Journal of Theoretical and Applied Information Technology
10th January 2013. Vol. 47 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

LC FEATURES COMBINED CHIRPLET TRANSFORM AND FRACTAL THEORY ON HIGH VOLTAGE INSULATORS

[1]ALI HUI, [2]HUI LIN
[1]Department of Electrical and Control Engineering, Xi'an University of Science and Technology, Xi'an 710054, Shaanxi, China
[2]Department of Automation, Northwest Polytechnical University, Xi'an 710076, Shaanxi, China

ABSTRACT

The voltage grade of electrical transmission line is getting higher and higher, consequently, flashover of transmission insulators is getting more and more severe in high-voltage (HV) and ultra-high-voltage (UHV) systems under serious pollutions, which menaces the safety of power transmission system heavily. The crux to enhance the security of power system is to discover ways of monitoring states of insulator's surface by some eigenvalues. A new method, combined chirplet transform with fractal theory, was proposed in this paper, and is taken as the ruler to define fractal dimension, which is used to describe characteristics of signals. Chirplet-fractal dimension is defined as the sum of residues of decomposed signals. The fractal characteristics of leakage current during flashover are obtained from this dimension. The results show that the chirplet-fractal dimension efficiently describes the information of arcs discharge in LC, and it is also a good eigenvalue for flashover discrimination and risk prediction.

Keywords: *Fractal Dimension, Chirplet Transform, Non-stationary Signal, Leakage Current, Flashover*

1. INTRODUCTION

As high-voltage (HV) and ultra-high-voltage (UHV) transmission lines have been used more and more widely, flashovers from contaminated insulators became the primary factor threatening the reliability of HV transmission system, and the harm from pollution flashover has surpassed the thunder impact by far[1]. At present, the most universal actions for preventing pollution flashover are regular cleaning, using antipollution material, and adjusting creepage distance. However, these methods have obvious defects such as waste of resources, blindness, and so on, which are resulted from the lack of accurate understanding of insulator surface condition. The key to improve the security of power system is to explore resultful methods of monitoring states of insulator's surface by some eigenvalues. Thus, it is important to choose an efficient eigenvalue.

At present, leakage current (LC) is the best discrimination standard with practical significance, because it generally reflects the voltage, the climate and the contamination. LC is a token of descending degree of insulation level, and is easier to supervise than other values, such as surface electric field, voltage distribution, infrared image[1].The study of LC is mainly focused on its maximum value, phase angle, different quantities of pulse and frequency features[2-4], but results express obvious different among them[5]. Since supervised LC, including disturbs and noise signals because of complex local environment and atrocious weather, is non-stationary random signal, it is vital to analyze LC with effective method.

In this paper, a new idea is proposed to use fractal to describe chirplet transform results of signals. It integrates chirplet transforms with fractal geometry, namely chirplet-fractal dimension. This dimension describes the change rule of the sum of residues from decomposed signals. The fractal characteristics of LC are calculated with chirplet-fractal dimension, and LC is obtained from artificial pollution test.

2. FRACTAL DIMENSION

2.1 Box Dimension

Fractal was firstly brought forward by Polish scientist Mandelbrot[6], and is used to study set topology, then applied to natural science and engineering later. In nature, the shape of objects and diverse figures can be divided into two kinds: one possesses characteristic scale that can be approached by line, face, and volume, and so on. Another doesn't possess character scale, whose shape is accidental and cannot be measured but has comparability between part and collectivity. This self-similar frame without characteristic scales called fractal. Fractal is used to research irregular complicated phenomenon existing widely in nature,

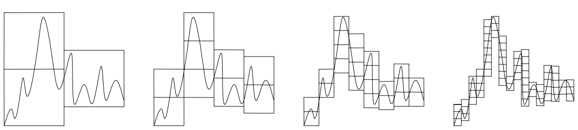
Journal of Theoretical and Applied Information Technology
10th January 2013. Vol. 47 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

and to describe the common structure of a great kind of irregular sets and functions that cannot be described by traditional Euclidean geometry and calculus method.

