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A New Approach for Discrimination between Inrush Current and Internal Faults in Power Transformers

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Abstract

This paper presents a new approach to distinguish between inrush current and internal faults of power transformer using a recursive Gauss Newton method.. The HS-transform (Hyperbolic S-transform) is used to extract patterns of inrush current and internal faults from the captured transformer current. HS-transform is a very powerful tool for non-stationary signal analysis giving the information of transient currents both in time and frequency domain. The spectral energy and standard deviation are calculated to distinguish between inrush current and internal fault. Classification of internal faults and inrush current is done through Fuzzy C-means clustering.

Introduction

Discrimination between inrush current and internal faults has been recognized as a very challenging power transformer protection problem. The inrush current contains a large second harmonic component in comparison to a fault. Sometimes also the second harmonic may be generated in case of internal faults in power transformer. This may be due to CT saturation and distributive capacitance in long transmission line to which the power transformer is connected. Also sometimes the magnitude of second harmonic in internal fault current can be close to that present in the inrush current. Also the inrush current magnitude is relatively less in modern power transformer due to design improvements. Therefore the traditionally provided protection system with harmonic restraint will not solve the problem.

Here most important requirement is to extract features from the non-stationary signals, as both inrush current and internal faults are non-stationary signal. For feature extraction or pattern recognition from non-stationary signal STFT(Short Time Fourier Transform), DWT(Discrete Wavelet Transform) are used[1-2]. Here in this paper, a new approach for patterns recognition using multi resolution HS-transform with varying window of varying shape is proposed. The S-transform is an invertible time-frequency spectral localization technique that combines elements of wavelet transforms and short-time Fourier transform.

The S-transform uses an analysis window whose width is decreasing with frequency providing a frequency dependent resolution. S-Transform is continuous wavelet transform with a phase correction. It produces a constant relative bandwidth analysis like wavelets while it maintains a direct link with Fourier spectrum. The S-transform has an advantage in that it provides multi resolution analysis while retaining the absolute phase of each frequency. This has led to its application for detection and interpretation of non-stationary signal like power system disturbance signal [5] and fault analysis. The inrush current and fault current are tuned through S-transform to get the patterns of inrush current and internal faults. Then the spectral energy and the standard deviation of inrush current and fault current are computed. The level of energy content and standard deviation gives the discrimination between inrush and fault current; accordingly the relay restrains or operates. Also time frequency contours in both fault and inrush are presented to distinguish the both events. The classification is done by fuzzy c-means clustering.

Hyperbolic S-Transform and Time-Frequency Analysis

The original S-transform [6] is defined as

$$S(\tau, f) = \int_{-\infty}^{\infty} h(t) \left\{ \frac{|f|}{\sqrt{2\pi}} \exp\left\{ -f^2(\tau - t)/2 \right\} \exp(-2\pi f t) \right\} dt \tag{1}$$

Where S denotes the S-transform of *h(t)*, which is the actual current signal varying with time, frequency is denoted by *f*, and the quantity τ is a parameter which controls the position of gaussian window on the time-axis. A small modification of the gaussian window has been suggested [7] for better performance.

$$W_{gs}(\tau - t, f, \alpha_{gs}) = \frac{|f|}{\sqrt{2\pi\alpha_{gs}}} \exp \frac{\left[-f^2(\tau - t) \right]}{2\alpha_{gs}^{2}} \tag{2}$$

and the S-transform with this window is given by

$$S(\tau, F, \alpha_{gs}) = \int_{-\infty}^{\infty} h(t) W_{gs}(\tau - t, f, \alpha_{gs}) \cdot \exp(-2\pi i f t)\, dt \tag{3}$$

where α_{gs} is to be chosen for providing suitable time and frequency resolution.

