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Modeling and Simulation of Modern Digital Differential Protection Scheme of Power Transformer based on FIS

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Abstract: In this paper, a differential protection schemes using fuzzy inference system (FIS) for power transformer protection is presented. First we review the concept of differential protection, and illustrate the magnetizing inrush current as they belong to the causes of the protection maloperation. Then relay logic and the algorithm that uses Discreet Fourier transformer for extraction of fundamental and higher harmonics components of differential current are presented.

Keywords: Transformer, differential protection, fuzzy rules, inrush current.

1. Conventional Protection Scheme For Power Transformer

Being a vital and expensive component in electrical transmission systems, Power Transformers requires special consideration when it comes to save mal functioning / false tripping of differential protection relay scheme. The Power Transformer protection scheme would be such that it avoid and block the tripping of differential relay during magnetizing inrush & over excitation and should speedily operate the relay tripping during internal faults. For this reason, it is required to choose an appropriate identification scheme which can make a distinction and discriminate the magnetizing inrush over excitation and internal fault current. Percentage restraint differential protective relays have been in service for many years [1]. Figure 1 shows a typical differential relay connection diagram. Differential current, Id, is proportional to the fault current for internal faults and advanced to zero for any other operating (ideal) conditions.

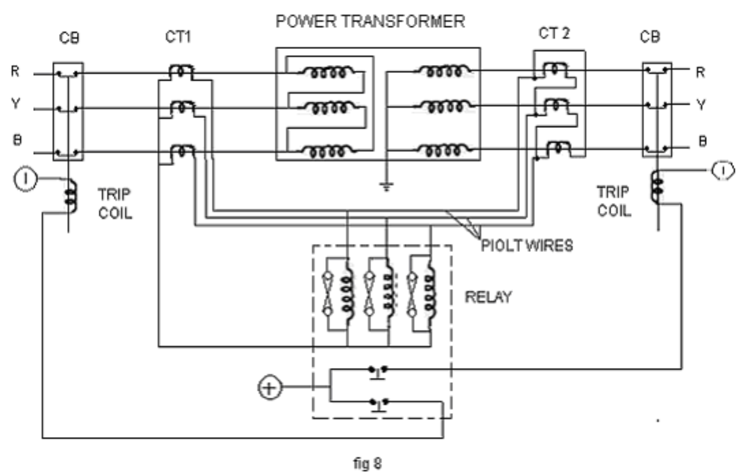

Figure 1 Differential Relay Connection Diagram

2. Cause Of False Differential Current

Certain phenomena can cause a substantial differential current to flow, when there is no fault, and these differential currents are generally sufficient to cause a percentage differential relay to trip. However, in these situations, the differential protection should not disconnect the system because it is not a transformer internal fault. Such phenomena can be due to the non-linearities in the transformer core. Some of these conditions are considered below.

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2.1 Inrush currents

Inrush currents of transformer may be divided into three categories: energization inrush, recovery inrush, and sympathetic inrush. The first, energization inrush, results from the reapplication of system voltage to a transformer which has been earlier de-energized. The second, recovery inrush, occurs when transformer voltage is restored after having been reduced by a nearby short circuit on the system. The third, sympathetic inrush can take place while an unloaded transformer, which is being switched on, encounter an inrush, an adjoining transformer, which is in service, may also experience a smaller degree of inrush. This sympathetic inrush may also occur when two or more transformers are operated in parallel. Offsets in inrush currents can circulate in transformers already energized, which in turn causes a mild inrush.

Energization inrush is the most generally probed form of inrush, and can result in the large current magnitudes. Figure 2 shows the inrush current with and without resonance .When we assume that transformer is switched on at positive zero, even if the initial value of flux is zero but subsequently the flux must have the same rate of change and same wave form as it has in steady state. Thus, the flux must reach a peak value of +2ϕm in half a cycle. Since power transformers operate near the knee of saturation curve, a flux demand of 2ϕm drives the transformer core deep into saturation, causing it to draw a very large magnetising

Magnetizing inrush current in transformers results from any abrupt change of the magnetizing voltage. Although usually considered as a result of energizing a transformer, the magnetizing inrush may be also caused by [2]:

i. Voltage recovery after clearing an external fault.
ii. Occurrence of an external fault.
iii. Out-of-phase synchronizing of a connected generator.
iv. Change of the character of a fault (for example when a phase-to-ground fault evolves into a phase-to-phase-to-ground fault).

