A Novel Technique for Power Transformer Protection based on Combined Wavelet Transformer and Neural Network

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Abstract – This paper present accurate discrimination between internal fault an internal fault and magnetizing inrush current in power Transformer by using combined wavelet transformer and neural network. Here Wavelet Transformer first applied to decompose the differential current signal of power transformer into series of detailed wavelet component. The spectral energy of the entire detailed component is calculate and given input for training the neural network to discriminate an internal fault from the magnetizing inrush current. Simulated result show the proposed technique can accurately discriminate between internal fault and magnetizing inrush current protection.

Keywords – protection, fault detection, magnetizing inrush current, wavelet transformer, artificial neural network.

I. INTRODUCTION

Power transformer is one of the most important class and very expensive element in power system and transformer protection is essential part of overall power system. Since it is very important minimize the frequency and duration unwanted outage so today there is lots of demand on power system protective relay. This include dependability associated with no mal-operation, security associated with no false tripping and operating speed associated with short time for fault clearing time. Design of protective relay has considered various non linear effects, which may malfunction of relay equipment .the most common method of transformer protection is percentage differential relay is primary protection. Discrimination between inrush current and internal fault current is long being challenging task since a magnetizing inrush current contain generally a large second harmonic comparison to internal fault current in modern large transformer because of CT saturation or presence of the shunt capacitor or distributive capacitance in long EHV transmission line to which transformer may be connected .in certain case the magnitude second harmonic current value in internal fault current is can be close to or greater than that present in magnetizing inrush current Moreover, the second harmonic component in magnetizing inrush current tends to be relatively small in modern large transformer because improvement in power transformer core material.[2]-[8] Consequently, the commonly employed conventional differential current protection based on second harmonic restraint will thus have difficulty in distinguished between internal fault and inrush current. thereby threatening transformer stability. Alternatively improved protection techniques for accurately and effectively discriminating between internal fault and inrush current thus have to found. Recently, ANN technique has been applied for power transformer protection because its capability of highly non linear mapping features. But in these proposed method the extraction technique are based on time or frequency domain signal, but it is very important to extract both time and frequency feature of signal for accurate discrimination between internal fault and other operating condition. Moreover to improve system performance is chosen for analyzing power transformer transient because it have good ability to extract information from transient signal in term of both time and frequency domain.[2]-[10]

The wavelet transformer is a relatively new power full tool in analyzing power transformer transient phenomena because its ability to acquire information from the transient signal both in time and frequency domain[11]-[12] .recently wavelet transformer have been applied to analyzed the power system transient as well as, power quality, fault detection problem. wavelet transformer and ANN was successfully employed in
power system application especially in discrimination of different transient phenomena in power transformer.[2]-[10]

The technique is to discriminate between an internal fault and other operating condition of power transformer by combining wavelet transformer is firstly applied to decomposed the differential current signal into detailed coefficient the spectral energy of the detailed coefficient is calculated the input given to neural network for training.

II. SIMULATION OF ENERGIZATION TRANSIENTS

A typical 750MVA, 27/420KV, Dy11Power transformer is connected between 25KV source at sending end 400 KV transmission line three phase connection diagram are shown in Fig.1(a)and (b), respectively in Fig.1(b) Iαd, Iβd, Iγd refer to a, b, c three phase differential current through CT secondary side; n1, n2 are the number turn on the low voltage (LV) and high voltage on (HV) the simulation of these power transformer is carried out using MATLAB software which is Shown in Fig1(c) in each simulation of the system parameter are varied including the fault type fault position, fault inception angle, remnant flux in power transformer core, and also the effect of CT saturation is also studied.

III. IMPLEMENTATION OF WAVELET TRANSFORM

The Frequency analysis can be an effective technique to analyze and classify signal with complex characteristic. Such effective analysis is achieved by employing new and efficient signal processing tools the tradition Frequency analysis tool is based on stationary and periodicity. However disturbance in the power system is non periodic, non stationary, short duration and impulsive in nature. the wavelet analysis is one of newly applied frequency analysis tool. For processing signal with complex characteristic there are many types of mother wavelets such as Harr, Daubechies, Coiflet, and symmlet wavelet the choice of mother wavelet play significant role in detecting and localizing different type of fault transient.
interested in detecting and analyzing the low amplitude short duration fast decaying and oscillating type of high frequency current signal one of the most popular type of mother wavelet suitable for wide range application used is Daubechies wavelet and the 1,2...10 is the order of the Daubechies, Haar wavelet is First order Daubechies. in this paper as we are interested in detecting and analyzing low amplitude, short duration, fast decaying and non continuous oscillating type of high frequency current therefore db4 used as mother wavelet [11]-[12].

