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A New Technique For Discrimination Between Inrush Current And Fault Current In A Power Transformers

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Abstract-* *This paper presents an accurate discrimination between fault and inrush current in power transformers. The method is based on that the waveform of the inrush distorts seriously, while the fault current nearly keeps sinusoid . The complicated signal can be decomposed into a finite intrinsic mode functions (IMF) by the Empirical Mode Decomposition (EMD), then define and compute the projection area on X-axis of each IMF-S_{ci}, the specific gravity of SIMF- K_{ci}, and the maximum of K_{ci}-K_{max}. Theoretical analysis show that the method can precisely discriminate inrush and fault current, fault clearance time is about 20ms. Moreover, it is convenient to achieve and hardly be affect by not-periodic component. Simulated results show the proposed technique can accurately discriminate between fault and inrush current in a power Transformer protection.

***Keywords*—Inrush Current, Transformer Protection, EMD, IMF, Fault detection.**

I. INTRODUCTION

Transformer protection is critical issue in power system and the issue lies in the accurate and rapid discrimination of inrush from fault current. This paper describes a new method to discriminate the inrush current and fault using the Empirical Mode Decomposition (EMD). At present, the domestic transformer primary protection in power system configuration mainly uses second harmonic restraint principle and longitudinal differential protection based on current discontinuous corner braking principle. The long-term operating experience shows that the differential protection cannot accurately distinguish the difference between the transformer internal faults and external faults, so the main contradiction is still focused on the identification of magnetizing inrush and internal fault [5].

II. METHOD

A. *Theorical Overview of EMD*

The Empirical Mode Decomposition (EMD) has been proposed as an adaptive time-frequency data analysis method [7]. This adaptive technique is derived from the simple assumption that any signal consists of different intrinsic mode functions (IMF) each of them representing an embedded distinctive oscillation on a separated time-scale. An IMF is defined by two criteria: i) the number of extrema and of zero crossings must either equal or differ at most by zone, and, ii) at any instant in time, the mean value of the envelope defined by the local maxima and the envelope of the local minima is zero. The following plan offers an idea about the principle algorithm of the EMD:

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1. Initialize $r_0(t) = x(t); j = 1$
2. Extract the $j\_th$ IMF:
  (a) Initialize $h_0(t) = r_j(t); k = 1$
  (b) Locate local maxima and minima of $h_{k-1}(t)$
  (c) Cubic spline interpolation to define upper and lower envelope of $h_{k-1}(t)$
  (d) Calculate mean $m_{k-1}(t)$ from upper and lower envelope of $h_{k-1}(t)$
  (e) Define $h_k(t) = h_{k-1}(t) - m_{k-1}(t)$
  (f) If stopping criteria are satisfied then $h_j(t) = h_k(t)$ else goto 2. (b) with $k = k + 1$
3. Define $r_j(t) = r_{j-1}(t) - h_j(t)$
  4. If $r_j(t)$ still has at least two extrema then go to 2.
  (a) with $j = j + 1$ else the EMD is finished
  5. $r_j(t)$ is the residue of $x(t)$
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At the end of this numerical sifting process the signal $x(t)$ can be expressed:

$$x(t) = \sum_{j=1}^{n} h_j(t) + r_n(t)$$

Where $h_j(t)$ indicates the j_th IMF, n as the number of sifted IMF and $r_n(t)$ denotes a residue which can be understood as the trend of the signal

B. *Decomposition Process of EMD Method*

The EMD decomposition method is based on the following as assumptions: 1) Data must include at least two extreme values, a maximum value and minimum value; 2) Local time domain characteristics of the data is uniquely determined by the time scale between the extreme points; 3) If data has an inflection point instead of extreme point, the decomposition results can be obtained by differentiating the data once or more times and integrating the extremism. The essence of this approach gets the intrinsic fluctuations mode by the characteristic time scale of the data, and then break down the data. This decomposition process can be vividly called “selecting” process.

Decomposition process: Find out all the maxima of the original data sequence x (t) and cubic saline interpolation function fitting form of the original data on envelope; Similarly, find out all the minimum point, and all of the minimum point formed by cubic spine interpolation function fitting the data under the envelope, the upper envelope and lower envelope means recorded as 1 m, The original data sequence x (t) by subtracting the average envelope obtain a new data sequence [5].

$$h_1 = x(t) - m_1$$

C. Simulation and Application

A system with a generator, a three phase transformer and a load has been simulated. A typical 750MVA, 27/420KV, Power transformer is connected between 25KV source at sending end 400 KV transmission line three phase connection diagram are shown in Figure 1. I_{ad} I_{bd} I_{cd} 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 Figure 2. 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 [16].