In fractal theory, fractal dimension is a significant parameter to depict fractal phenomenon, and it is the further development of traditional dimensions. Fraction describes the degree and complicacy of the fractal collection to fill space. Since the birth of fractal dimension, more than ten kinds of different fractal dimensions have been defined in allusion to different objects, for example, box dimension, Hausdorff dimension, similarity dimension, information dimension, and correlation dimension, and so on [6,7]. Among these dimensions, box dimension is the easiest and most widely used. As shown in figure 1, the box dimension of a set S with n-dimension is defined as follows: for any $\delta > 0$, let $N(\delta)$ be the minimum number of n-dimension cubes of side-length δ needed to cover S. The box dimension D_B of S [8] is:

$$D_B = \lim_{\delta \to 0} \left[\ln N(\delta) / \ln(\delta) \right] \quad (1)$$



(a) $\delta = 1$ (b) $\delta = 1/2$ (c) $\delta = 1/4$ (d) $\delta = 1/8$

Figure 1: Definition Of Box Dimension

The ideal fractal has infinite details. However, fractal phenomenon in nature generally doesn't have fractal characteristic on condition of finite scale, so box dimension cannot be calculated by equation (1). The approximate method is usually used to compute it in practice, viz. take ruler, with certain length, Δ as the minimum (or maximum) side-length of meshes, then magnify (or minify) them to $k\Delta, k \in z^+, k < N_0$ step by step, note $N_{k\Delta}$ as the number of meshes that cover S in side-length of $k\Delta$, and $N_{k\Delta}$ is shown as:

$$N_{k\Delta} = \sum_{j=1}^{N_0/k} ceil\{\max\{x[(j-1)k+1 : jk]\} - \min\{x[(j-1)k+1 : jk]\} / k\Delta\} \quad (2)$$

where $ceil(y)$ takes integer upward, namely $ceil(m+\delta) = m+1$.

The famous Richardson plot[7] depicts the curve of $\ln k\Delta \sim \ln N_{k\Delta}$, as shown in figure 2. This figure can be divided into three regions A, B and C in terms of different slopes of the curve. $k\Delta$ is very small in region A, and fractals in nature generally doesn't have scale-free self-similarity. At the same time, $k\Delta$ is too large to reflect details of the curve in region C. So region B with preferable linearity is commonly regarded as the scale-free region. Suppose the start point and the end point of this region are k_1 and k_2, respectively, then $\ln k\Delta \sim \ln N_{k\Delta}$ satisfies linear

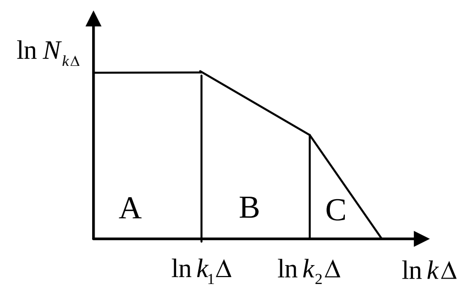


Figure 2: Richardson Plot

regress model,

$$\ln N_{k\Delta} = -D_B \ln k\Delta + b, \qquad k_1 \le k \le k_2 \quad (3)$$

where D_B is the slope of the curve in region B and is defined as box dimension.

2.2 Chirplet-fractal Dimension

According to the definition of wavelet transform, radix function package, changed by translating and dilating mother wavelet $\psi(t)$, is:

$$\psi_{a,b}(t) = |a|^{-1/2} \psi\left[(t-b)/a\right] \qquad b \in R, a \in R^+, a \neq 0 \quad (4)$$

Journal of Theoretical and Applied Information Technology
10th January 2013. Vol. 47 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