In applications, which require simultaneous identification of time-frequency signatures of different disturbance in power system like voltage sag, voltage swell, multiple notch, multiple spike, oscillatory transient, chip etc. and it may be advantageous to use a window having frequency dependent asymmetry. Thus, at high frequencies where the window is narrowed and time resolution is good, a more symmetrical window needs to be chosen. On the other hand, at low frequencies where a window is wider and frequency resolution is less critical, a more asymmetrical window may be used to prevent the event from appearing too far ahead on the S-transform. Thus a hyperbolic window of the form given below is used.

$$W_{hy} = \frac{2|f|}{\sqrt{2\pi(\alpha_{hy}+\beta_{hy})}}.\exp\left\{\frac{-f^2X^2}{2}\right\} \tag{4}$$

Where

$$X = \frac{\alpha_{hy}+\beta_{hy}}{2\alpha_{hy}\beta_{hy}}(\tau-t-\xi)+\frac{\alpha_{hy}-\beta_{hy}}{2\alpha_{hy}\beta_{hy}}\sqrt{(\tau-t-\xi)^2+\lambda_{hy}{}^2} \tag{5}$$

In the above expression $0\langle\alpha_{hy}\langle\beta_{hy}$ and ξ is defined as

$$\xi = \frac{\sqrt{(\beta_{hy}-\alpha_{hy})^2\lambda_{hy}{}^2}}{4\alpha_{hy}\beta_{hy}} \tag{6}$$

The translation by ξ ensures that the peak W_{hy} occurs at $\tau - t = 0$.

At $f = 0$, W_{hy} is very asymmetrical, but when f increases, the shape of W_{hy} converges towards that of W_{gs}, the symmetrical gaussian window given in equation (2). For different values of α_{hy} and β_{hy} and with $\lambda_{hy}{}^2 = 1$. Fig.-1 shows the nature of the window as the function of time $\tau - t$. As seen from the figure the change in the shape from an asymmetrical window to a symmetrical one occurs more rapidly with increasing f.

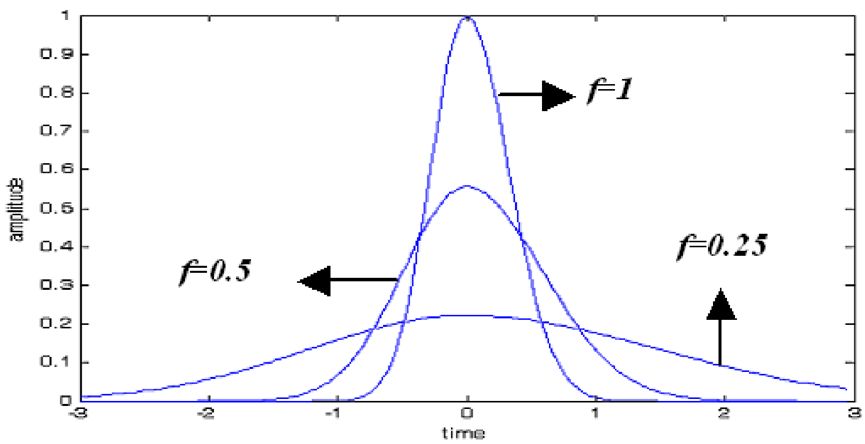

Figure 1: varying window *why* at *f=1,f=0.5 and f=0.25.*

The discrete version of the Hyperbolic S-transform of the internal faults and inrush current signal samples is calculated as $S[n,j]=\sum_{m=0}^{N-1}H[m+n].G(m,n)\exp(i2\pi mj)$, Where N is the total number of samples and the indices n, m, j are $n=0,1....N-1, m=0,1.....N-1,$ and $j=0,1.......N-1.$ The $G(m,n)$ denotes the Fourier transform of the Hyperbolic window and is given by

$$G(m,n)=\frac{2|f\ |}{\sqrt{2\pi(\alpha_{hy}+\beta_{hy})}}\exp(\frac{-f^2X^2}{2n^2}) \tag{7}$$

and

$$X=\frac{(\alpha_{hy}+\beta_{hy})}{2\alpha_{hy}\beta_{hy}}t+\frac{\beta_{hy}-\alpha_{hy}}{2\alpha_{hy}\beta_{hy}}(\sqrt{t^2+\lambda_{hy}}) \tag{8}$$

and $H(m,n)$ is the frequency shifted discrete Fourier transform $H[m]$, where

$$H(m)=\frac{1}{N}\sum_{m=0}^{N-1}h(k)\exp(-i2\pi nk) \tag{9}$$

Simulation Study

The simulation study has been done on the system shown in the fig.2. 1000MVA generator and 450 MVA transformer with 15Kv/220Kv. The study has been made for inrush current and various internal fault conditions like winding–ground, winding-winding, winding-winding-ground without load and with load. The sampling rate is 15.36 kHz. Half cycle data has been processed through HS-transform to give the energy and standard deviation. The simulation model is developed using matlab-simulink. 200 cases (examples) for internal faults and inrush current at various conditions were simulated and tested using the proposed method.