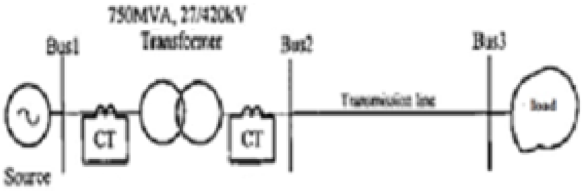

Fig.1. Simulated Power system model

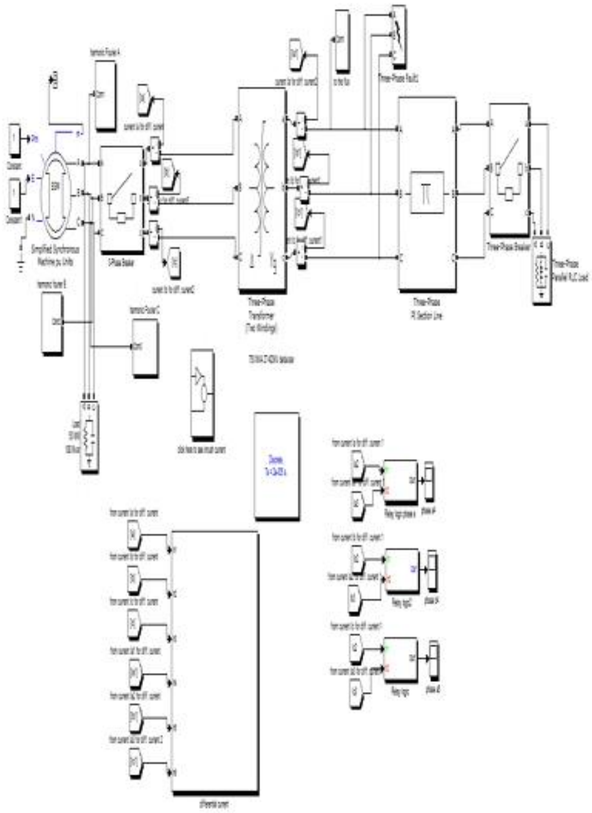

Fig.2. MATLAB model

D. Specific Methods and Protection Criteria Search IMF [5].

The dominant IMF is broken down into component of the IMF with a large amplitude .In order to search for the dominant IMF easily, this article defines IMF component C_i on the horizontal axis of the projected area S_{ci} as follows:

$$S_{ci} = \int_{t_0}^{t_n} |C_i(t)| dt$$

$$S_{ci} = \sum_{1}^{n} |C_i(t)\Delta t|$$

According to formula the way to get the dominant IMF is: Calculate the various components coif IMF then $S_{max} = \max\{S_{ci}, i = 1 \ldots . n\}$, if the S_{ci} of C_i have a difference with S_{max} in 20%, ci of IMF is the dominant IMF.

E. Protection Criteria

The According to this identification principle, we define the proportion c_i of component coefficient k_{ci} is:

$$K_{ci} = \frac{S_{ci}}{\sum_1^n S_{ci} + S_r}$$

Assume the largest proportion of coefficients of IMF is K_{max},

$$K_{max} = \frac{max_1^n\{S_{ci}\}}{\sum_1^n S_{ci} + S_r}$$

As it can be seen in formula, the value of K_{max} changes between 0~1, When the differential current is fault current, since it contains only one dominant IMF, the value of k_{max} is very large, almost above 0.9. When the differential current is inrush current due to the presume to the presence of two or more similar to the proportion coefficient leading the IMF the value of k_{max} is 0.5. Additionally, when the magnitude of the differential current data window is not greater than the maximum unbalanced current the value of k_{max} is 0. Therefore, we can obtain protection criterion as shows:

$$K_{max} \geq K_{zd}$$

K_{zd} = 0.8 respectively calculate three-phase differential current K_{max} Define [5].

F. *Proposed Protection Algorithm*

A Flowchart of the proposed algorithm is seen in Figure 4 [14].

