AI (artificial-intelligence) features for protective relaying have been developed [7-12]. Periz, proposed algorithm based on artificial neural networks [7]. Wisziewski *et al.* suggested differential protective relay based on fuzzy logic [8]. Wavelet-based algorithm is reported [10]. Most of these approaches are liable in the case of magnetizing inrush with low second harmonic component and internal faults with high second harmonic component[3-5]. This paper describes fuzzy logic-based relaying for power transformer protection and includes clear fault discrimination between magnetizing inrush and internal faults. To enhance the fault detection sensitivity of traditional percentage differential current relaying algorithm, fuzzy logic approaches are used. Input variables of the proposed fuzzy based relaying are flux differential current derivative curve, second harmonic restraint, and percentage differential characteristic curve [1,2,11]. To evaluate the performance of the proposed relaying, we used the transformer inrush currents, external fault currents, and internal fault signals, which were sampled with 500 Hz per cycle and obtained from MATLAB simulation software [13,14].

II. Digital Relaying for Power Transformer

The digital protective relaying scheme based on

(1) Flux-Differential Current Slope

Flux-differential current slope method is not affected by remnant flux because it uses the slope of ($d\Phi/di\text{-}i_d$) curve, which can solve problems of prior flux-current method. Flux-differential current slope method is calculated by equation (1)

$$\left(\frac{d\Phi}{di_d}\right)_k = \frac{\left\{\frac{\Delta t}{2}\left(v_{p.k}-v_{p.k-1}\right)-L_p\left(i_{p.k}-i_{p.k-1}\right)\right\}}{\left(i_{p.k}-i_{s.k}\right)-\left(i_{p.k-1}-i_{s.k-1}\right)} \quad \ldots (1)$$

Where subscripts (p) and (s) represent primary and secondary side of power transformer, (Δt) is sampling interval, (i_d) is differential current, and (L_p) is the leakage inductance of the primary winding at k_{th} sample. This approach can be used as a good quantity to discriminate between fault and non fault cases, when it estimated correctly [11].

(2) Second Harmonic for Differential Current

When the transformer is energized high primary current flow through the power transformer as a result of magnetization inrush current condition (this current about 6-10 as a rated current flow in the primary winding only) and the result is high differential current, this current contain high second harmonic component comparing with fundamental component [2]. Because of improving core steel of the power transformer which represent by reducing magnetizing resistance [1], and the probability to produce EHV under ground cable where the capacity of power system increase, the second harmonic component will have very high value in the fault case.[6].

(3) Percentage Differential Principle

Percentage differential principle used to overcome the problem of tap changer, different CT characteristic, and different in length of pilot wire. The characteristic curve of percentage differential take slop between (25-50) [3].

III. Design of Fuzzy Logic-Based Protective Relay

Fuzzy inference is a process that makes a decision in parallel. Because of this property, there is no data loss during the process and so final fault detection will be far more precise than that of conventional relaying techniques.

Fuzzy information approach is used. Fuzzification gives the following results; uncertainty of input relaying signals is quantified and all data contained in input relaying signals are acquired without loss. The rationality of quantified uncertainty and quality of acquired data depends on input and output fuzzy sets [15]. Now, the proposed fuzzy based relaying uses three fuzzy inputs defined as:

I_1 represent the ratio ($d\Phi/di_d$).

I_2 represent 2nd harmonic of differential current.

I_3 represent the ratio between r.m.s value of restraint current to the r.m.s value of operation current (i_r/i_d).

Fig (1) shows the block diagram of the proposed relaying technique.

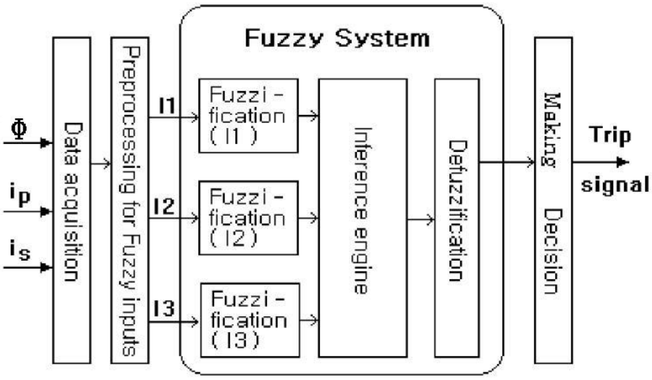

Fig (1) Block Diagram of the Proposed Relaying Technique

IV. Membership Functions of Proposed Approach

A membership function is a function that define how each point in the input space (universe of discourse) is mapped to a membership value varies between 0 and 1. The section of membership function type depend upon the designer experience and the problem under consideration [15], the membership function for power transformer protection approach consist form three group shown in Fig (2).