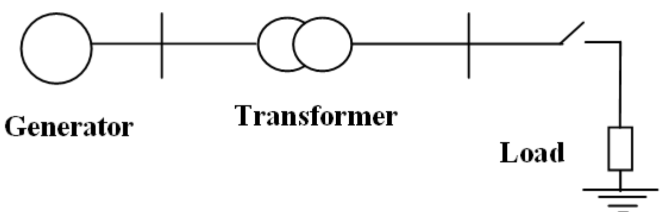

Figure 2: System model.

Results and Discussion

Feature extraction using S-transform

From the simulation model data for inrush current and internal faults at different bus with and without load are generated. The HS-transform of the half cycle data from the inception of inrush and faults is computed. The normalized frequency contours are obtained as shown in fig.3 (a) through fig.3 (f). It is clear from the normalized frequency contours that in case of inrush current the normalized frequency contours are interrupted in nature compared to internal faults. In case of fault conditions, the normalized frequency contours are regular throughout the time series.

Apart from the normalized frequency contour for inrush current and fault current, the spectral energy and the standard deviation of the HS-transform of the signal are found out. The spectral energy and standard deviation for inrush current and fault current at various conditions are depicted in Table-1 through Table-2. It is clearly seen from tables that the spectral energy of the HS-transform of the inrush current is much less compared to the spectral energy of the HS-transform of the internal fault current signal. From the spectral energy and standard deviation, the classification of inrush and internal fault is done using fuzzy C-means clustering technique.

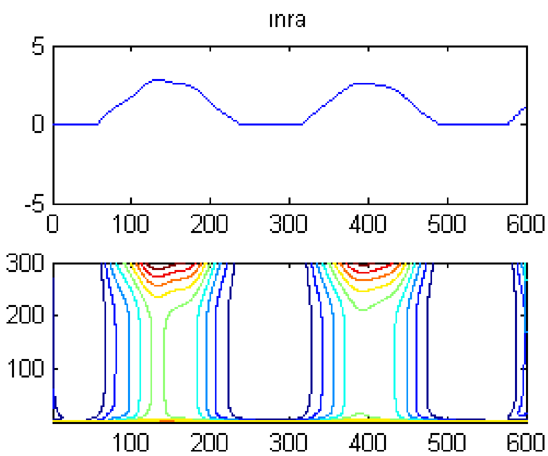

Figure 3(a): Normalized frequency contours for inrush current of a-phase.

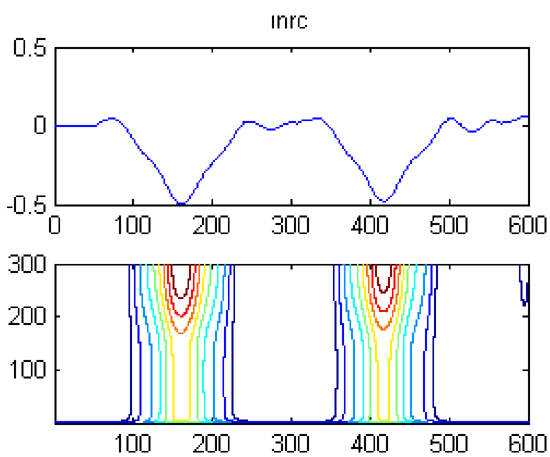

Figure 3(b): Normalized frequency contours for Inrush current of c-phase.