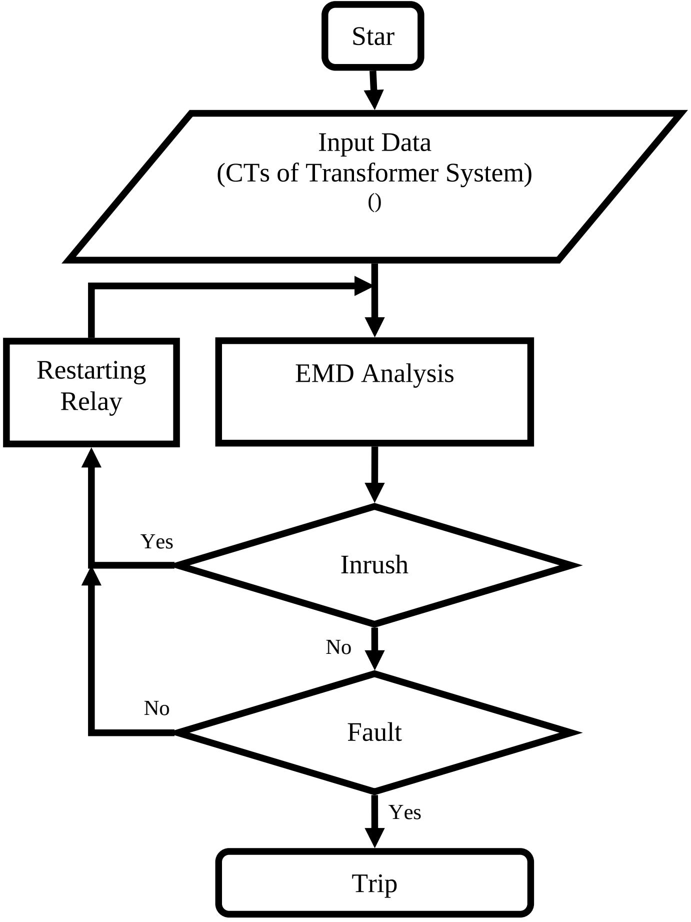

Fig. 4: A flowchart of the proposed algorithm

III. TESTS AND RESULTS

A. *Case A: Transformer DD*

Experimental transformer no-load inrush current and load interterm fault cases, the two sets of waveforms, and a group of normal waveform. Since this article transformer experiment is the presence of harmonic components in the laboratory, during the test, so the experimental results from the waveform is not sinusoidal waveform, but presents the trend of a square wave. Transformer inrush current experimental waveform graph is showed in Figure 5 and EMD analysis is showed in Table 1. Transformer fault current experimental waveform is showed in Figure 6 and EMD analysis is showed in Table 2.

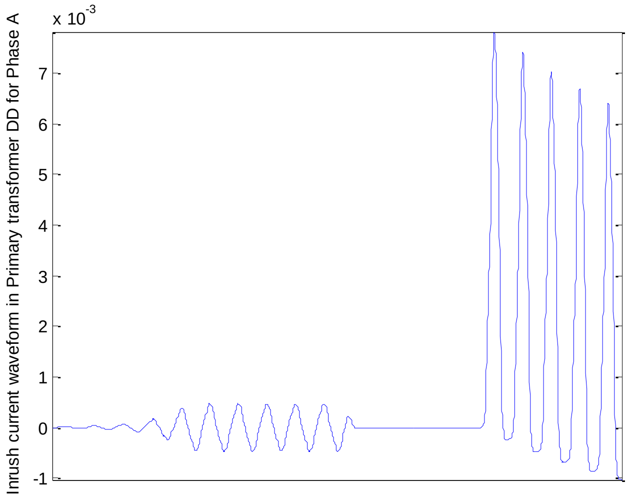

Fig. 5: Inrush current waveform in Primary transformer DD for Phase A

Table 1: EMD analysis of inrush current in Primary transformer DD for Phase A

IMF-S_{ci}		K_{max}
i=1	0.0000	2.238
i=2	0.0001	
i=3	0.0000	
i=4	0.0001	
i=5	0.0003	
i=6	0.0067	
i=7	0.0502	
i=8	0.0025	
i=9	0.0078	
i=10	0.0206	
i=11	0.0550	
i=12	0.2939	

