International Journal of Scientific & Engineering Research, Volume 4, Issue 8, August 2013
ISSN 2229-5518

Fault Analysis and Digital Protection of Busbars Using Curvelet Transform Based Approach

P Kiran, P Kanakasabapathy, G Ravikrishnan

Abstract— The reliability and stability of a power system depends to a great extent on the efficiency of busbar protection scheme. The proposed protection scheme makes use of curvelet transform based analysis. Curvelet transform overcomes the weakness of wavelets in higher dimensions and will better capture the curve singularities and hyper plane singularities of high dimensional signals. The detail and fine coefficients of curvelets are strongly orientation sensitive, which is a useful property for detecting curves in signals. The proposed algorithm was tested using the busbar modeled in Simulink and simulating various fault conditions. The signal analysis was done by using wrapping based fast discrete curvelet transform. Results presented in this paper showed the capability of implementing a busbar protection scheme using the proposed approach.

Index Terms— Busbars, Curvelet transform, FFT, Fourier transform, Simulink, Wavelets, Wavelet transform

1 Introduction

POWER system protection has evolved over years from simple electromechanical relays to highly complex digital relays with the aim of achieving fast and reliable operation. Busbar faults are likely to cause extensive damage and may possibly destroy an entire substation. So high speed relaying is necessary especially in high voltage buses. Digital protection is essential for busbars especially with the highly sophisticated load.

With the advances in signal processing techniques and computational power of digital processors, many techniques utilizing features extracted from fault generated transients have been proposed. Most of them follows wavelet transform based analysis. Kang etal. proposed a busbar current differential protection relay suitable for use with measurement type current transformers [1]. Eissa proposed a technique based on a feature signal extracted from the original current value using the wavelet packet transform method [2]. A wavelet transform based directional algorithm was proposed by Simi etal. [3]. Fourier Transform only gives the spectral content of the signal and no information regarding where in time those spectral components appear, it is not a suitable technique for non-stationary signals.This paper proposes a new digital protection scheme using curvelet transform based analysis. This overcomes the weakness of wavelet transform based analysis. Curvelet transform requires only fewer coefficients to account for edges.

- *P Kiran completed his masters degree (M.Tech) in Power and Energy from Amrita University, Kerala, India. He received his bachelors degree (B.Tech) in Electrical and Electronics Engineering from University of Calicut, Kerala, India.His research interests are in the field of power system protection, restructured power systems and renewable energy sources.*
- *P Kanakasabapathy received his Phd from IIT Madras and currently he is the associate professor of department of Electrical and Electronics Engineering, Amrita University, Kerala, India.*
- *G Ravikrishnan completed his masters degree (M.Tech) in Power and Energy from Amrita University, Kerala, India. He received his bachelors degree (B.Tech) in Electrical and Electronics Engineering from MG University, Kerala, India.*

2 Curvelet Transform

The curvelet transform is a multiscale directional transform that allows an optimal nonadaptive sparse representation of the objects with edges. This belongs to the family of multiscale geometric transforms. It is a multiscale pyramid with many directions and positions at each length scale and needle shaped elements at fine scales. This will overcome the limitations of traditional multiscale representations such as wavelets [4]. This has the added advantage of optimally sparse representation of objects with edges and optimal image reconstruction in severely ill posed problems.

First generation curvelet transform consists of sub-band decomposition, smooth partitioning, renormalization and ridgelet analysis [5]. This involves complex series of steps and the performance was exceedingly slow. Then it came the second generation curvelet transform. This may be either wrapping based approach or unequally spaced fast fourier transform based approach. In this protection scheme wrapping based approach [6] is being used.

3 Proposed Protection Scheme

3.1 Structure of Data Flow

The proposed method is based on deriving the directional signal. Fault causes transients in both voltage and current signals. Here curvelet transform is applied to both the voltage and current signals in order to extract the information and hence to obtain the directional signal. This gives high frequency details of voltage and current signals. A disturbance is detected if the first difference of voltage high frequency details exceeds the threshold value. In order to discriminate between internal and external fault it is necessary to derive high frequency power details from high frequency voltage and current details. The data flow structure is given in fig.1.

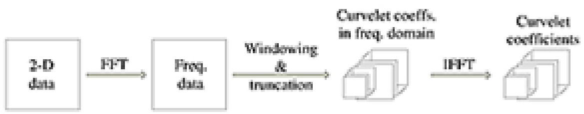

Fig.1 Data Flow Structure

By using fast fourier transform the data is first transformed into frequency domain. The transformed data is then multiplied with a set of window functions. The shapes of these windows are designed according to the requirements of the ideal curvelet transform. Later the inverse of FFT will give the curvelet coefficients [7]. The wrapping based approach is based on this algorithm.