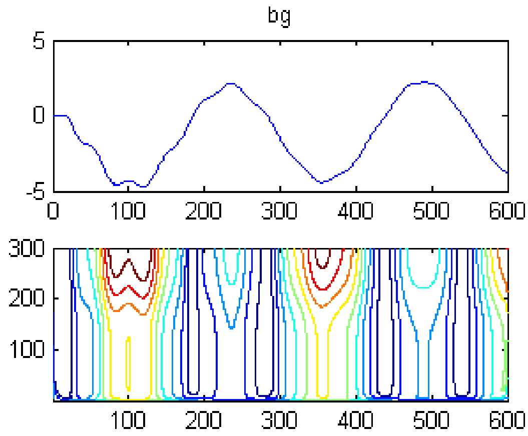

Figure 3(c): Normalized frequency contours for winding to ground fault of b-phase.

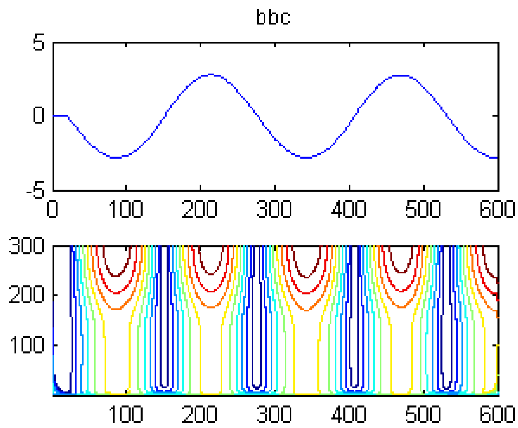

Figure 3(d): Normalized frequency contours for winding to winding(b-c) fault of b-phase.

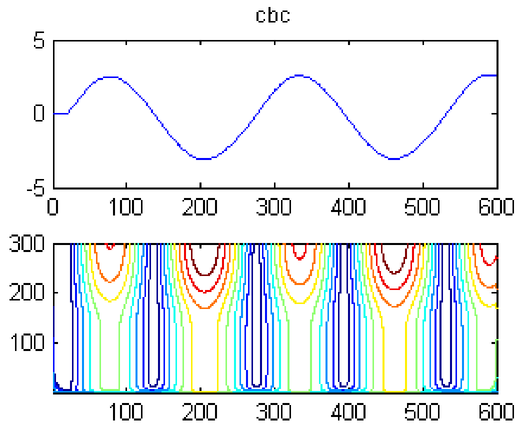

Figure 3(e): Normalized frequency contours for winding to winding(b-c) fault of c-phase.

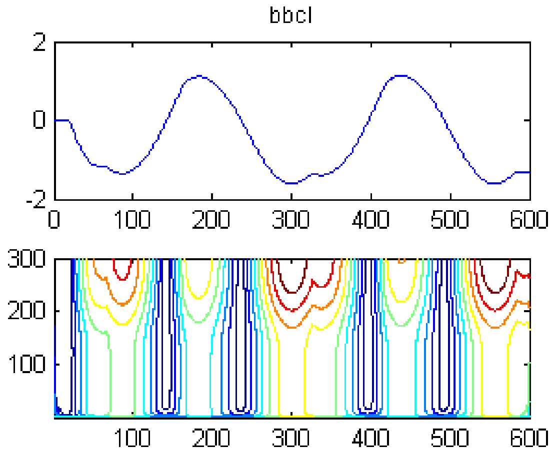

Figure 3(f): Normalized frequency contours for Winding to winding(b-c) fault of b-phase with load.

Table 1: spectral energy and standard deviation for inrush current and fault without load.

Inrush/Fault (without load)	Energy	Std
inr-a	**461.1**	**0.3666**
inr-b	**212.9**	**0.2040**
inr-c	**65.2**	**0.0663**
ag	1028.0	0.7995
bg	821.3	0.6974
cg	797.4	0.6562
aab	875.7	0.6687
bab	792.6	0.6184
aca	882.2	0.6815
cac	773.3	0.6211
bbc	627.0	0.5211
cbc	625.5	0.4603

Table 2: spectral energy and standard deviation for inrush current and fault with load.

Inrush/Fault (with load)	Energy	Std
inrl-a	**425.2**	**0.3538**
inrl-b	**184.6**	**0.2131**
inrl-c	**86.0**	**0.1109**
agl	975.9	0.7632
bgl	779.9	0.6795
cgl	770.1	0.6007
aabl	879.4	0.6873

babl	789.4	0.6462
acal	887.5	0.7030
cacl	774.9	0.6600
bbcl	632.8	0.4464
cbcl	622.5	0.4460

Classification using Fuzzy C-means clustering

After calculating the spectral energy and standard deviation from the HS-transform of the inrush and internal fault current, classification of inrush current and internal fault is done by applying clustering technique.