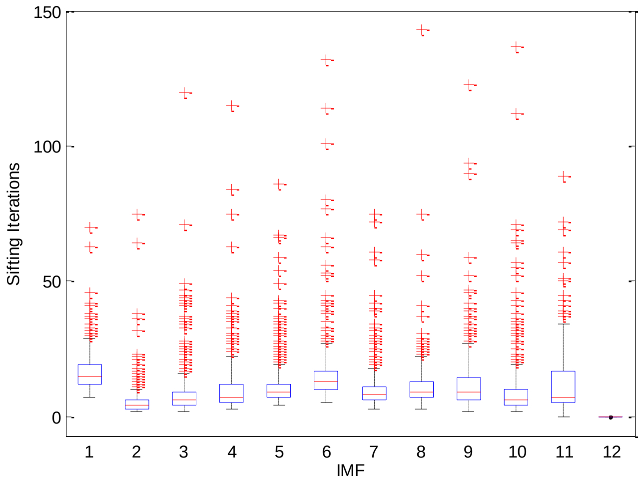

Fig. 6: Boxplots showing the sifting iterations for each mode Inrush current transformer DD with EEMD

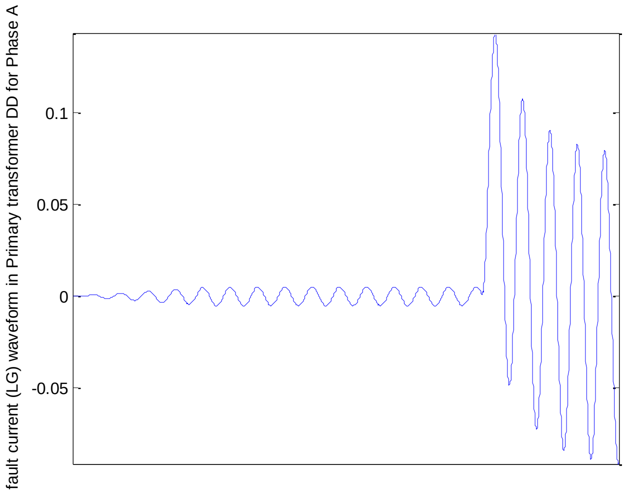

Fig. 7: fault current (LG) waveform in Primary transformer DD for Phase A

Table 2: EMD analysis of fault current (LG) in Primary transformer DD for Phase A

IMF-S_{ci}		K_{max}
i=1	0.0004	3.267
i=2	0.0004	
i=3	0.0103	
i=4	0.0055	
i=5	0.0035	
i=6	0.0040	
i=7	0.0094	
i=8	0.1384	
i=9	0.4296	
i=10	0.8038	
i=11	0.2480	
i=12	3.2554	

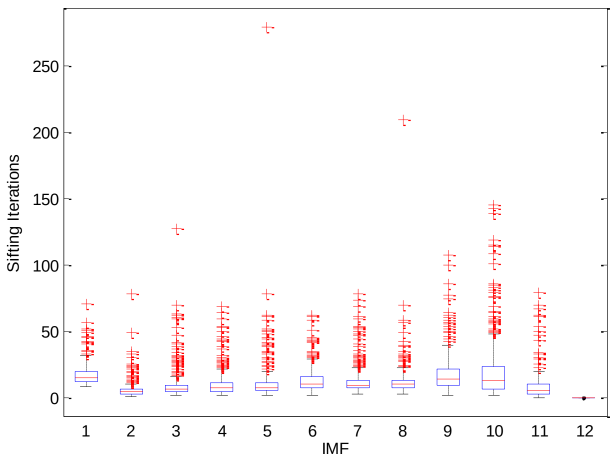

Fig. 8: Boxplots showing the sifting iterations for each mode fault current (LG) transformer DD with EEMD

B. Case A:Transformer YD

Experimental transformer no-load inrush current and load interterm fault cases, the two sets of waveforms, and a group of normal waveform. Since this article transformer experiment is the presence of harmonic components in the laboratory, during the test, so the experimental results from the waveform is not sinusoidal waveform, but presents the trend of a square wave. Transformer inrush current experimental waveform graph is showed in Figure 7 and EMD analysis is showed in Table 3. Transformer fault current experimental waveform is showed in Figure 8 and EMD analysis is showed in Table 4.