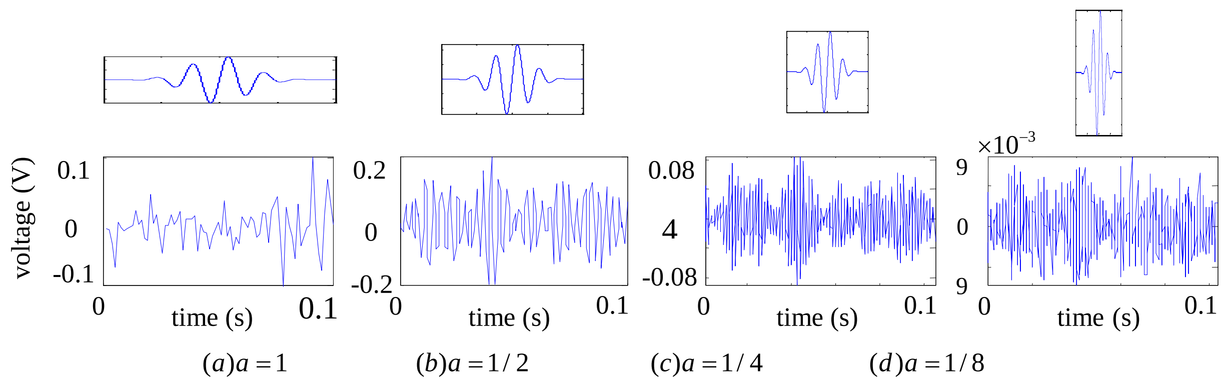


Figure 3: Wavelet Decomposition Of Time Sequence Signals

Any measurable function $f(t) \in L^2(R)$ can be constructed through $\{\psi_{a,b}(t)\}$ with different point of view and different time-frequency resolution. A fractal set F with self-similarity, studied in fractal theory, can be formed similarly by function $\beta(t)$ [6], with the compactly support set, namely:

$$\beta(t) = r^H \beta(rt) \qquad r, H > 0 \tag{5}$$

where r is the self-similar affined operator, H is a parameter related with dimension.

Through comparing operator r with operator a, the following conclusion is: the principle of wavelet transform from low frequency to high frequency is consistent with the thought of recognizing essence of things from collectivity to part, and from macroscopy to microcosm. Figure 3 shows the four-level wavelet decomposition results of time sequence signals decomposed by Db4 orthogonal wavelet. The upper four figures are Db4 orthogonal wavelets of different scales, while the lower four figures are high frequency coefficients of wavelet decomposition. Since the process of recognizing things through fractal is to measure signals with a length ruler of different scales, and studying the essential characteristics of things by measurement results, while wavelet transform is with a wavelet ruler of different scales, fractal and wavelet transform have similar process by comparing figure 1 with figure 3.

Chirplet transform is the extension of short-time Fourier transforms (STFTs) and wavelet transforms[9]. It has time-frequency (TF) locality as wavelet transform, and its time-frequency window is more flexible than wavelet transform. Wavelet is a signal wave obtained through modulating harmonic oscillations with a short fundamental wave, while chirplet is achieved by modulating linear frequency modulation (FM) oscillations with a short fundamental wave. Chirplet transform includes not only translation in time and frequency, and dilation in frequency, but also dilation and rotation of rectangular mesh along oblique direction, through which the time-frequency features of non-stationary signals are presented efficiently.

Affine time-frequency transform of short Fourier, wavelet and chirplet[9] are shown in figure 4. In figure 4(a), time-frequency mesh is just translated in time and frequency, but complex change is shown in figure 4(b), which includes dilations in time and frequency besides aforementioned changes, in other words, short Fourier transform analyzes mesh with invariable time-frequency in shape and size, but wavelet transform, whose bandwidth is proportional to frequency, analyzes mesh with the time-frequency,. According to time-frequency uncertainty principle, the area of mesh is constant. Therefore, short Fourier transform is suitable for non-stationary signals with constant bandwidth, but wavelet transform for non-stationary signals with changeless proportional bandwidth. However, signals often approximately equal to constant proportional bandwidth in practical application, whose analyses need more complex time-frequency mesh than rectangle. Thus chirplet transform appears, with dilations and rotations of rectangular mesh in oblique direction considered, as shown in figure 4(c).

Journal of Theoretical and Applied Information Technology
10th January 2013. Vol. 47 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

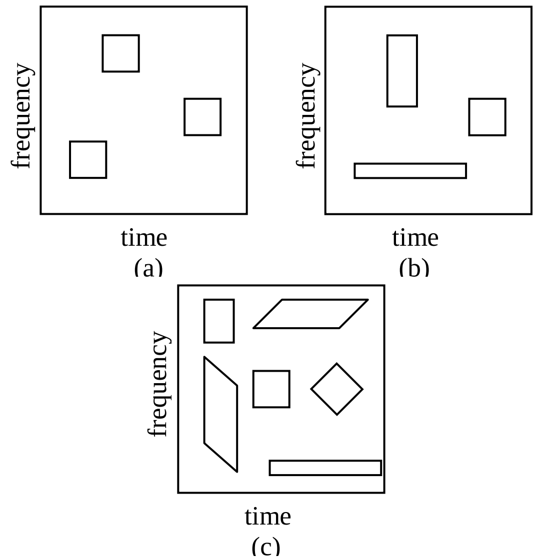


Figure 4: Different Time-Frequency Form

Figure 5 shows five different affine transformations, and table 1 shows the operators corresponding to the coordinate axes of the chirplet transform parameter space[9].