Where:

- FI_1 represent the membership function of flux differential current slop, which consist from FI_{1S} (Small), FI_{1M} (Medium), and FI_{1L}(Large), as shown in Fig (2a).
- FI_2 represent the membership function of second harmonic differential current, which consist from FI_{2S} (Small), and FI_{2L} (Large), as shown in Fig (2b).
- FI_3 represent membership function of percentage differential current, which consist from FI_{3S} (Small), FI_{3M} (Medium), and FI_{3L} (Large), as shown in Fig (2c).

The output of proposed fuzzy based relaying result from the center of area defuzzification method.

The membership function of the output shown in Fig (3), where it consist from two membership function (Trip, and No Trip), if the value of the output is greater or equal to 2, then the case is trip, and if the value is smaller than 2, then the case is no trip.

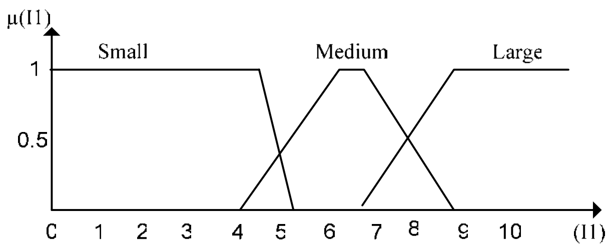

Fig (2a) I1 Fuzzy Membership Functions

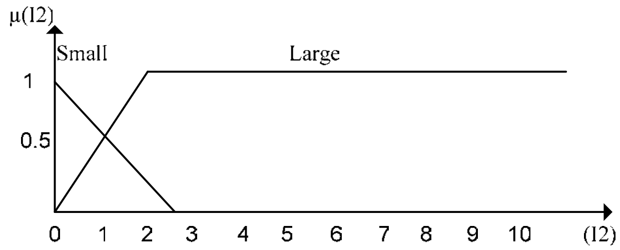

Fig (2b) I2 Fuzzy Membership Functions

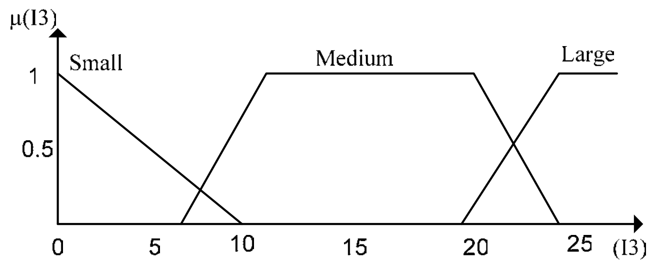

Fig (2c) I3 Fuzzy Membership Functions

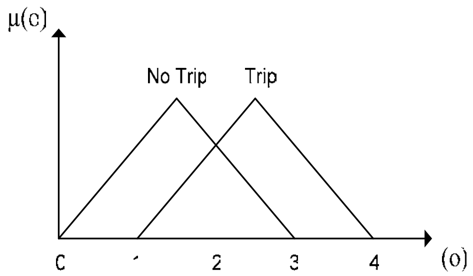

Fig (3) Output Fuzzy Membership Functions

V. Control Rule Base of the Proposed Approach

The control rule base's content is a linguistic description of how the expert will behave to achieve the control function. This linguistic based description take the form IF primes Then consequent rule. Number of fuzzy inference rules for the proposed relaying for transformer protection is 21 rules. All rules consist of two antecedents for input and consequent for the output. The twenty one fuzzy inference rules are classified to three categories depending on the matrix of input variable. In this work, the compositional fuzzy inference matrix were using, where (Max-Min) method is chosen to perform a mathematical operation. The rules are shown in Table (1)