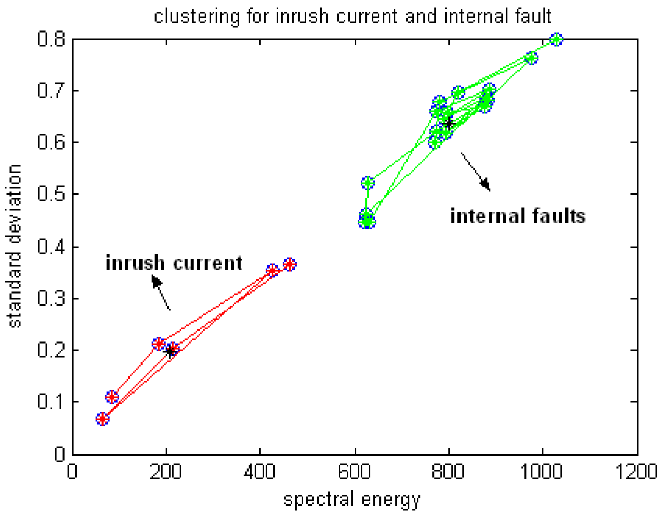

Figure 4: Fuzzy C-means clustering to discriminate inrush current and internal fault.

Here in this paper Fuzzy C-means clustering is used to generate clusters to discriminate between inrush and internal fault. The data generated from HS-transform, the spectral energy and the standard deviation are used as 2-D data for Fuzzy C-means clustering as shown in Fig.4, which clearly distinguish between inrush current and internal faults.

Conclusions

This paper presents a new approach for discrimination between inrush current and internal faults in power transformer by pattern recognition technique using HS-transform. The HS-transform gives the normalized frequency contours for inrush current and internal fault very distinctly as shown in the figures where second harmonic is pronounced in case of inrush current compared to faults. Also the spectral energy and standard deviation are calculated and Fuzzy C-means clustering is used to distinguish the inrush current from internal faults. As HS-transform is less prone to noise compared to Wavelet transform, it gives the effective protection for large power transformers.

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Authors Biography

Er. J.P. Patra was born on 12.9.1965, at Bhubaneswar, India.He received his Bachelore's Degree in Electrical Engg. from Sambalpur University, Orissa, india in the year 1988. He also received his bachelor's degree in law from utkal university, bhubaneswar, india in the year 2002. HE received his master's degree in electrical power system from IASE university, rajasthan, india in the year 2008.He is presently persuing his 3nd year of Doctoral Degree with SOA University, Bhubaneswar, india. He was a former Senior Scientific Officer-II of the Ministry of Defence, Govt. of India, belonging to the Defence Aeronautical Quality Assurance Service (DAQAS) at Bangalore, india.He was also a former Engineer at the National Sugar Instt. at Kanpur (UP), india. He has been in the orissa (INDIA) technical education profession since last more than 10 years, as a full time faculty. His industrial experience of more than 5 years exist in prominent industries like ferro-alloys plant from ELKEM, NORWAY, thermal power plant from ASEA BROWN BOVERI, SWEDEN, hydro power plant, experimental sugar factory, ADVANCED LIGHT HELICOPTERS AND AERO ENGINES FACTORY OF HINDUSTHAN AERO NAUTICS LTD, BANGALORE, INDIA. Presently, he is teaching in UG and PG level in CV Raman Engg. college, Bhubaneswar, INDIA, as an Asst Professor in Electrical Engg.His areas of interest include distributed generation, power apparatus and systems. HE has by 23rd dec 2010 published 2 papers in national conference and international symposium in India as author and submitted 1 paper as co-author to european transactions on electrical power(status :-rejected on 2/12/2010) with comments, planning resubmission) and 1 paper to IEEE transactions on industrial electronics as co-author(status:-pending in AE's office).He is presently life member of many prestigious professional technical bodies like IE, ISTE, ISCA, OEC in India and also a graduate student member of IEEE.