A NEW METHOD TO IDENTIFY FAULT CURRENT AND INRUSH CURRENT ON TRANSFORMER BY JILES–ATHERTON MODEL

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ABSTRACT. This paper proposes a new method to detect transformer inside incipient fault current using transformer internal parameters to determine the inside structure of transformer at good condition or bad. A transformer model was established by Jiles–Atherton theory using measured voltage and current and the initial parameters which were found using Genetic Algorithm (GA). Then, transformer internal parameters $k$ and $c$ can be estimated using Simplex method to easily differentiate inrush currents and incipient fault currents.

Keywords: Transformer, Jiles–Atherton theory, Genetic algorithm, Inrush current, Incipient fault

1. Introduction. Transformer which is one of the important equipments of power system can reduce the loss of power delivery and also the most fragile due to protecting the safety of generators and loads. It would spend unnecessary cost taking apart transformers to predict the cause of fault. Inside fault of transformer includes faults of arrester, potential transformer (PT), Insulated phase bus duct (IPBD), etc. The faults include two types: an active fault and an incipient fault. The active fault means transformer or other related equipments immediately breakdown or malfunction. The incipient fault means partial weakness due to over heat, over excitation or over pressure of gases dissolved in transformer oil when transformer works. The weakness will slowly and continuously deteriorate to breakdown. Active faults can trigger the protection like differential relay or overcurrent relay but incipient fault current is too small to trigger relays and to be detected. The weakness could deteriorate to make disintegration if it cannot be detected and repaired.

Therefore, this study proposes a new method to identify inrush currents and incipient fault currents to detect transformer fault/deformation [1]. The parameters $k$ and $c$ are the most apparent difference of parameters and we can accurately and easily identify inrush current and fault current to differentiate transformer fault/deformation or not. Among the published papers, a method discriminates the inrush current from the internal fault current by comparing the similarity between the actual wave and tow reference waves under two different frequency conditions per each half cycle [2]. A Wavelet-Based method to identify inrush currents and fault currents by extracting the wavelet components contained in the three line currents using data window less than half power frequency cycle [3]. All aim to identify inrush current and fault current and so do this paper.

2. Jiles–Atherton Model. All ferro-magnetic materials have hysteresis character and it can be analyzed by the characteristics of ferro-magnetic materials, example Jiles–Atherton
model. The entire J-A model contains five significant material parameters, which are saturation magnetization, unit volume pinning location density constant, reversible magnetization constant, anhysteresis curve constant, and magnetic domains coupling constant.

A. Reversible component and irreversible component

The J–A theory of ferromagnetic hysteresis decomposes the magnetization $M$ into its reversible component, $M_{\text{rev}}$ and irreversible component, $M_{\text{irr}}$. The magnetization $M$ equals to summation of reversible component, $M_{\text{rev}}$ and irreversible component, $M_{\text{irr}}$ [4].

\[ M = M_{\text{rev}} + M_{\text{irr}} \]  

Then, calculated by effective field $H$ as follows

\[ \frac{dM}{dH} = \frac{dM_{\text{irr}}}{dH} + \frac{dM_{\text{rev}}}{dH} \]  

B. Hysteretic equation of Jiles-Atherton

The effective magnetic field $H_e$ and flux density $\beta$ of ferromagnetic material can be presented by

\[ H_e = H + \alpha M \]  

where $H$ is the magnetization force in the core, $\alpha$ is an interdomain coupling factor, and $\mu_0$ is the permeability of free space. The anhysteretic magnetization $M_{\text{an}}$ is given by the Langevin function.

\[ M_{\text{an}} = M_s \left( \coth \frac{H_e}{a} - \frac{a}{H_e} \right) \]  

\[ \frac{dM_{\text{an}}}{dH_e} = M_s \left( -\frac{\csch^2 H_e}{a} + \frac{a}{H_e^2} \right) \]  

\[ M_{\text{irr}} = \frac{1}{1-c} M - \frac{c}{1-c} M_{\text{an}} \]  

\[ \frac{dM_{\text{irr}}}{dH} = \frac{\delta_m (M_{\text{an}} - M_{\text{irr}})}{k \delta - \alpha (M_{\text{an}} - M_{\text{irr}})}, \text{ for} \]

\[ \delta_m = \begin{cases} 1 : \text{ if } dH/dt > 0 \text{ and } M_{\text{an}} > M_{\text{irr}} \\ 1 : \text{ if } dH/dt < 0 \text{ and } M_{\text{an}} < M_{\text{irr}} \\ 0 : \text{ otherwise} \end{cases} \]

\[ \delta = \begin{cases} 1 : \text{ if } dH/dt > 0 \\ -1 : \text{ if } dH/dt < 0 \\ 0 : \text{ if } dH/dt = 0 \end{cases} \]  

There are five parameters of Jiles-Atherton model: $M_s$ is saturation magnetization (Amp/meter); $\alpha$ is experimental parameter, is an inter-domain coupling factor; $k$ is hysteresis domain wall constant (Amp/meter); $c$ is bowing parameter of hysteresis domain wall.