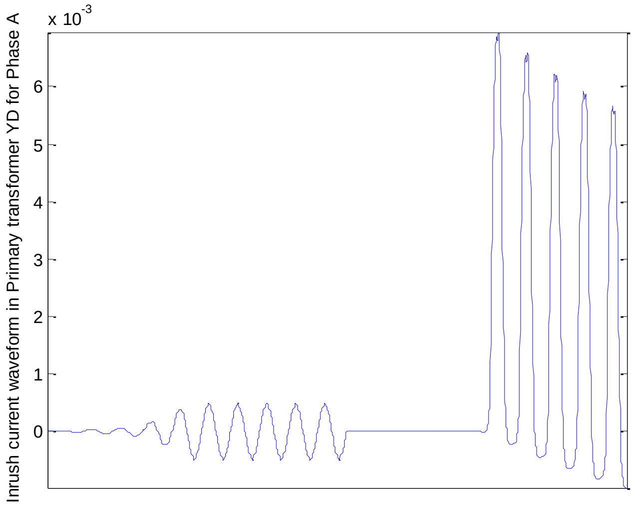

Fig. 9: Inrush current waveform in Primary transformer YD for Phase A

Table 3: EMD analysis of inrush current in Primary transformer YD for Phase A

IMF-S_{ci}		K_{max}
i=1	0.0003	0.881
i=2	0.0002	
i=3	0.0016	
i=4	0.0008	
i=5	0.0001	
i=6	0.0019	
i=7	0.0506	
i=8	0.0013	
i=9	0.0130	
i=10	0.0225	
i=11	0.0742	
i=12	0.2594	

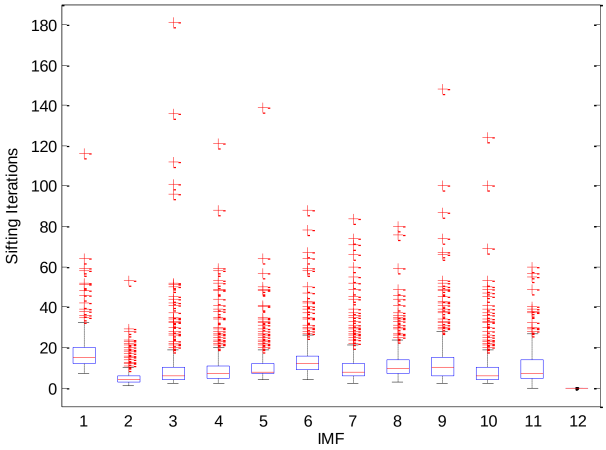

Fig. 10: Boxplots showing the sifting iterations for each mode Inrush current transformer YD with EEMD

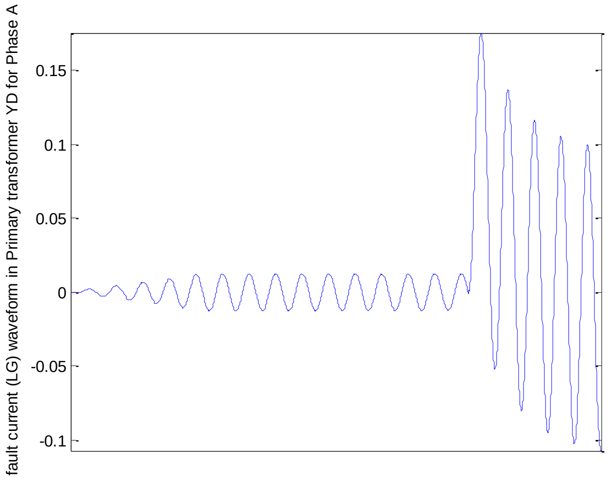

Fig. 11: fault current (LG) waveform in Primary transformer YD for Phase A

Table 4: EMD analysis of fault current (LG) in Primary transformer YD for Phase A

IMF-S_{ci}		K_{max}
i=1	0.0024	6.04
i=2	0.0036	
i=3	0.0180	
i=4	0.0140	
i=5	0.0032	
i=6	0.0026	
i=7	0.0112	
i=8	0.1547	
i=9	0.7522	
i=10	0.8783	
i=11	0.5879	
i=12	4.4711	