The wavelet provides a tiling of the TF plane with tiles that are lined up with the time and frequency axes, whereas the chirplet construct a more general tiling of the TF plane because the tiles may rotate or shear. As a matter of fact, wavelet can be regarded as chirplet with zero FM slope. Hence, it is easy to understand that chirplet transform is extension of wavelet. It is readily discernible that fourier transform and wavelet transform are special cases of chirplet transform[9]. Consequently, chirplet transform can provide more characteristics of signals than wavelet transform.

Based on this idea, a new dimension is proposed in this paper, namely chirplet-fractal dimension, by describing the results of chirplet transform[10] with the concept of fractal dimension, that is, the fractal characteristics of signals is expressed by chirplet-fractal dimensions.

Chirplet-fractal dimension is defined as follows:

1) Decompose signals with orthogonal chirplet transform, then high frequency coefficients are results of measuring signals with chirplet ruler. And note the coefficients with different scales as:

$$\left\{ D_{j,k} \middle| k = 1, 2, \cdots M_j \right\} \quad (6)$$

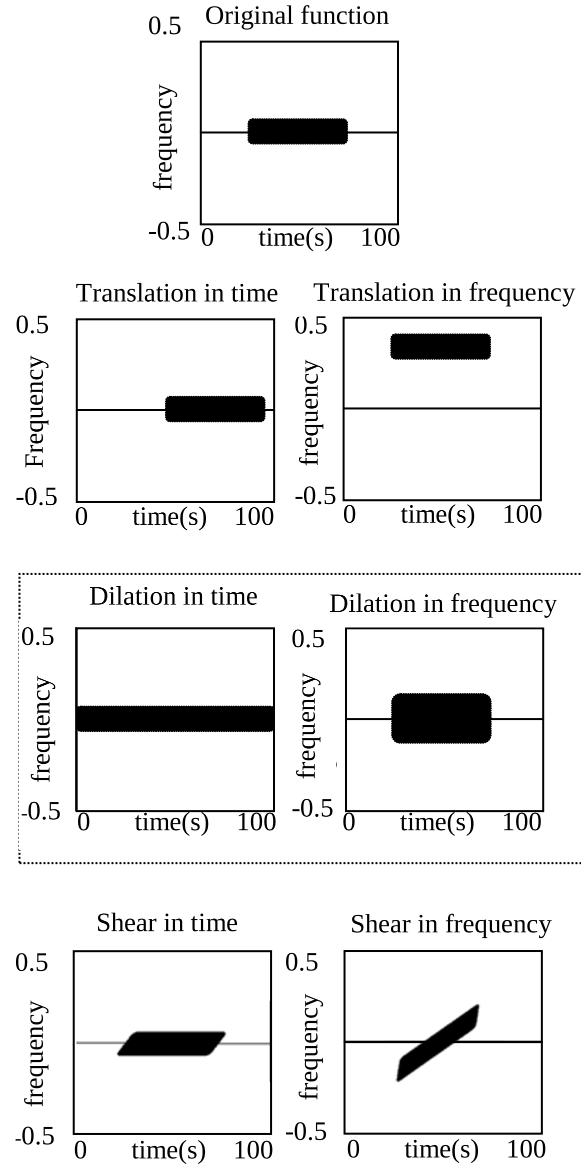


Figure 5: Five Affine Transformations Of TF Plane

where j is the level of decomposition, and M_j is the sample length of high frequency sequence in chirplet transform.

