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Fault Detection and Classification in Transmission lines based on a Combination of Wavelet Singular Values and Fuzzy Logic

Majid NAYERİPOUR[1,*], Amir Hosein RAJAEİ[1], Mohammad Mehdi GHANBARİAN[1], Moslem DEHGHANİ[2]

[1]*Department of Electrical and Electronics Engineering, Shiraz University of Technology, IRAN*

[2]*School of Engineering, Islamic Azad University-Kazerun Branch, IRAN*

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Abstract. In this paper, a new method for fault detection and classification in transmission lines has been used. This method, called Fuzzy-Wavelet Singular Values, combines the advantages of wavelet transform and singular value decomposition, then uses fuzzy logic to detect and classify the fault. The proposed algorithm uses the singular values of wavelet transform of three phases and zero sequence current for fault detection and classification. The input of fuzzy logic is singular values wavelet transform of zero sequence and three phase currents, three phase indexes are used to detect the faulty phase from sound phase, and the zero sequence index is used to detect phase to ground fault. The designed algorithm is able to detect various types of fault such as single phase to ground, double phase to ground, three phase to ground and phase to phase and this protection scheme is robustness to parameters such as fault resistance, fault location and fault type. The proposed scheme is able to detect the fault within 10 ms from the fault inception to prevent some problems such as stability and equipment damage. The Matlab software is used to model the system and performance of the algorithm.

Keywords: Wavelet transform, fault classification, fault detection, fuzzy logic, singular value decomposition.

1. INTRODUCTION

To keep the stability of power system, system disturbance such as fault inception should be detected immediately. The protection relay in transmission line should disconnect the faulty part from the system in the shortest possible time and prevent incidence problems such as the loss of stability and equipment damage. The faulty part is then detected and the relay is operated, the damaged part must be repaired to allow the faulty part to enter to the system. Because of the length of the transmission line, the fault location algorithms must be used to determine the faulty point [1]. Thus, fault detection and classification are two major categories of transmission lines.

In general, fault classification methods are classified into two groups: the first group of methods is based on the variation of voltage and current lines and the second group is intelligence method based on fuzzy logic, artificial intelligence, neural network, etc [2].

Different methods of fault detection and classification have been presented in recent years, a number of which are mentioned as follows: in reference [3], wavelet singular entropy (WSE)

* Corresponding author. *Email address*: *nayeri@sutech.ac.ir*

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technique combines the advantages of wavelet transform (WT), singular value decomposition (SVD) and Shannon entropy are used for fault detection and classification in transmission lines. In reference [4], WT feature extraction method is presented for automatic fault detection and classification in electrical power systems, and it is shown that the WSE is sensitive to noise and abrupt variation of signal. The WSE is used in fault detection and protection for out-of-step blocking in power oscillation [5]. In [6], functional analysis and intelligent computing is used to detect and classify the fault in transmission line of power system. Reference [7] describes a new distance relay for fault detection and classification in transmission line that is used in wavelet transform. Fault detection based on rate of change of frequency relay (ROCOF) and vector surge (VS) relay is presented and the two types of relay are compared [8]. [9] presents a method based on wavelet multi-resolution analysis (MRA) for fault classification. In reference [10], S transform is used to calculate the statistical properties of the current signal and then the tree decision is used as the input index of fuzzy logic to classify the fault. In [11], only the three phase current signals are sampled as the input index of fuzzy logic to classify the fault type at the end of lines. In [12] wavelet MRA algorithm is presented to classify fault in transmission lines and it is shown that the algorithm is independent of the fault location, fault resistance and the fault inception angle. An intelligence technique for automatic fault detection is presented in [13]; this method combines fuzzy logic and genetic algorithms (GA). In [14] wavelet fuzzy analysis method is presented to detect fault.

In this paper, a new technique based on a combination of features and applications of wavelet transform [15], singular value decomposition [16] and fuzzy logic (FIS) [17] is presented. This combination creates an effective method with high speed performance in fault detection and classification and causes relays to perform correctly and accurately.

The three phase currents are sampled where the relay is placed and zero sequence of currents is calculated, then the currents are analyzed by wavelet transform to obtain the components. The singular values coefficients are obtained by SVD, and finally five indexes are defined, three of which are based on the wavelet singular value of three phase current a, b, c, one index is based on the summation of singular values of three phase current and the remaining index is based on the wavelet singular value of zero sequence current. These five indexes are applied as input parameters of fuzzy system to detect fault, sound phase and faulty phase.

This paper is organized as follows: in section (2), the principle of SVD, WT and FIS has been studied. System modeling and simulation results are expressed in section (3). In section (4), the main conclusion is expressed.