Table (1a) Rule Base of I_1-I_2

I_2 \ I_1	Small	Medium	Large
Small	No Trip	No trip	No trip
Large	Trip	Trip	Trip

Table (1b) Rule Base of I_1-I_3

I_3 \ I_1	Small	Medium	Large
Small	Trip	Trip	No Trip
Medium	No Trip	No trip	No trip
Large	No trip	No trip	No trip

Table (1c) Rule Base of I_2-I_3

I_3 \ I_2	Small	Large
Small	Trip	Trip
Medium	No Trip	Trip
Large	No trip	Trip

VI. Simulation Environment

Modeling and simulation of complex power networks required available diverse software tool. General purpose modeling and simulation tool MATLAB with its toolbox simPower system has been used for the power network modeling [14].The simulation environment based on MATLAB software package is selected as the main engineering tool for performing and simulation of power systems and relays, as well as interfacing the user and appropriate simulation programs, this program also include fuzzy logic control software. In this work power transformer with (500/230) Kv is simulate .

VII. Scenario of Simulation and the Results

The scenario of training and test the proposed approach are generated during nominal power system operating condition by using MATLAB simulation software. Linear load (full load, 0.75 full load, 0.5 full load, and 0.25 full load) and non linear load (with firing angle 30°,60°,and 90°) cases are taken to cover diversity of fault event. When the output of fuzzy logic control is greater or equal to 2 then the output case is trip and when the output is less than 2 then the output case is no trip.

The type of fault that simulated includes.

- Start of operation.
- External single line to ground in the high voltage side.
- External single line to ground in the low voltage side.
- External double line fault in high voltage side.
- External double line fault in low voltage side.
- External double line to ground fault in high voltage side.
- External double line to ground fault in low voltage side.
- External symmetrical fault in high voltage side.
- External symmetrical fault in low voltage side.
- Internal single line to ground in the high voltage side.
- Internal single line to ground in the low voltage side.
- Internal double line fault in high voltage side.
- Internal double line fault in low voltage side.
- Internal double line to ground fault in high voltage side.

- Internal double line to ground fault in low voltage side.
- Internal symmetrical fault in high voltage side.
- Internal symmetrical fault in low voltage side.
- Inter turn fault at 20% of winding in high voltage side.
- Inter turn fault at 20% of winding in low voltage side.
- Transformer earth fault in high voltage side.
- Transformer earth fault in low voltage side.

Simulation example of internal single line to ground fault in high voltage side for 0.25 full load case is taken. Where the input signal to the fuzzy control system and the output signal are shown in Fig (4).

Table (2) explaining the magnitude and time delay for output signal of linear full load case by using fuzzy approach and comparison with another approaches, example of linear full load case shown in Fig (5).

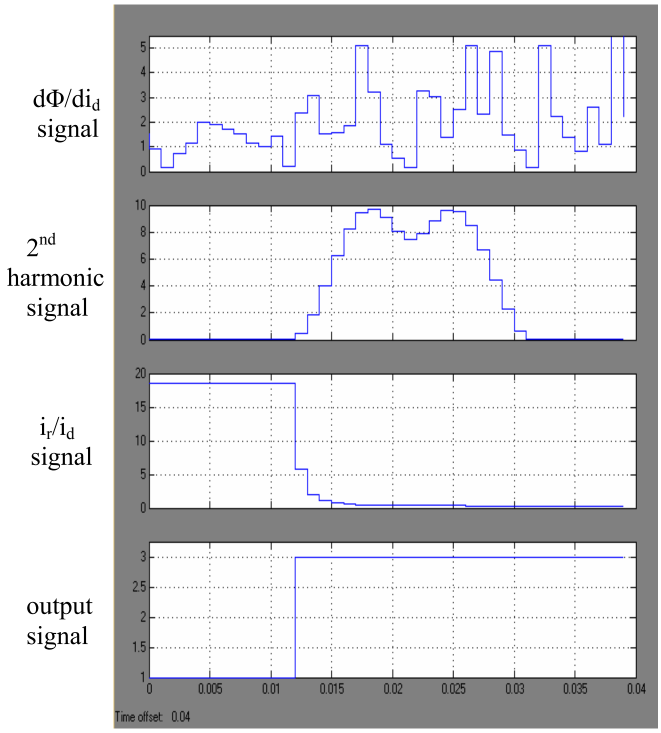

Fig (4) Input and Output Signal to the Fuzzy Control System for Internal Single Line to Ground Fault in High Voltage Side with 0.25 Full Load Case.