2) Take the sum of the absolute values of modified coefficients as a measurement of decomposition result obtained by chirplet transform, note it as:

$$S_j = \sum_{k=1}^{M_j} \left| D_{j,k} \right|^2 \quad (7)$$

Journal of Theoretical and Applied Information Technology
10th January 2013. Vol. 47 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 1 Five Operators Corresponding To Chirplet Transform

	1-parameter notation	**Composite notation**	**Time domain *g*(*t*)**
Time translation	$\boxed{\Rightarrow}_{t_c} g(t)$	$= M_{t_c,0,0,0,0} g(t)$	$g(t-t_c)$
Frequency translation	$\boxed{\uparrow\uparrow}_{t_c} g(t)$	$= M_{0,f_c,0,0,0} g(t)$	$e^{j2\pi f_c t} g(t)$
Time dilation /Frequency dilation	$\boxed{\Leftrightarrow}_{a} g(t)$	$= M_{0,0,a,0,0} g(t)$	$e^{-a/2} g[e^{-a}(t-a)]$
Time shear	$\boxed{\square}_{p} g(t)$	$= M_{0,0,0,p,0} g(t)$	$(-jp)^{-1/2} e^{j\pi \frac{1}{p} t^2} * g(t)$
Frequency shear	$\boxed{\downarrow\uparrow}_{q} g(t)$	$= M_{0,0,0,0,q} g(t)$	$e^{j2\pi \frac{q}{2} t^2} g(t)$

3) Plot the curve of $\ln j \sim \ln S_j$, then get Richardson plot in a similar way as box dimension, and divide the curve into three regions A, B and C in terms of different slopes, and regard region B as the scale-free region. Suppose the start point and the end point of this region are j_1 and j_2, respectively, then $\ln j \sim \ln S_j$ satisfies linear regress model:

$$\ln S_j = -D_C \ln j + b, \qquad j_1 \le j \le j_2 \tag{8}$$

The slope D_C is defined as chirplet-fractal dimension of discrete sequence, and can be gotten through least square method:

$$D_C = -\frac{(j_2 - j_1 + 1)\sum \ln j \ln S_j - \sum \ln j \sum \ln S_j}{(j_2 - j_1 + 1)\sum \ln^2 j - \left(\sum \ln j\right)^2} \tag{9}$$

where $j_1 \le j \le j_2$.

3. TESTS AND RESULTS

3.1 Test Model

The chirplet-fractal dimension of LC on HV insulators is gotten from the method proposed in this paper. And LC is gotten from the following artificial test of contaminated insulator flashover: the test is under the condition of clean fog, constant voltage and contaminating beforehand with solid pollution method. The fog room is 1.8 $m \times$ 1.8 $m \times$ 2.0 m in size, the rated capacity, rated current and rated voltage of the variable transformer are 125/250 kVA , 312.5/0.5 A and 0.4/250 kV , respectively. The tested insulator is XP-70. Among 7 pieces of insulator string in 63 kV to simulate 110 kV transmission lines, NSDD is 2.0 mg/cm^2, ESDD are 0.10 mg/cm^2, 0.15 mg/cm^2, and 0.20 mg/cm^2, respectively.

3.2 Results

The chirplet-fractal dimension of denoised LC is calculated through the method mentioned above. Figure 6 to figure 11 are LC curves of the artificial test and the corresponding chirplet-fractal dimensions, and their ESDD are 0.10, 0.15 and 0.20 mg/cm^2, respectively.

The chirplet-fractal dimensions of LC decreases along with the increasing of the LC amplitude. In initial stage, because pollution layer is being humidified in low humidity, the impact of LC is very small with sporadic spark and glow discharge, and the corresponding chirplet-fractal dimension changes hardly. Little arcs begin to discharge along with sufficiently humidified pollution layer, which leads to large impacts of LC. But owing to a few distinguish among intensities of little arcs and multiple little arcs existing at one time, the impacts of arcs discharge counteract each other, which results in some fluctuation of LC[11], and the corresponding chirplet-fractal dimension increases evenly. And then a big arc occurs and develops to the primary arc, meanwhile, LC fluctuates obviously[12]. While the primary arc runs through the whole insulator string and the flashover was brought on, LC presents a very large impact, shown as the final impact current close to 0.3A in Figures 6, 8, and 10, and the chirplet-fractal dimension concusses acutely. At the moment of flashover, the chirplet-fractal dimension decreases heavily, shown as the time of 19 in Figure7, time of 18 and 20 in Figure8, and time of 14 and 20 in Figure11.