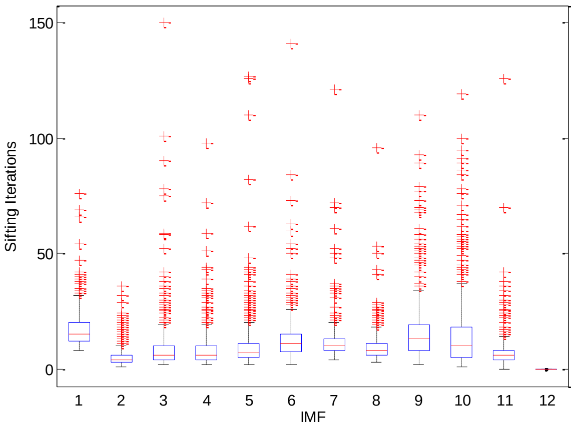

Fig. 12: Boxplots showing the sifting iterations for each mode fault current (LG) transformer YD with EEMD

C. Case A: Transformer YY

Experimental transformer no-load inrush current and load interterm fault cases, the two sets of waveforms, and a group of normal waveform. Since this article transformer experiment is the presence of harmonic components in the laboratory, during the test, so the experimental results from the waveform is not sinusoidal waveform, but presents the trend of a square wave. Transformer inrush current experimental waveform graph is showed in Figure 9 and EMD analysis is showed in Table 5. Transformer fault current experimental waveform is showed in Figure 10 and EMD analysis is showed in Table 6.

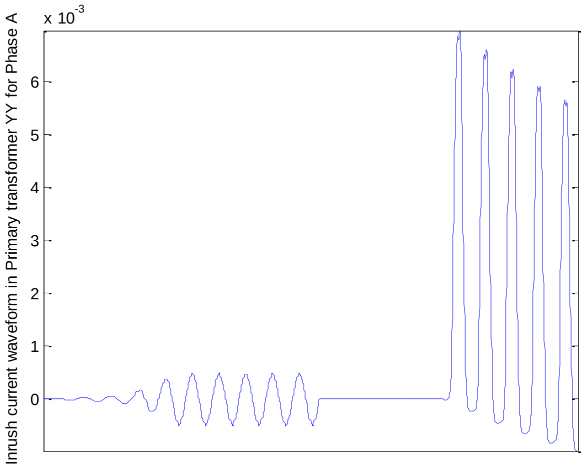

Fig. 13: Inrush current waveform in Primary transformer YY for Phase A

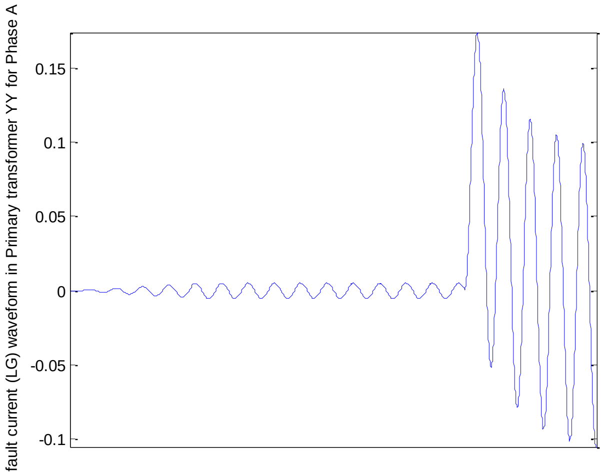

Fig. 15: fault current (LG) waveform in Primary transformer YY for Phase A

Table 5: EMD analysis of inrush current in Primary transformer YY for Phase A

IMF-S_{ci}		K_{max}
i=1	0.0005	0.285
i=2	0.0003	
i=3	0.0003	
i=4	0.0004	
i=5	0.0002	
i=6	0.0012	
i=7	0.0510	
i=8	0.0030	
i=9	0.0091	
i=10	0.0203	
i=11	0.0637	
i=12	0.486	

Table 6: EMD analysis of fault current (LG) in Primary transformer YY for Phase A

IMF-S_{ci}		K_{max}
i=1	0.0076	3.320
i=2	0.0028	
i=3	0.0270	
i=4	0.0181	
i=5	0.0011	
i=6	0.0048	
i=7	0.0185	
i=8	0.1375	
i=9	0.6485	
i=10	0.9977	
i=11	0.4552	
i=12	4.6194	