2. Fuzzy-Wavelet singular values

a. Wavelet transform

Wavelet transform is one of the most widely used mathematical transformations in the field of processing, in particular, in signal and image processing. Due to the nature of multi-resolution analysis, this transform has been utilized in many processing applications and is an efficient tool.

In wavelet analysis, the desired signal is multiplied in a wavelet function like a discrete fourier transform, in fact, it plays the role of window function.

Accordingly, a continuous wavelet transform is defined as [15]:

$$W_{\tau,m}(t) = \frac{1}{\sqrt{m}} \int_{-\infty}^{+\infty} x(t)\,\Psi\left(\frac{t-\tau}{m}\right) dt \tag{1}$$

Where, τ and m are translation parameter and scaling parameter, respectively. The wavelet transform does not have a direct frequency parameter. Instead, there is a scale parameter which is inversely related to the frequency. In other words, s=1/f. In relation (1), Ψ is the window function which is called mother wavelet.

Wavelet transform coefficient C(m, τ) is defined as follows:

$$C(m,\tau) = \int_{0}^{+\infty} x(t)\,\Psi'_{\tau,m}(t)\, dt \tag{2}$$

b. Singular value decomposition

Singular value decomposition is a method which decomposes matrix A (m*n) into three matrixes U, D and V, any obtained matrix from this decomposition has unique features. m*r matrix U is a column orthogonal matrix, r*r matrix D is a diagonal matrix whereby the singular values are on the diagonal, and the transpose of the matrix V is an orthogonal n*r matrix. SVD decomposition of the matrix A can be expressed as follows [16]:

$$A = UDV^{T} \tag{3}$$

$$D = \begin{bmatrix} \lambda_1 & 0 & \dots & 0 \\ 0 & & & \vdots \\ \vdots & & \lambda_i & 0 \\ 0 & \dots & 0 & \lambda_r \end{bmatrix} ;\ i = 1,\dots,r \tag{4}$$

Values on the diagonal matrix D are defined as a 1*r row matrix Q which is expressed as:

$Q = \text{diag}[D] = [\lambda_1 \lambda_2 \ \ldots \ \lambda_{r-1} \lambda_r]$ (5)

where $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_{r-1} \geq \lambda_r > 0$

And λ_i $(i = 1, 2, \ldots, r)$ is called nonzero singular value of matrix D.

c. Fuzzy Logic

The fuzzy system is a process that uses a set of rules and fuzzy membership functions to make decisions about data uses. The algorithm is based on variations outside the allowable amount of wavelet singular values of each phase, that can detect fault and fault type. So, the classification indexes are defined for each phase and another index is defined to detect ground fault.

The indexes below are used to evaluate variation:

$$m = \lambda_{total} - \lambda_{base} \tag{6}$$

Index m is used to detect fault wherein λ_{total} is the summation of singular values of phases a, b and c.

$$\lambda_{total} = \lambda_c + \lambda_b + \lambda_a \tag{7}$$

And λ_{base} is the summation of singular values of wavelet transform of phases a, b and c in normal condition. λ_{total} is calculated consistently and is subtracted from λ_{base} of the system (λ_{base} is constant) to obtain the index m.

If a fault occurrs in the system, λ_{total} is made higher than the λ_{base} and thus the fault is detected.

m_a, m_b, m_c and m_g indexes are used for fault classification, in which indexes are defined as the phases a, b, c and ground, respectively.

$$m_a = \lambda_a - \lambda_{base\,(a)} \tag{8}$$

$$m_b = \lambda_b - \lambda_{base\,(b)} \tag{9}$$

$$m_c = \lambda_c - \lambda_{base\,(c)} \tag{10}$$

$$m_g = \lambda_g$$

λ_a, λ_b, λ_c and λ_g are wavelet transform singular values of three phase current a, b, c and zero sequence respectively, which is calculated continuously. $\lambda_{base\,(a)}$, $\lambda_{base\,(b)}$ and $\lambda_{base\,(c)}$ are wavelet singular values of three phase current a, b and c in normal condition, respectively. Fault detection and classification algorithm based on fuzzy wavelet singular values is shown in figure (1);