The comparison of three chirplet-fractal dimensions of different LC is shown in figure 12. With the increase of LC, the chirplet-fractal dimension of LC presents obvious increasing trend, which includes changing hardly in the initial stage, increasing in the middle stage, and surging in the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

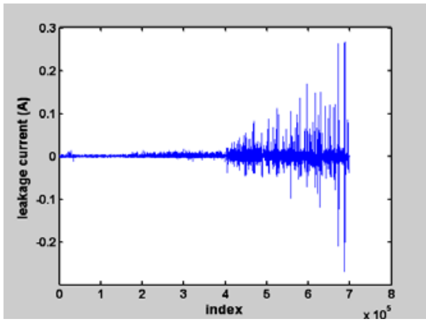


Figure 6: Leakage Current (ESDD=0.10)

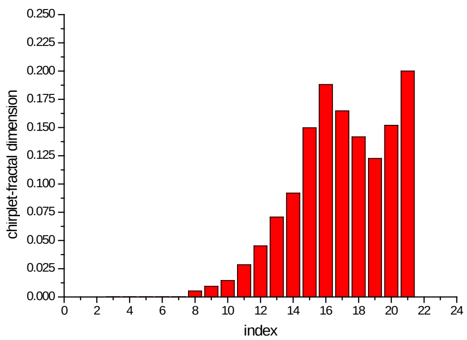


Figure 7: Chirplet-Fractal Dimension Of Figure 6

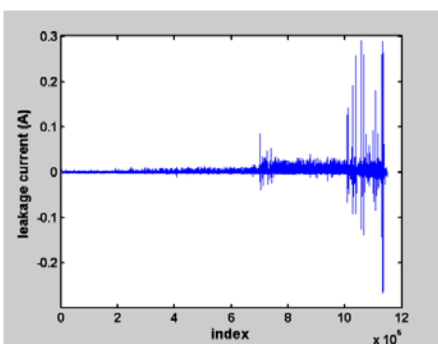


Figure 8: Leakage Current (ESDD=0.15)

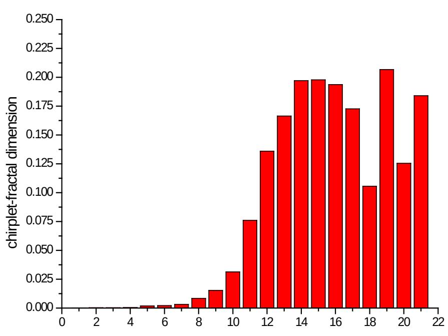


Figure 9: Chirplet-Fractal Dimension Of Figure 8

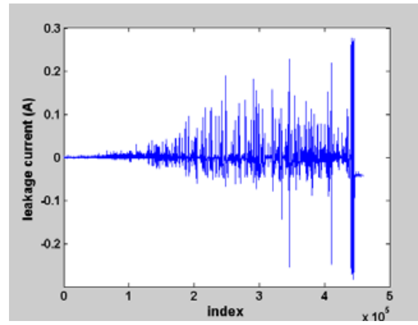


Figure 10: Leakage Current (ESDD=0.20)

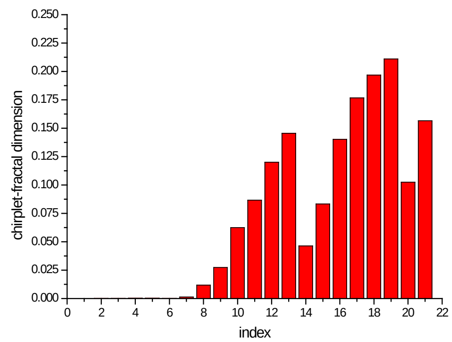


Figure 11: Chirplet-Fractal Dimension Of Figure 10

final stage. Especially, the chirplet-fractal dimension decreases heavily when LC concusses acutely. This shows that the chirplet-fractal dimension describes the information of arcs discharge in LC efficiently. Therefore, taking chirplet-fractal dimensions of LC as the eigenvalue can reflect the change law of LC during the flashover, and the supervision of LC can be realized exactly through the change of chirplet-fractal dimension.

4. CONCLUSION

A new idea called chirplet-fractal dimension, using chirplet as the ruler to define fractal dimension, is proposed in this paper, and the algorithm is described too.