3.2 Disturbance Detection

The disturbances are detected if the three phase disturbance signals derived using (1) is high for any voltage signal, where HFV represents High Frequency Voltage details. From the high frequency power details derive the directional signals for each phase of every connected branch (fig 2). A trip signal is issued for the phase if the directional signals for all the branches of that phase are same. The overall block diagram is shown in fig 3.

$$D(n)=\begin{cases}1, if \left|HFV(n)-HFV(n-1)\right|>Thd \\ 0, otherwise\end{cases} \quad (1)$$

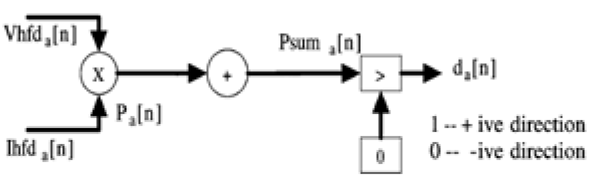

Fig.2 Deriving Directional Signal

3.3 Fault Discrimination

The proposed scheme will correctly discriminate between the internal and external fault. The directional signals which is derived from high frequency details is fed to the AND gate. In the case of internal fault the magnitude of directional signal will be positive. If all the signals are in the same direction a trip signal is issued else the fault will be external as given by (2), where HFP represents high frequency power details. For wavelet analysis need to consider the approximated signal and its details. Analysis using curvelet transform is done by using the approximated signal obtained from the wrapping based approach and its corresponding coefficients.

$$DIR1(n)=\begin{cases}1, if DHFP1(n)>0 \\ 0, otherwise\end{cases} \quad (2)$$

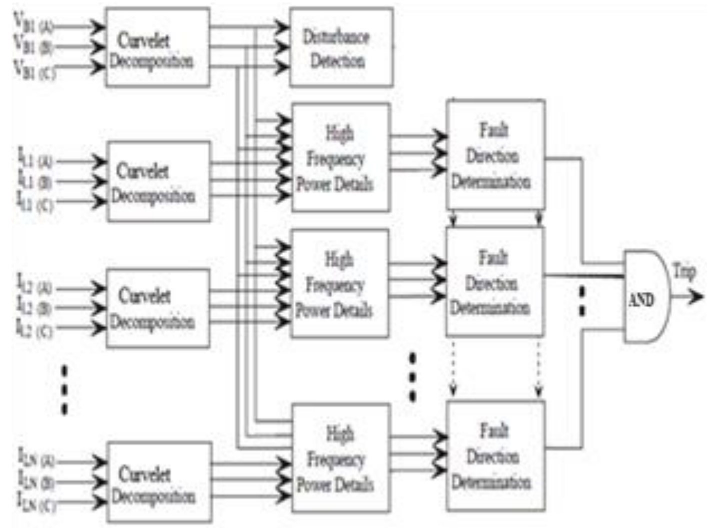

Fig.3 Overall Block Diagram

4 Simulation Results

4.1 System Model

The proposed algorithm was developed in MATLAB environment. The busbar was modeled in Simulink platform. A three bus system is used for the analysis purpose (fig 4). The test waveforms for various types of faults were obtained. Matlab programming was done by using the curvelet tool box [8] and the curvelet coefficients for different fault signals were obtained.

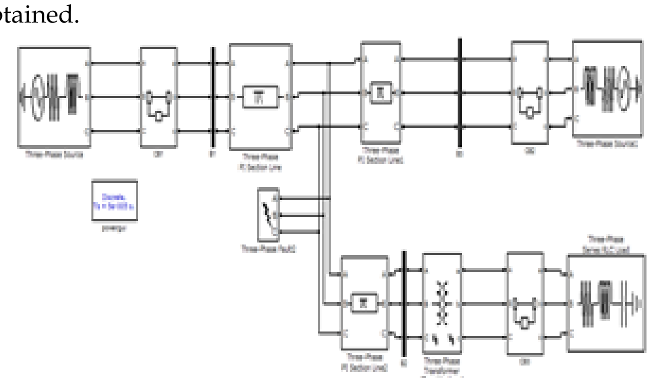

Fig.4 Simulink Model

4.2 Curvelet Decomposition

The wrapping based approach was used for the analysis purpose. The curvelet decomposition is shown in figure 5. The low frequency coefficients are placed at the center of the decomposition. The outer corona corresponds to higher frequencies. Each panel represents coefficients at a specified scale and along the orientation suggested by the position of the panel [9].