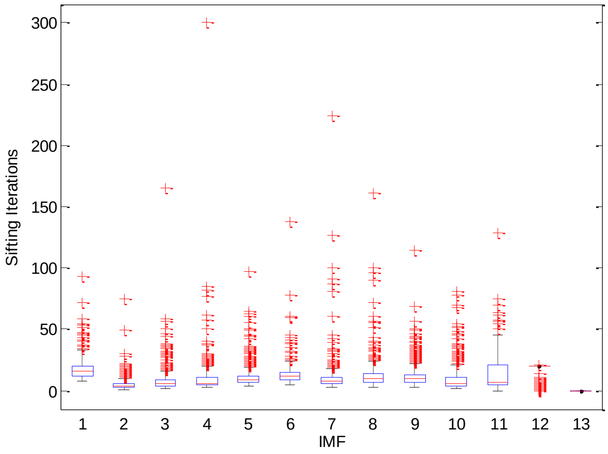

Fig. 14: Boxplots showing the sifting iterations for each mode fault current (LG) transformer YY with EEMD

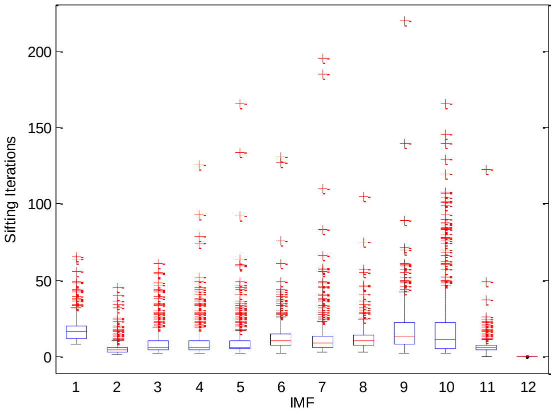

Fig. 16: Boxplots showing the sifting iterations for each mode fault current (LG) transformer YY with EEMD

The value of k_{max} based on EMD analysis in transformer with DD connection is 2.238 for inrush current and 3.267 for fault current, in transformer with YD connection is 0.881for inrush current and 6.04 for fault current, in transformer with YY connection is 0.285 for inrush current and 3.320 for fault current. It is concluded that Kmax is less than 3 for inrush current and more than 3 for fault current.

The value of Scifor IMFs based on EMD analysis; in transformer with DD connection is 0.2939 for inrush current and 3.2554for fault current, in transformer with YD connection is 0.2594 for inrush current and 4.4711 for fault current, in transformer with YD connection is 0.486 for inrush current and 4.6194 for fault current. It is concluded from IMFs that Sci is less than 1 for inrush current and more than 3 for fault current.

IV. CONCLUSIONS

The processing method, fundamentally speaking, is based on the analysis of the three-phase current fundamental and higher harmonics, and then determines the algorithm of the higher harmonic content, but makes the method different from the conventional signal due to the role of the EMD methods of analysis. It is more convenient from the principles and experimental methods to distinguish normal airdrop and fault conditions, but there are also some shortcomings. The main reason is that the EMD algorithm is still not perfect in the border problem and envelope fitting: Firstly, there is not a suitable envelope exploded function resulting in fluctuations of max K; secondly, there is no particularly good boundary processing method.

References

[1] T. Y. Li, Y. Zhao and N. Li, “A New Method for Power Quality Detection Based on HHT,” *Proceedings of the Csee*, Vol. 25, No. 17, 2005, pp. 52-56

[2] Z. Ke, J. Jie and T. Q. Zhang, “Distinguishing Magnetizing Inrush Based on Characteristic of Equivalent Instantaneous Inductance,” *Power System Protection and Control*, 2010, pp. 12-16

[3] J. A. Sykes and L. F. Morrison, “A Proposed Method of Harmonic Restraint Differential Protection of Transformers by Digital Computer,” *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-91, pp.

[4] F. M. Cao and P. P. Su, “The Application of Wavelet transform in Transformer’s Differential Protection,” *Electric Power*, Vol. 31, No. 11, 1998, pp. 21-24.

[5] Fanyuan Zeng, Qianjin Liu, Chao Shi." The Discrimination of Inrush Current from Internal Fault of Power Transformer based on EMD"; *Energy and Power Engineering*, 2013, 5, 1425-1428

[6] M.A. Rahman, B. So, M. R. Zaman, M.A. Hoque", Testing of Algorithms for A Stand-Alone Digital Relay for Power Transformers, *IEEE Transactions on Power Delivery*, Vol. 13, No. 2, April 1998.

[7] M. Habib, M.A. Marin", A Comparative Analysis of Digital Relaying Algorithms for Deferential Protection of Three Phase Transformers, *IEEE Transactions on Power Systems*, Vol. 3. No. 3, August 1988.