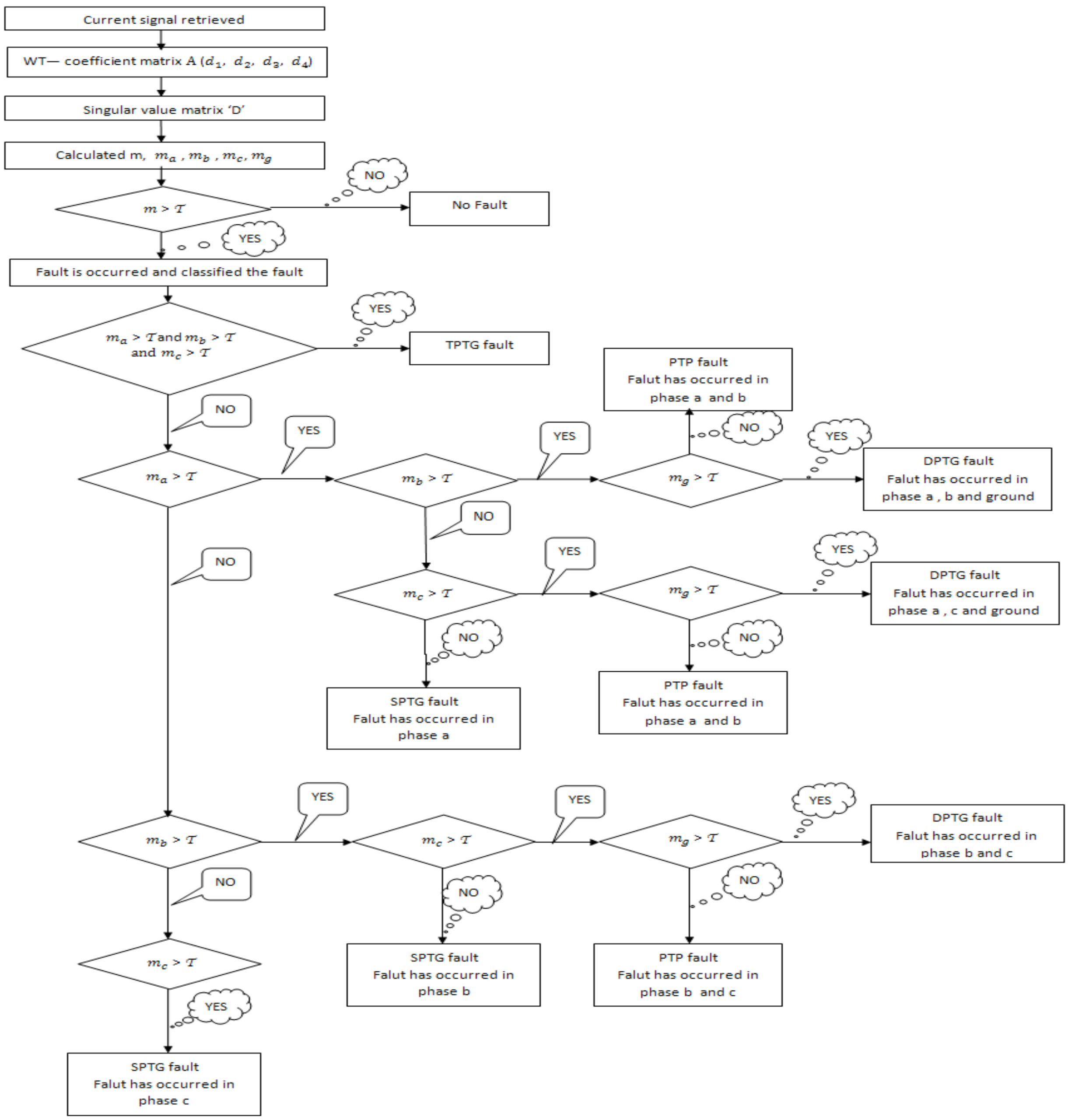

Figure 1. Fault detection and classification algorithm flowchart.

3. MODELİNG AND SİMULATİON SYSTEM

a. Sample system

Figure (2) shows the three phase system that consists of two machines which are placed in the source and target to produce the phases current under different condition. Relay is placed after synchronous machines and before transmission lines to sample the current and voltage signals. Matlab software is used for simulation. The simulation is studied in normal condition and different types of fault such as single phase to ground (SPTG), double phase to ground

(DPTP), three phase to ground (TPTG) and phase to phase (PTP) under various conditions such as fault resistance, power angle shift and different location of fault inception.

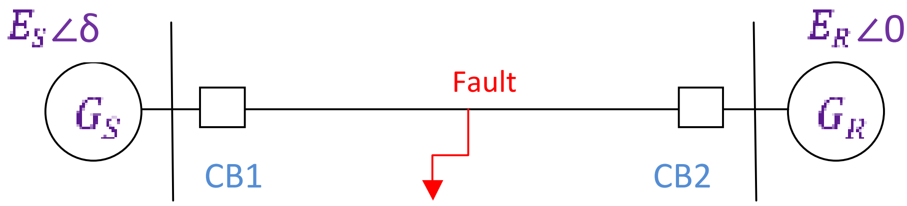

Figure 2. Power system model.

Details of generators and transmission lines are presented in the following:

G_S: Rate short circuit MVA = 20000 , f = 50 Hz, V_{base} = 735 KV, Phase angle of phase A (degrees) = 15, X/R ratio = 10.