The configuration used for analysis is shown in table 1. The toolbox used is curvelab 2.1.3 and the transform used is wrapping based fast discrete curvelet transform.

International Journal of Scientific & Engineering Research Volume 4, Issue 8, August-2013
ISSN 2229-5518

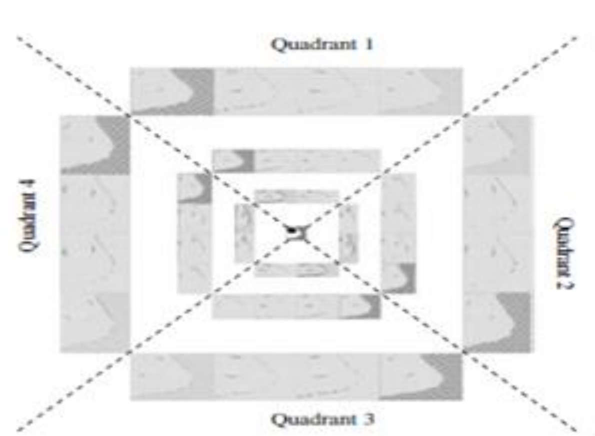

Fig.5 Curvelet decomposition

Table 1 Configuration used for analysis

Platform	MATLAB
Version	7.12.0 (R2011a)
Toolbox	Curvelab 2.1.3
Transform	Wrapping based
Mother wavelet	db 3
Level of details	5

The waveforms obtained for single phase to ground fault (internal) is shown in fig.6, which includes the voltage, current and faulty signal. The curvelet transform is applied to this faulty signal.

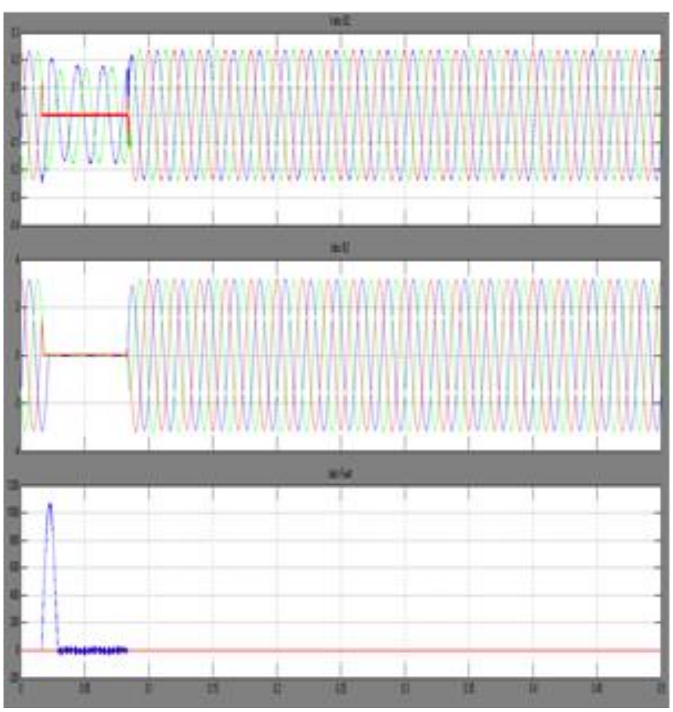

Fig.6 Voltage, Current and Faulty signal

4.3 Coefficient Details

The toolbox available in Matlab was used for the analysis purpose. The mother wavelet used is db3 and the level of details is chosen as 5 [10]. Fig. 7 shows the faulty current signal for single line to ground fault, its coefficients and details. Similarly the coefficients can be obtained for all other faults and hence can correctly discriminate between internal and external faults. The corresponding curvelet coefficients were obtained by wrapping based approach.