[8] M. Fancisco, A.A. Jose, Wavelet Based ANN Approach For Transmission Line Protection, *IEEE Power Engineering Review*, 2003.

[9] P. Liu, O. P. Malik, D. S. Chen, G. S. Hope and Y. Guo, “Improved Operation of Differential Protection of Power Transformers for Intemal Faults,” *IEEE Transactions on Power Delivery*, Vo1. 7,1992.

[10] S. H. Jiao, W. S. Liu, J. F. Liu, Z. H. Zhang and Q. X. Yang, “A New Principle of Discrimination between Inrrush Current and Fault Current of Transformer Based on Wavelet,” *Proceedings of the CSEE*, Jul. 1999, pp. 1-5.

[11] Y.W. Seng, Q. Wang, A. Wavelet Based Method to Discriminate Between Inrush Current and Internal Fault, Power System Technology, 2000. Proceedings. PowerCon 2000. *International Conference*, Volume: 2, 4-7 Dec. 2000, Page(s): 927 -931 vol. 2.

[12] L. M. Peilin, R.K. Aggarwal, A Novel, Approach to the Classication of the Transient Phenomena in Power Transformers Using Combined Wavelet Transform and Neural Network, *IEEE Transactions on Power Delivery*, Vol. 16, No. 4, October, 2002.

[13] M. Vannucci, P.J. Brown, T. Fearn, A Decision Theoretical Approach to Wavelet Regression on Curves With a High Number of Regressors. *Journal of Statistical Planning and Inference*, 112(1-2), 195-212, 2003

[14] Mahdi Mozaffari Legha, Rouhollah Abdollahzadeh Sangrood, Ardalan Zargar Raeiszadeh, Mohammad Mozaffari Legha,, “CONDUCTOR SIZE SELECTION IN PLANNING OF RADIAL DISTRIBUTION SYSTEMS FOR PRODUCTIVITY IMPROVEMENT USING IMPERIALIST COMPETITIVE ALGORITHM”, International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 15, Vol. 5, No. 2, pp. 65-69, June 2013.

[15] M.A. Rahman, B. Jeyasurya", A State-of-The-Art Review of Transformer Protection Algorithms, *IEEE Transactions on Power Delivery*, Vol. 3, No. 2, April 1988.

[16] Mohammad Nayeem A Tahasildar & S. L. Shaikh" A Novel Technique for Power Transformer Protection based on Combined Wavelet Transformer and Neural Network"; *International Journal of Advanced Electrical and Electronics Engineering, (IJAEEE)*, Volume-2, Issue-4, 2013, pp: 2278-8948.

[17] Mahdi Mozaffari Legha, Mohammad Mohammadi, “Aging Analysis and Reconductoring of Overhead Conductors for Radial Distribution Systems Using Genetic Algorithm“ *Journal of Electrical Engineering & Technology (JEET)* , 2014.

[18] Mahdi Mozaffari Legha, Hassan Javaheri, Mohammad Mozaffari Legha, “Optimal Conductor Selection in Radial Distribution Systems for Productivity Improvement Using Genetic Algorithm “*Iraqi Journal for Electrical and Electronic Engineering (IJEEE)*, Vol.9 No.1 , 2013, 29-36.

[19] Okan OZG ONENEL, Guven ONBILGIN, Cagr KOCAMAN." Transformer Protection Using the

Wavelet Transform". *Power Turk J Elec Engin, TUBITAK* 2005, VOL.13, NO.1,pp: 119-135.

[20] M. Mozaffari Legha, (2011) Determination of exhaustion and junction of in distribution network and its loss maximum, due to geographical condition, MS.c Thesis. Islamic Azad University, Saveh Branch, Markazi Province, Iran.

[21] Mahdi Mozaffari Legha Majid Gandomkar, “Reconfiguration of MV network for balancing and reducing losses to by CYMEDIST software in Khorramabad”, 16th Electric Power Distribution Conference (EPDC16), pp. 25-32, 2012.

BIOGRAPHIES

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Mohammad Mozaffari Legha MSc student of Communication Engineering from Department of Electrical Engineering, Institute of Higher Education Besat, Kerman. He is interested in the Renewable Energy, stability of power systems and power distribution systems, reliability and power electronics. He has presented more than 5 journal papers and 15 conference papers.