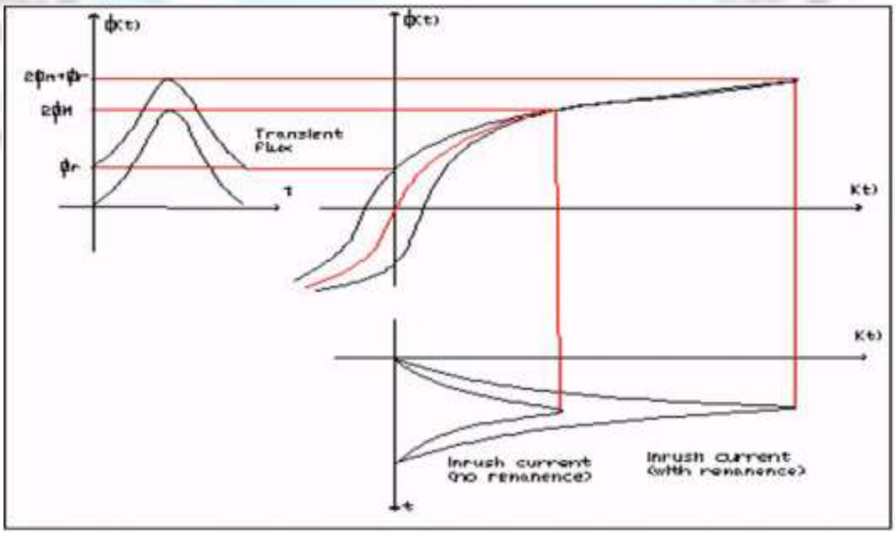

Figure 2 Inrush currents with and without Resonance

Since the magnetizing branch representing the core appears as a shunt element in the transformer equivalent circuit, the magnetizing current upsets the balance between the currents at the transformer terminals, and is therefore experienced by the differential relay as a “false” differential current. The relay, however, must remain stable during inrush conditions. Further, as such high current flows only on one side of the transformer, on the side which is being connected to supply; it looks like an internal fault to the differential scheme and ends up as spill current. The shape, magnitude and duration of inrush current depend on several factors such as size of transformer, Impedance of system from which a transformer is energized, magnetic properties of the core material, remanence in the core, way a transformer is switched in [3].. The problems caused by inrush are unbalance and harmonics.

Other disturbances caused by inrush are: incorrect operation and failures of electrical machines and relay systems, irregular voltage distribution along the transformer windings, high amount of voltage drop at the power system at energization times, electrical and mechanical vibrations among the windings of the transformer.

2.2 Current transformer saturation [4]

The effect of CT saturation on transformer differential protection is double-edged. Although, the percentage restraint reduce the effect of the unbalanced differential current, in the case of an external faults, the resulting differential current which may be of very high magnitude can lead to a relay male-operation.

3. Fuzzy Protection Scheme

In this paper, fuzzy logic is used for internal fault detection in differential protection of power transformers. In this method of protection, algorithm of fault detection is based on ruled out non-internal fault phenomena. For internal fault detection are the criteria for inrush current are defined appropriate membership functions and criteria signals.

This algorithm for protection of power transformers is described followed by a MATLAB/SIMULINK modeling.

Classical (Boolean) logic based on the concept of truth/ falsity cannot effectively cope with the many ambiguities that arise during operation of the power system. Therefore, fuzzy logic is increasingly being used in decision-making, whereas the criteria signals are described by membership functions. The use of fuzzy logic increases the confidence of the decision-making within an area of uncertainty, since the fuzzy logic can deal better (as compared to Boolean logic) with suspense and missing data. In addition, inferencing with multiple objectives in such systems is a natural way of processing information – it is therefore utterly possible to use numerous criteria in parallel [5]. The main idea of action relies on fuzzification of differential current I_d.

4. Relay Algorithm

Modelling and simulation of electric power systems has been a common practice for more than thirty years. Electric power utilities use computer-based relay models to confirm how the relay would perform during systems disturbances and normal operating conditions and to make the necessary corrective adjustment on the relay settings. The basic relay model consists of the following main components:

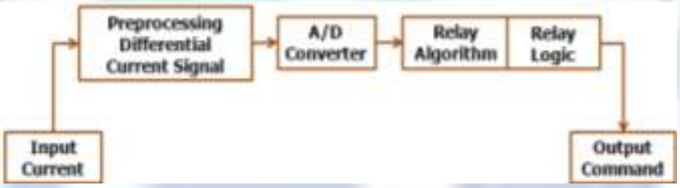

Figure 3 Basic Relay Model

Several algorithms have been proposed in the literature to calculate the fundamental and other harmonics component phasors. These algorithms take sample values of currents as input and provide the fundamental and second harmonic components phasors as output. These algorithms can be classified as

- **i** Least error square approach,
- **ii** Discrete Fourier transform technique,
- **iii** Correlation techniques,
- **iv** Kalman filtering approach.

In the presented algorithm use of Discrete Fourier transform technique is made as Discrete Fourier transformer is a power tool that helps us to extract the fundamental and higher harmonics from differential current. Fourier analysis provides a set of mathematical tools which can be used to break down a signal into its various frequency components [3].