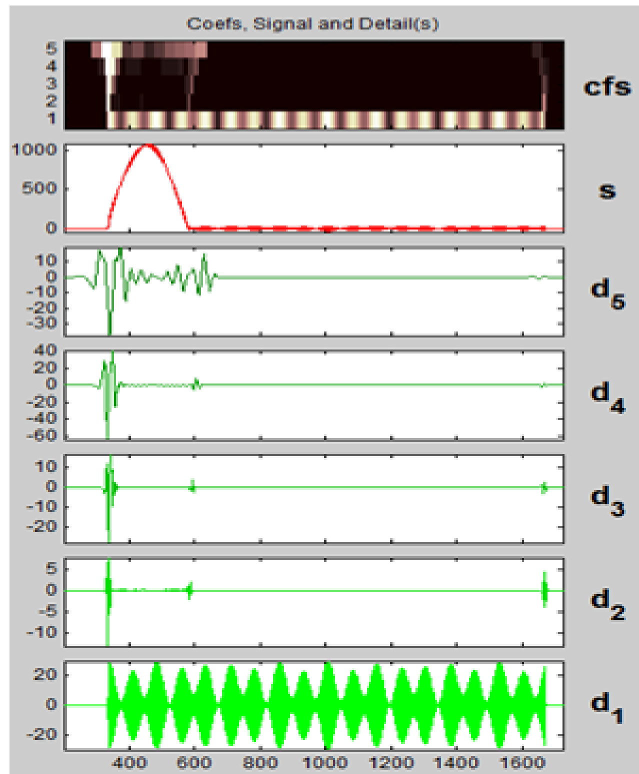

Fig.7 Signal coefficients and details

4.4 Curvelet Analysis

The analysis is done by using curvelet toolbox. The approximated signal obtained using wrapping based curvelet transform is shown in fig.8 and corresponding curvelet coefficients are shown in fig.9. Curvelet coefficients with value zero are marked in white whereas the coefficients with larger magnitude are dark. The frequency increases from center to outer coronae.

The low frequency coefficients are placed at the center of the display. Each panel represents coefficients at a specified scale and along the orientation suggested by the position of the panel. The elapsed time to take fdct wrapping is 0.79 sec and for ifdct (inverse) wrapping 0.76 sec. Therefore the resultant time is about 0.03 sec. The number of significant coefficients is about 7 and the total number of coefficients is about 625. The curvelet analysis has done for various types of faults and from the results obtained it is able to discriminate between the internal and external fault.

ISSN 2229-5518

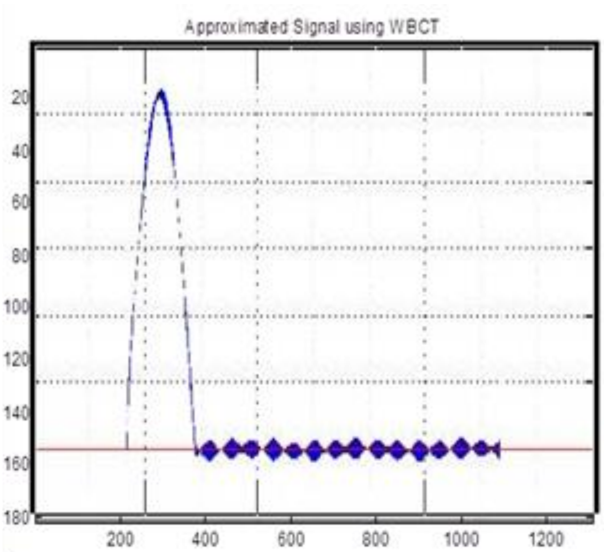

Fig.8 Approximated internal faulty signal using wrapping based curvelet transform

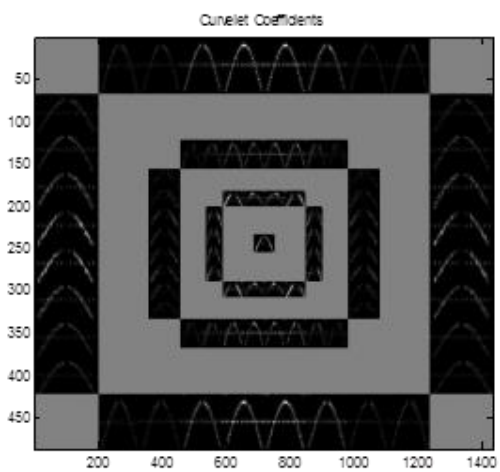

Fig.9 Curvelet Coefficients

The curvelet transform decomposes the signal in several frequency bands. At the coarsest scale, isotropic wavelets are used as basic functions. At the finest scale, curvelets take over this role. Similar analysis for single-phase to ground fault (external) is shown in fig.10.