![Fig. 2: Implementation of DWT.](image)

The most common implementation Procedure of DWT (Discrete Wavelet Transform) which is illustrate in Fig.2 in which x[n] is original signal h[n] and g[n] are high pass and low pass filter, respectively, the original signal divide into two halves of frequency bandwidth and sent to high pass filter and low pass filter then output of low pass filter is further cut again in two half of the frequency bandwidth and send to further stage this procedure repeated until signal decompose to predefined level. all the set of signal represent the original signal, but all correspond to different frequency bands. Frequency band of each detailed of the DWT is directly related sampling rate of original signal is being sampled at Fs Hz, the highest frequency that the signal could contain from Nyquist’s Theorem, would be Fs/2 Hz. Band frequency capture for detailed 1 is In between Fs/2 and Fs/4 similarly Band frequency capture for detailed 2 is In between Fs/4 and Fs/8 so on.

A. Wavelet Transformer of Inrush Current

Transformer is energized in light load condition a transient magnetizing inrush current flow in primary side. The current may be reached several times a, b and c three phase differential current through CT Secondary side of power transformer as can be seen the current waveform distorted significantly, gap is appear over the time inrush currents. The current contain high D.C. component of current so the waveform is unidirectional in nature. the above decomposition is done when core is saturate and energized at lowest angle. at the edges of gap the current magnitude changes sudden zero to significant value or significant value to zero this is expected fact that the change from one state to different state produce the small ripple, which is not visible due to only large fundamental frequency signal is apparent

![Fig.3: 5 successive detail and approximation for inrush current](image)

In Fig.3. (detail 1) these phenomena is clearly demonstrate by wavelet transform. For brevity, only DWT of the a-phase differential current shown herein. For implementation of DWT original signal is sampled at 50 kHz and passed through the DWT based on structure shown in Fig.2. five detailed signal that contain frequency band of 25kHu12.5kH
frequency domain the low frequency component located better than higher frequency component. In this study we are interested employed detail 1-3 for analysis and feature extraction from detail 1-3 large number of spike during the period of inrush current transient. The ripple here because of two reason first is change in state of edges from high to low, and low to high and second is primary winding connected to delta so that the differential current of phase a is difference between a and c phase this cause non smooth point in current waveform. Which causes sharp spike appears in the DWT of current waveforms. But here, for this simulation we have taking variable transport delay to avoid phase shift in between delta star transformer.

B. Wavelet Transform of Internal Fault Current

Fig. 4 typifies current signal for an internal fault, and correspond to a, b and c three phase differential current through CT side under an a-b internal fault on high voltage side of the power. It is seen from Fig. 4 that high frequency distortion in the current waveform this is direct consequence of the effect of the distributed inductance and capacitance of transmission line. So this can be lead to significant second harmonic in internal fault, so thereby it is difficulty inaccurate discrimination between magnetizing inrush and internal fault current by conventional method of protection. For brevity, only the DWT of a phase presented here see Fig. a5-d1 these correspond to detail 1-3of the DWT and it can be seen that there is spike appearing immediately following the fault inception time however, in contrast to inrush current case, these sharp spike decay near to zero within one cycle. Whereas that sharp spike associated with inrush current suffer from little attenuation during entire transient period, which last from 10 cycles for small transformer to 1 min large unit. It is apparent that this difference can be effectively used as the key feature to distinguish the internal fault from inrush current.

C. Wavelet Transformer of External Fault Current with CT Saturation

A relay is designed restraint under normal and external fault current condition. However, external short circuit can in fact result in very large differential current if CTs saturate. It is difficult to ascertain CT saturation effect on the measured current under external fault. The severity of CT saturation is higher in the presence of residual flux in CT core. Fig. 5 show the simulated differential current waveform (through the CT secondary sides) for an external three phase short circuit, which occur beyond the line here the assumption is that there residual flux (65% rated flux) in a-phase CT core on low voltage side and zero residual flux on high voltage side. So that effect there is a significant imbalance current appearing in a-phase differential current. From detail 1-3 DWT it can be seen the several sharp spike during entire period of saturation of transient, which depend upon D.C. component and the residual flux of CT core. However, unlike the case for inrush current these burst spike clustered very close to each other again here it is the unique feature that can be used to discriminate the internal fault and external fault under CT saturation.

Fig. 4: 5-succeesive detail and approximation for a-b two phase to earth fault on high voltage side.
IV. ARCHITECTURE OF NEURAL NETWORK

A. Selection of Neural Network Input

The set of input data organized in form of moving data window with a fixed window length half cycle. It is not practical to directly use window wavelet to input to ANN. Because it causes large number input to ANN (large size of ANN), thereby causing difficulty in ANN convergence. So in this approach spectral energy of wavelet signal is calculated within time length $\Delta t$; this not only reduces ANN size, but also retain important feature of wavelet signal in this study, the data window is divide into 3 equal time period to calculate the spectral energy and hence 9 sample obtain from each phase of detail 1-3, thus for three phase, there are total 27 inputs that are fed into the ANN.