The change rule of chirplet-fractal dimension of LC in artificial test of contaminated insulators is studied. The results show that the chirplet-fractal dimension can efficiently describe the change law of LC: it ascends along with the ascending of LC, and falls quickly when LC impacts wildly. Thus, chirplet-fractal dimension is a valid method to depict feature of signals, and it is also a good eigenvalue for flashover discriminations and risk predictions.

Journal of Theoretical and Applied Information Technology
10th January 2013. Vol. 47 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

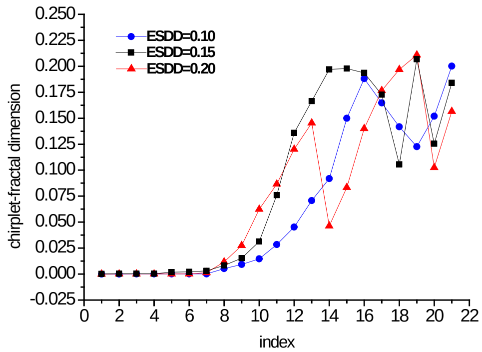


Figure 12: Chirplet-Fractal Dimensions Of LC

REFERENCES:

[1] Ramirez, Isaias, Hernández, Ramiro, Montoya, Gerardo, "Measurement of leakage current for monitoring the performance of outdoor insulators in polluted environments", *IEEE Electrical Insulation Magazine*, Vol.28, No.4, 2012, pp. 29–34.

[2] Douar, M. A., Mekhaldi, A., Bouzidi, M. C., "Flashover process and frequency analysis of the leakage current on insulator model under non-uniform pollution conditions", *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol.17, No.4, 2010, pp. 1284-1297.

[3] Chandrasekar, S., Kalaivanan, C., Cavallini, Andrea, Montanari, Gian, "Investigations on leakage current and phase angle characteristics of porcelain and polymeric insulator under contaminated conditions", *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol.16, No.2, 2009, pp. 574-583.

[4] Boudissa, Rabah, Djafri, Saâdi, Haddad, A., Belaicha, R. Bearsch, R., "Effect of insulator shape on surface discharges and flashover under polluted conditions", *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol.12, No.3, 2005, pp. 429-437.

[5] Y. Mizuno, K. Naito, W. Naganawa, "A study on probabilistic assessment of contamination flashover of high voltage insulators", *IEEE Transaction on Power Delivery*, Vol.10, No.3, 1995, pp. 1378-1383.

[6] Benoit Mandelbrot, "How long is the coast of Britain? Statistical self-similarity and fractional dimension", *Science*, Vol.156, No.3775, 1967, pp. 636-638.

[7] Tang, Dongming, Marangoni, Alejandro G., "Computer simulation of fractal dimensions of fat crystal networks", *Journal of the American Oil Chemists' Society*, Vol.83, No.4, 2006, pp. 309-314.

[8] Delgado Prieto, Miguel, Garcia Espinosa, Antonio, Riba Ruiz, Jordi-Roger, Urresty, Julio César, Ortega, Juan Antonio, "Feature extraction of demagnetization faults in permanent-magnet synchronous motors based on box-counting fractal dimension", *IEEE Transactions on Industrial Electronics*, Vol.58, No.5, 2011, pp. 1594-1605.

[9] Steve Mann, Simon Haykin, "The chirplet transform: physical considerations", *IEEE Transactions on Signal Processing*, Vol. 43, No.11, 1995, pp. 2745-2761.

[10] Yufeng Lu, Ramazan Demirli, Guilherme Cardoso, Jafar Sanii, "A successive parameter estimation algorithm for chirplet signal decomposition", *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency control*, Vol.53, No.11, 2006, pp. 2121-2131.

[11] Chrzan, Krystian Leonard, Moro, Federico, "Flashover of contaminated nonceramic outdoor insulators in a wet atmosphere", *IEEE Transactions on Power Delivery*, Vol.22, No.1, 2007, pp. 466-471.

[12] Dhahbi-Megriche, N. Beroual, A., "Dynamic model of discharge propagation on polluted surfaces under impulse voltages", *IEE Proceedings: Generation, Transmission and Distribution*, Vol. 147, No.5, 2000, pp. 279-284.