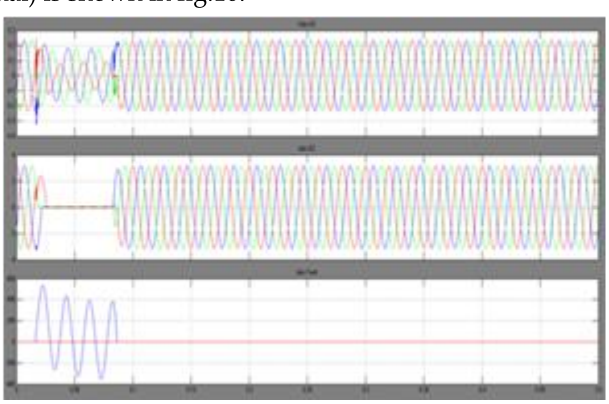

Fig.10 Volage, current and faulty signal

The analysis done by using wavelet toolbox [11] is shown in fig.11 and those done by using curvelab toolbox are shown in fig.12.

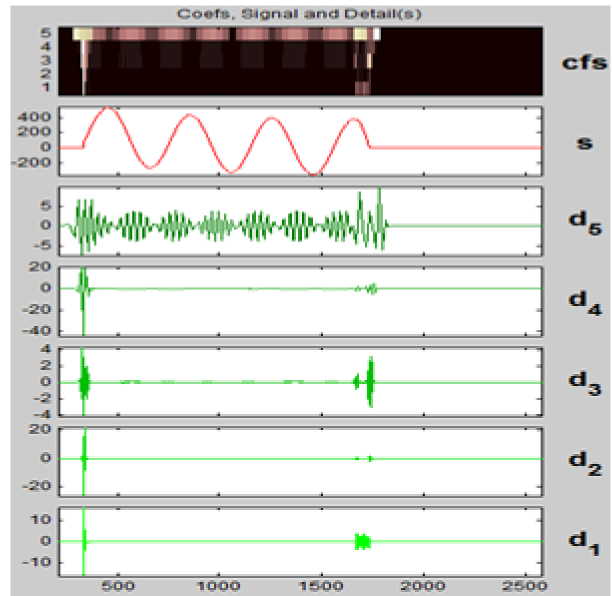

Fig.11 Signal coefficients and details

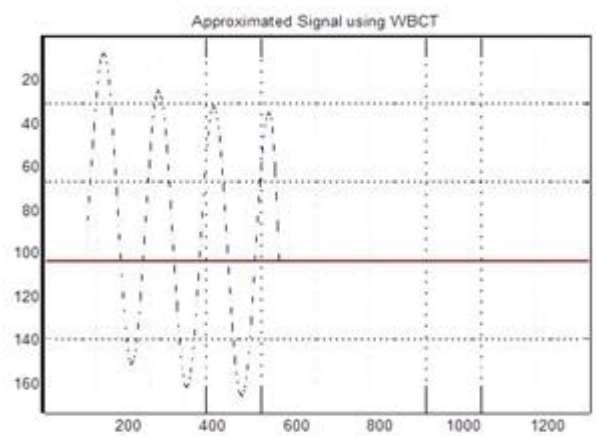

Fig.12 Approximated external faulty signal using wrapping based curvelet transform

4.5 Algorithm

Step 1: Input the signal, apply 2D fast fourier transform and hence obtain the fourier samples.

Step 2: Form the product of the fourier samples and the signal axis coefficients.

Step 3: Wrap this product around the origin.

Step 4: Apply the inverse FFT to wrap data to get the discrete curvelet transform coefficients.

Step 5: Repeat the steps for different scales and angles.

4.6 Results

The original external fault signal and its wavelet coefficients are shown in fig.13.