B. Neural Network Training and Structure

ANN is exact simulation of real nervous system a multi layered feed forward network consist of one input layer ,an output layer one or more hidden layer between its input and output layer each layer consist of number of neuron back propagation neural network commonly used for training multi layered FFNN it can be used complex matching pattern problem.[13]

Network learn a pre-defined set of input -output Training pair, the applied input pattern to the first layer propagates through each upper layer until output is generated these output is compare with desire output a error signal is computed for each output unit .the error signal are then transmitted Backward from the output layer of each node in intermediate layer. This process repeat layer by layer Based on error signal is received, the connection weights are updated to cause the network converge toward the state that allow to all training pattern to be encoded with the 27 input, the target output of ANN was built in such way that the value 1 represent internal fault; the value -1 represent magnetizing inrush current or external fault.

One of the most critical problems in constructing the ANN is the choice of number hidden layer and numbers of neuron for each layer. Using too few hidden layer may prevent the training process to converge, and using too many neurons would produce long training time, and/or result of ANN lose generalization attribute. In this study number of Test is performed varying the one or two hidden layer as well as varying neuron in hidden layer table I show architecture tested for this purpose, from it 5 neuron in first hidden layer 4neuron in second hidden layer is give best performance.

<table>
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<th>ANN SIZE</th>
<th>ERROR</th>
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<tr>
<td>27/5/1</td>
<td>0.1230</td>
</tr>
<tr>
<td>27/12/1</td>
<td>0.0420</td>
</tr>
<tr>
<td>27/20/1</td>
<td>0.0405</td>
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</tr>
<tr>
<td>27/9/4/1</td>
<td>0.0365</td>
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</tbody>
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Fig.6 : Relay logic based on wavelet transformer and neural network
V. PROTECTION TECHNIQUE

The proposed relay logic for distinguished an internal fault from a magnetizing inrush current by combining the wavelet with neural network is shown in Fig.6. the relay is operating when the one of the phase of differential current increase predefined threshold. Thus the a, b, and c three phase wavelet signal, i.e. $I_{a\text{-det1}}$, $I_{a\text{-det2}}$, $I_{a\text{-det3}}$ at detail 1-3 for a phase, i.e. $I_{b\text{-det1}}$, $I_{b\text{-det2}}$, $I_{b\text{-det3}}$ at detail 1-3 for b phase, i.e. $I_{c\text{-det1}}$, $I_{c\text{-det2}}$, $I_{c\text{-det3}}$ at detail 1-3 for c phase are obtained then the spectral energy of wavelet signal is calculated by the following equation.

$$P_a - \text{det} \ i = \sum_{k=1}^{n} I_{a\text{-det} i}^2 - (k)\Delta t ;$$

$$P_b - \text{det} \ i = \sum_{k=1}^{n} I_{b\text{-det} i}^2 - (k)\Delta t ;$$

$$P_c - \text{det} \ i = \sum_{k=1}^{n} I_{c\text{-det} i}^2 - (k)\Delta t ;$$

Where $P_a - \text{det} \ i$, $P_b - \text{det} \ i$, $P_c - \text{det} \ i$, Respectively represent spectral energies of wavelet signal in a,b and c three phase;

$i=1, 2, 3;\quad \Delta t=\text{time step length};\quad n=\text{no. of sample in window.}$

The obtained spectral energies of wavelet signal are then input to neural network to discrimination internal fault and inrush current. If the internal fault is detected tripping signal is issued otherwise relay will be restraint.

VI. RESPONSE EVALUATION

A total of 220 cases were simulated using the MATLAB software under internal fault and magnetizing inrush current as well as external fault. Broadly, the following electromagnetic transient event of the power transformer were taken into consideration in design/testing of ANN,

a) Internal fault including:
   i) Terminal three phase fault;
   ii) Terminal two-phase to earth fault
   iii) Terminal two phase fault
   iv) Terminal single-phase to earth fault

b) Various magnetizing inrush current, such as inrush current with different energizing angle and different residual flux in core of the power transformer.

C. External fault with extreme CT saturation.
VII. CONCLUSION

From above all the result we conclude that, Conventional relay, harmonic restraint relay is improper to operate for energization condition. In some cases Second harmonic component is dominant in internal fault due to saturation of CT core and transformer core, capacitance and inductance of line. In some cases Second harmonic component is lower in magnetizing inrush current. Inrush current have high frequency component due to switching from one state to other, and which is attenuated next cycle and present up to 10 cycle for small transformer 1 minute for large transformer Internal fault have high frequency component in the form of spike and end in within one cycle External fault have high frequency component close to each other and present up to entire cycle. Today hunger world for electricity to avoid unnecessary tripping it is essential to use the wavelet and neural combination to protect the costly element in power system.

VIII. REFERENCES


Fig.9: Response of relay for external fault with CT saturation on LV side