3. Value Optimization. The advantage of Jiles-Atherton Model is sample to install with just five parameters which are estimated by Genetic Algorithm.

1. Genetic Algorithm

A Genetic Algorithm (GA) which was developed by J. H. Holland [5], University of Michigan, imitates the natural law of ‘survival of the fittest’ and is stochastic search technique based on natural selection and natural genetics. The random search can gradually represent the optimum solution to the problem. Figure 1 presents the genetic algorithm computation flow chart [6-8].
4. **Experiment Methods.** We measured voltage (V) and current (I) of an 11kV/20MVA three-phase transformer manufactured in 1965 when inrush current occurred to estimate transformer internal parameters, $a$, $\alpha$, $Ms$, $c$, $k$ to determine inrush current or fault current.

**A. Jiles-Atherton model setup**

The initial values of *Jiles-Atherton model* are found by GA. Table 1 presents the five initial values, $a$, $\alpha$, $Ms$, $c$, $k$.

<table>
<thead>
<tr>
<th>$a$ (A/m)</th>
<th>$Ms$ (A/m)</th>
<th>$k$ (A/m)</th>
<th>$\alpha$</th>
<th>$c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>1.34e6</td>
<td>60</td>
<td>8e-5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Figure 2.** Simulation of B and M in Jiles-Atherton model

The Figure 2~4 show the results in 10 periods of simulating the inrush current, incipient fault current, hysteresis curve by Jiles-Atherton model.

The initial parameters are found by GA and then calculated by Simplex algorithm with measured voltage and current of the 11kV/20MVA three-phase transformer.

**B. Value optimization-Simplex algorithm**

We defined the five parameters first and catch the maximum, minimum, and three non-zero values, five values totally of each parameter. ($a_1 \ldots a_5$, $\alpha_1 \ldots \alpha_5$, $Ms_1 \ldots Ms_5$, $c_1 \ldots c_5$).
Figure 3. Inrush current simulation in Jiles-Atherton model

Figure 4. Determination of Jiles-Atherton model parameters \((a, \alpha, M_s, c, k)\)

c1...c5, k1...k5). Then, we average each value of parameters to next cycle calculation by Matlab \((\bar{a}, \bar{\alpha}, \bar{M_s}, \bar{c}, \bar{k})\). The flow chart is shown in Figure 5.

Three-phase transformer
Voltage(V)
Current(I)

Average three values of each parameter (all \(a, \alpha, M_s, c, k\))

Determine the value is zero or not

Each parameter averaging

Calculate 50 times \(n=50\)

STOP

Figure 5. Simplex algorithm follow chart
5. **Simulation Results.** The inrush current may cause protective relay operating to result outage of power. On the other hand, the incipient fault currents are smaller than sensibility of protective relay and damage the transformer immediately. Therefore, we analyze parameters of inrush current and incipient fault current to determine of them. Figure 6 and 7 shows the difference between inrush current and incipient fault current.

Figure 7 shows the simulating results and the difference between inrush current and incipient fault current can be easily observed. Among the five parameters, parameter $k$, hysteresis domain wall constant (Amp/meter), and parameter $c$, bowing parameter of hysteresis domain wall, are large changing that we determine the two parameters are the major factors to influence curves.

The numerical experiments indicated that the parameter $k$ of inrush current without incipient fault current or with 10% incipient fault current increases progressively after 50 times calculations. Oppositely, when incipient fault current is 30%, 50%, 80%, and 100%, parameter $k$ decreases progressively as in Figure 8 shown. We can also observe that parameter $c$ of inrush current without incipient fault current or with 10% fault current is almost zero, but it is larger than zero when incipient fault current is 30%, 50%, 80%, 100% as Figure 9 shown. We can determine inrush current and incipient fault current by rules above.

![Figure 6. Inrush current and incipient fault current curves](image1)

![Figure 7. Magnetic hysteresis of inrush current and incipient fault current](image2)

6. **Conclusions.** This paper proposes a new method of simulating transformer internal parameters of $a$, $\alpha$, $Ms$, $c$, $k$ based on voltage and current to detect transformer incipient fault current. The simulation also showed the difference of parameters resulted by inrush
The parameter $k$ of inrush current with 100%, 80%, 50%, 30%, 10% fault current increases progressively after cycling calculations and is very small near zero. Parameter $k$ of incipient fault current (30%-100% incipient fault current) decrease progressively and $c$ is larger than inrush current’s. Therefore, we can identify it is incipient fault current if the inrush current has over 10% incipient fault current.

REFERENCES