The differential current is analyzed in terms of its Fourier series and the amplitude of each harmonic can be found as follows:

$$f(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} C_k \cos(k\omega t) + S_k \sin(k\omega t)$$

Where: a_0 is the DC component of the f (t), and C_k, S_k are the cosine and sine coefficients of the frequencies present in $f(t)$), respectively. The discrete forms of the coefficientsC_k, S_k are:

$$C_k = \frac{2}{N}\sum_{n=1}^{N-1} x(n)\cos\left(\frac{2k\omega t}{N}\right)$$

$$S_k = \frac{2}{N}\sum_{n=1}^{N-1} x(n)\sin\left(\frac{2k\omega t}{N}\right)$$

The Fourier harmonic coefficients can be expressed as:

$$\mathrm{F}^2{}_{\mathrm{k}} = \sqrt{(\mathrm{S}^2{}_{\mathrm{k}} + \mathrm{C}^2{}_{\mathrm{k}})}$$

Where F_k is the Fourier coefficients, and S_k, C_k are the sinus and cosines of Fourier coefficients.

It should be noted that the following equations are used to calculate the fundamental and second harmonic components of inrush current, where N, T and f are number of samples in each cycle, period and frequency of the power system, respectively. Also, m indicates fundamental and second components with the numbers 1 and 2, respectively.

$$a_m = \sum_{n=1}^{N} \frac{2}{T}\left(\int_{t_n}^{t_{n+1}} i_n.\cos(m.2\pi f.x)\,dx\right.$$

$$b_m = \sum_{n=1}^{N} \frac{2}{T}\left(\int_{t_n}^{t_{n+1}} i_n.\sin(m.2\pi f.x)\,dx\right.$$

$$c_m = \sqrt{{a_m}^2 + {b_m}^2}$$

$$\%\ 2^{\mathrm{nd}}\ \text{harmonic content} = \frac{\mathrm{c}_2}{\mathrm{c}_1} \times 100$$

5. Relay Logic

The relay logic part of the scheme accepts the phasor current values of the fundamental and second harmonic components from the relay algorithm. Based on theses phasors, a trip decision is made. The trip decision is based on the relative amplitude of the fundamental component compared to the second harmonic components. Past Research has shown that magnetizing inrush produces current with a high second harmonics content, i.e., second harmonic component, F_2, is higher than F_1 for magnetizing inrush current [6]. Based on above fact, the discrimination between fault current and magnetizing inrush current has been made.

The multi-criteria differential relay using the fuzzy logic approach is applied to protective relaying.

In this technique:

i The criteria signals (amplitudes, harmonic contents) are fuzzified in order to account for dynamic errors of the measuring algorithms. Thus, instead of real numbers, the signals are represented by fuzzy numbers. Since the fuzzification process provides a special kind of flexible filtering, faster measuring algorithms that speed up the operation of protective relays may be used.

ii The thresholds for the criteria signals are also represented by fuzzy numbers to account for the lack of precision in dividing the space of the criteria signal between the tripping and blocking regions.

iii The fuzzy signals are compared with the fuzzy settings. The comparison result is a fuzzy logic variable between the Boolean absolute levels of truth and false.

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- iv Several relaying criteria are used in parallel. The criteria are aggregated by means of formal multicriteria decision-making algorithms that allow the criteria to be assigned a weight according to the reasoning ability.
- v The tripping decision depends on the multi-criteria evaluation of the status of a protected element (steady state vs. faulty).

The relay will sense the occurrence of magnetizing inrush current if the value of 2^{nd} harmonics component in differential current exceeds the predetermined value and will avoid/block the tripping of CBs.

6. Simulation And Results

For analysis purpose the data from a 10MVA, 11/132kV, 50Hz, star/star connected Power Transformer is used in this system. The implementation is done using Matlab/Simulink environment. Figure 4 shows the simulated power system built in Matlab/Simulink environment

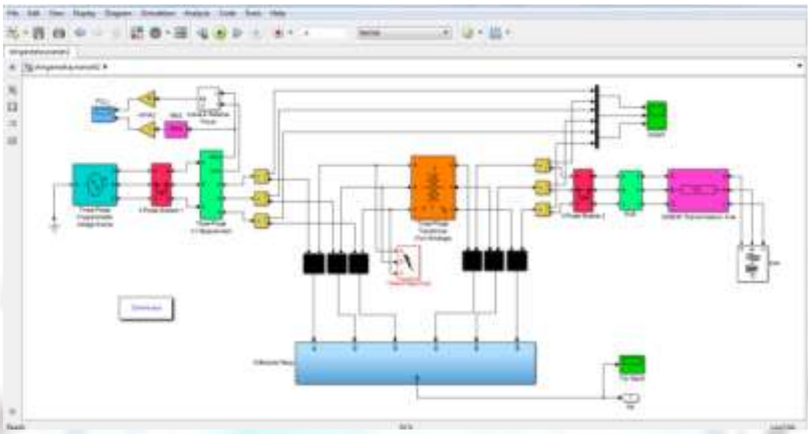

Figure 4: Matlab/Simulink Model of the proposed system

The results will be given for different cases. Two cases are considered here: -

1. Internal fault.
2. Inrush current condition

Case 1: Internal Fault:

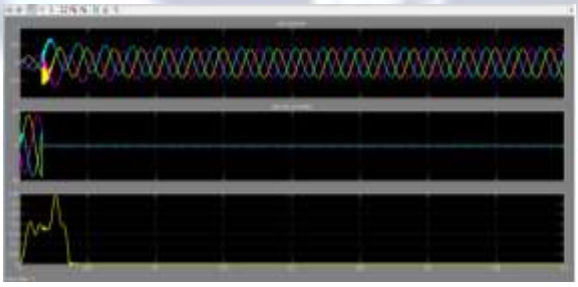

Figure 5 (a) Three phase fault at the primary side of transformer.

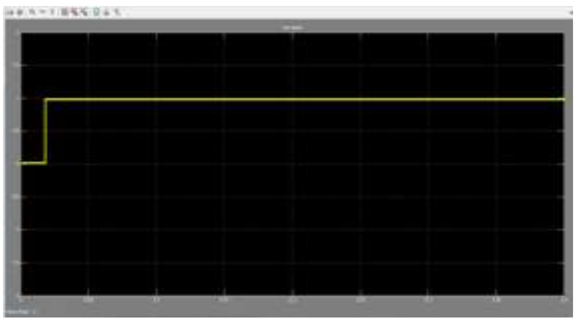

Figure 5 (b) Relay Output/Trip Signal

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- Figure 5 (a) shows the internal fault (three phase fault) at the primary side of the power transformer
- And the Figure 5 (b) shows the relay output.
- In the faulty condition it attains the value above the threshold value.
- So it gives the trip signal to the circuit breaker.

Case 2: Inrush Current Condition

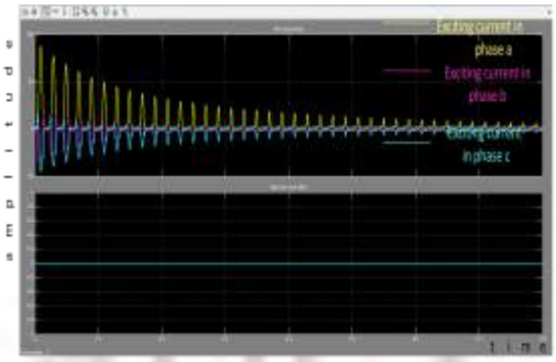

Figure 6 (a) Primary side current and secondary side current of transformer

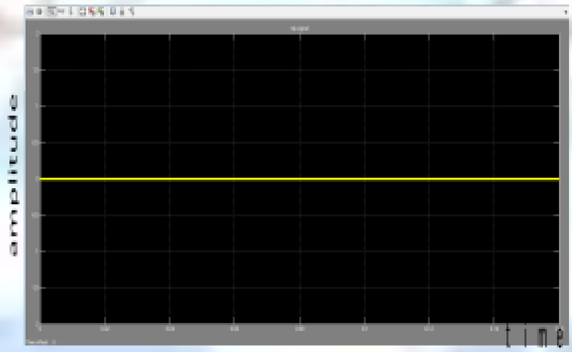

Figure 6 (b) Relay Output/Trip Signal

- Figure 6 (a) shows the transformer Magnetizing Inrush currents transients in the primary side and secondary side current during energization of the transformer without any load.
    - And Figure 6 (b) shows the relay output.
    - This is not a case of internal/permanent fault. So no trip signal should be released.
    - From Figure 6 (b), the value zero concludes that in the case of magnetizing inrush current the proposed relay is not giving any trip signal to the circuit breaker.
    - Thus it is observed that the proposed technique is deterministic.

Simulation Results of Relay

Table 5.4 Summary of the performance of the designed differential relay at different cases

Various Cases	Corresponding Figure	Relay Output
Internal Fault	Figure 5 (b)	Trip
Magnetizing Inrush Current	Figure 6 (b)	No Trip

7. Conclusion

In this paper, the design and implementation of a differential transformer protection based on fuzzy inference system is presented. The current signals for different cases for a power transformer are obtained using MATLAB/SIMULINK. With the use of proposed algorithm/technique, it is possible to distinguish between fault current and false differential current. The criteria have been aggregated and combined in order to generate more reliable tripping signal.

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