Table (2) Results of Simulation for Linear Full Load Case

		Fuzzy Logic		Harmonic Restraint		Flux Restraint		Power Differential	
NO	Output	Output	Time (ms)	Output	Time (ms)	Output	Time (ms)	Output	Time (ms)
1	Start of Operation	No trip	_	Trip	2	No trip	_	No trip	_
2	Ex. L-G in H.V	No trip	_	No trip	_	No trip	_	No trip	_
3	Ex. L-G in L.V	No trip	_	No trip	_	No trip	_	No trip	_
4	Ex. L-L in H.V	No trip	_	No trip	_	No trip	_	No trip	_
5	Ex. L-L in L.V	No trip	_	No trip	_	No trip	_	No trip	_
6	Ex. L-L-G in H.V	No trip	_	No trip	_	No trip	_	No trip	_
7	Ex. L-L-G in L.V	No trip	_	No trip	_	No trip	_	No trip	_
8	Ex. Sym. In H.V	No trip	_	No trip	_	No trip	_	No trip	_
9	Ex. Sym. In L.V	No trip	_	No trip	_	No trip	_	No trip	_
10	In .L-G in H.V	Trip	2	Trip	2	Trip	3	Trip	2
11	In. L-G in L.V	Trip	2	Trip	2	Trip	3	Trip	2
12	In. L-L in H.V	Trip	2	Trip	2	Trip	3	No trip	_
13	In. L-L in L.V	Trip	2	Trip	2	Trip	3	No trip	_
14	In. L-L-G in H.V	Trip	2	Trip	2	Trip	2	No trip	_
15	In. L-L-G in L.V	Trip	2	Trip	2	Trip	3	No trip	_
16	In. Sym. In H.V	Trip	2	Trip	2	Trip	3	No trip	_
17	In. Sym. In L.V	Trip	2	Trip	2	Trip	3	No trip	_
18	Inter turn 20% H.V	Trip	4	Trip	3	Trip	5	Trip	4
19	Inter turn 20% L.V	Trip	4	Trip	3	Trip	5	Trip	5
20	Earth Fault in H.V	Trip	4	Trip	3	Trip	5	Trip	4
21	Earth Fault in L.V	Trip	5	Trip	3	Trip	6	Trip	4

Table (2) shows that the proposed approach has no trip output signal for start of operation and external faults cases, while in cases of internal faults it has trip output signal with delay time (2-5) ms.

Harmonic restraint method [1] has trip output signal for start of operation and internal faults cases with delay time (2-3) ms, with no trip output signal for external faults cases.

Flux Restraint method [11] has no trip output signal for start of operation and external faults cases, while in cases of internal faults it has trip output signal with delay time (3-6) ms.

Power differential method [11] has no trip output signal for start of operation, external faults cases and same cases for internal faults.

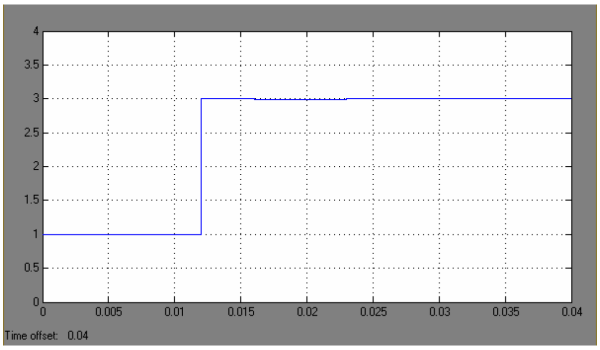

Fig (5) Output Signal for Double Line Fault in Low Voltage Side for Linear Full Load Case, Explained the Trip Signal.

This approach has the properties of good protection relay from speed of operation, sensitivity and reliability, where its has about half cycle as an average to operate , with good sensitive to lees dangerous fault as transformer earth fault in low voltage side with high reliability to discriminate between fault and non fault case.

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