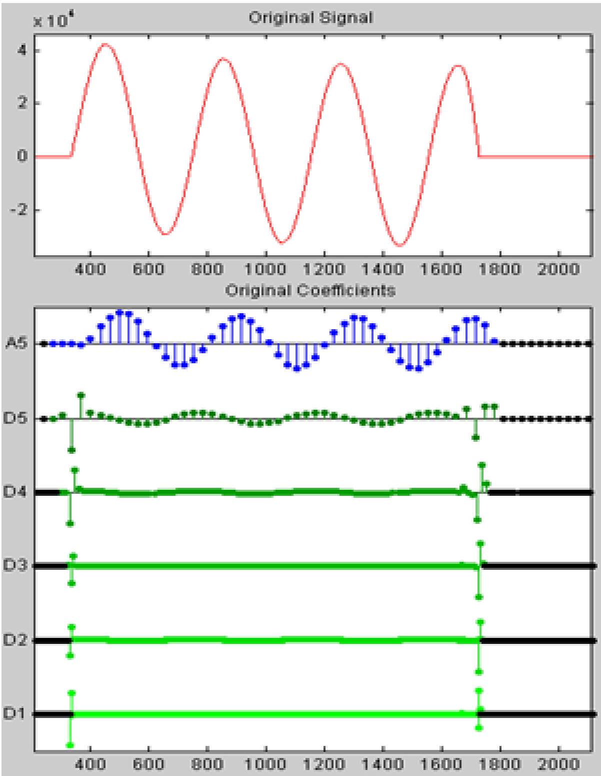

Fig.13 Wavelets Coefficients of External Faulty Signal

The total number of coefficients in the case of external faulty signal is 286 and out of which the number of significant coefficients are 14 and the analysis was done by using wrapping based fast discrete curvelet transform.

A commonly used mother wavelet suitable for protection applications is Daubechies's wavelet and for this work, the db-3 wavelet was used. The computational speed depends upon the type of processor and the image dimensions. Here for the analysis purpose the processor used was intel core i5 and the time taken between the transform and its inverse is about 0.03 sec and 0.051 sec for internal and external fault respectively.

From the analysis it is clear that more number of curvelet coefficients is required for the fault internal to the busbar than fault outside the busbar section. The resultant time for analysis of internal fault is less than the external fault. So curvelet transform based analysis requires only less number of coefficients for fault analysis than the wavelet transform based analysis

5 Conclusion

A novel computationally efficient and faster digital protection scheme for busbars is proposed. Curvelet transform is a good signal analyzing method with good potential. From the results obtained it is clear that less number of coefficients is required to account for edges in case of curvelet transform based analysis when compared to wavelet analysis. Faster computation time can be achieved by using wrapping based method. This method can be used for both disturbance detection and fault discrimination. Even though the computational time depends on the processor speed, curvelet transform possess very high computational efficiency which can accurately discriminate the internal and external fault conditions as well as the phase to ground faults. The proposed approach uses the number of significant and insignificant curvelet coefficients in the signal. However for nonfaulty signal wavelet transform based analysis is preferred. The hardware implementation of the proposed scheme can be implemented by using field programmable gate array [12].

Acknowledgment

The authors thank the developers of fast discrete curvelet transforms and the makers of the curvelab toolbox.

References

[1] Y.C. Kang, U.J. Lim, S.H. Kang and P.A. Crossely, "A Busbar differential protection relay suitable for use with measurement type current transformers " ,IEEE Transaction on Power delivery, vol.20, no.2, pt.2, pp.1291-1298, Apr.2005.

[2] M.M. Eissa, "High speed differential busbar protection using wavelet packet transform", Proc. Inst. Elect. Gen., Trans., Distrib, vol.152, no.6, pp. 927-933, Nov.2005.

[3] Simi.P.Valsan and K.S.Swarup, "Computationally efficient wavelet transform based digital directional protection for busbars", IEEE Transaction on power delivery, vol.22, no.3, pp.1342- 1350, July 2007.

[4] Jianwei Ma and Gerlind Plonka, "The Curvelet Transform-A review of recent applications", IEEE Signal processing magazine, vol.3, pp.118-133, March 2010

[5] David Dohono and Mark Duncan, "Digital curvelet transform: Strategy, implementation and experiments", Stanford University, Nov 1999.

[6] Emmanuel Candes, Laurent Demanet, David Dohono and Lexing Ying, "Fast discrete curvelet transforms", Stanford University, March 2006.

[7] Truong.T.Nguyen and Herve Chauris, "Uniform discrete curvelet transform", IEEE Transaction on signal processing, vol.58, no.7, pp.3618-3634, July 2010.

[8] Emmanuel candes, Laurent Demanet and Lexing Ying, "Curvelab toolbox-version2" California institute of technology, 2005.

[9] Linda Tessens, Aleksandra Pizurica etal. "Context adaptive image denoising through modeling of curvelet domain statistics", Journal of electronic imaging, vol.17, Sept. 2008

[10] N. Perera, A.D. Rajapakse and D. Muthumuni, "Wavelet based transient directional method for busbar protection", International conference on power system transients, in Delft, The Netherlands, June 2011.

[11] Wavelet toolbox users guide for use with Matlab, version 1, The MathWorks, Inc.

[12] Simi.P.Valsan and K.Shanti Swarup, "High speed fault classification in power lines: Theory and FPGA based implementation", IEEE Transactions on industrial electronics, vol.56, no.5, pp.1793-1800, May 2009.