G_R: Rate short circuit MVA = 20000 , f = 50 Hz, V_{base} = 735 KV, Phase angle of phase A (degrees) = 0, X/R ratio = 10.

Distribution line = 600 Km, r1 = 0.027 Ω/Km, r0 = 0.1948 Ω/Km, L1 = 0.8858e-3 H/Km, L0 = 2.067e-3 H/Km, C1 = 12.7e-9 F/Km, C0 = 9e-9 F/Km, f = 50 Hz.

b. Simulation results

In this study, three phase current signals are retrieved where the relay is placed and the zero sequence current is calculated, then the indexes m, m_a, m_b, m_c and m_g that are the input indexes of fuzzy logic are calculated based on what is mentioned in section (2). If a fault occurs in the system, m is out of range and fuzzy system detects that a fault has occurred in the system. After fault detection, fuzzy system uses m_a, m_b, m_c and m_g indexes to detect fault type that has occurred in the system.

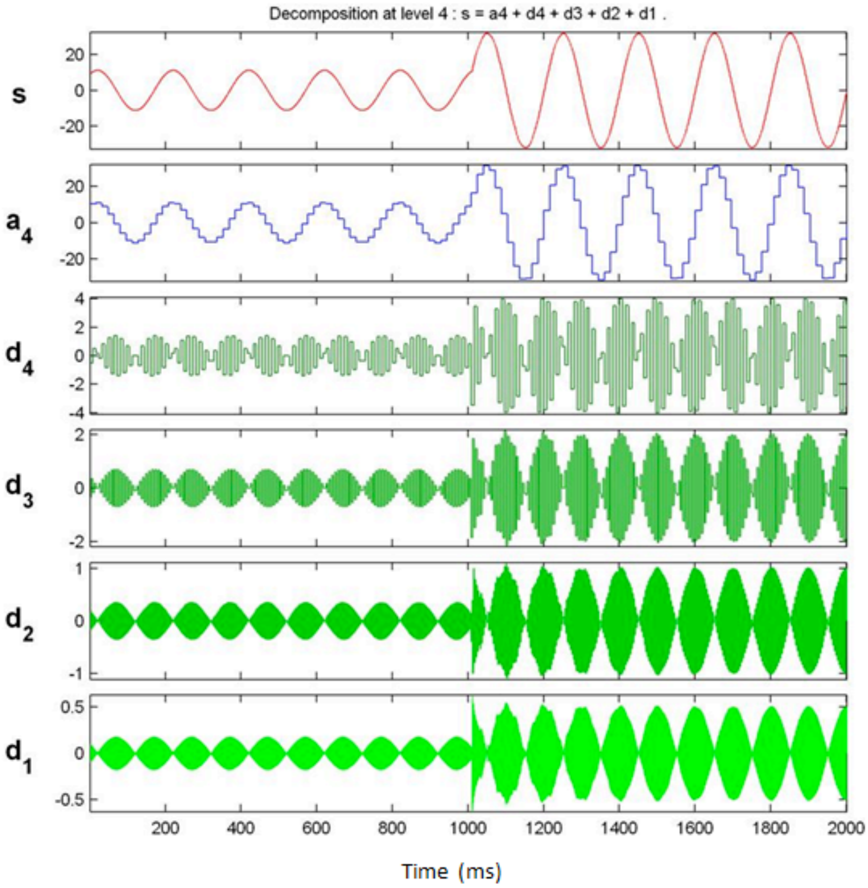

Figure 3. Wavelet analysis.

Figure (3) shows current signal of phase a and 4-level wavelet decomposition when a three phase fault occurs in the system. Fault occurrs in ‘1’ second after the start of simulation. Wavelet coefficients (d1, …, d4) made matrix A, in which the singular values of matrix A are used to calculated the indexes of fuzzy logic.

Fuzzy rules and membership functions for input and output are defined as follows:

Fuzzy system has five inputs, m, m_a, m_b, m_c and m_g; membership function of fault detection, membership function of sound and faulty phase detection, membership function of the ground fault detection are shown below, respectively.

Fault detection in the system has two trapezoidal low and high membership functions with the following parameters.

Low: [-0.01 0 48 52]

High: [50 54 6000 6002]

Sound phase from faulty phase detection index has two trapezoidal low and high membership functions with the following parameters.

Low: [-0.01 0 49.5 50]

High: [49.7 50.2 1999 2000]

Ground fault detection index has two trapezoidal low and high membership functions with the following parameters.

Low: [-0.01 0 0.9 1]

High: [0.95 1.05 499 500]

Conclusion fuzzy system has 11 states that are expressed in table (I). Triangular membership function is used to indicate the state of the system under normal condition or a type of fault in the output. Figure (4) shows the output of fuzzy system and the values are reported in table (II).

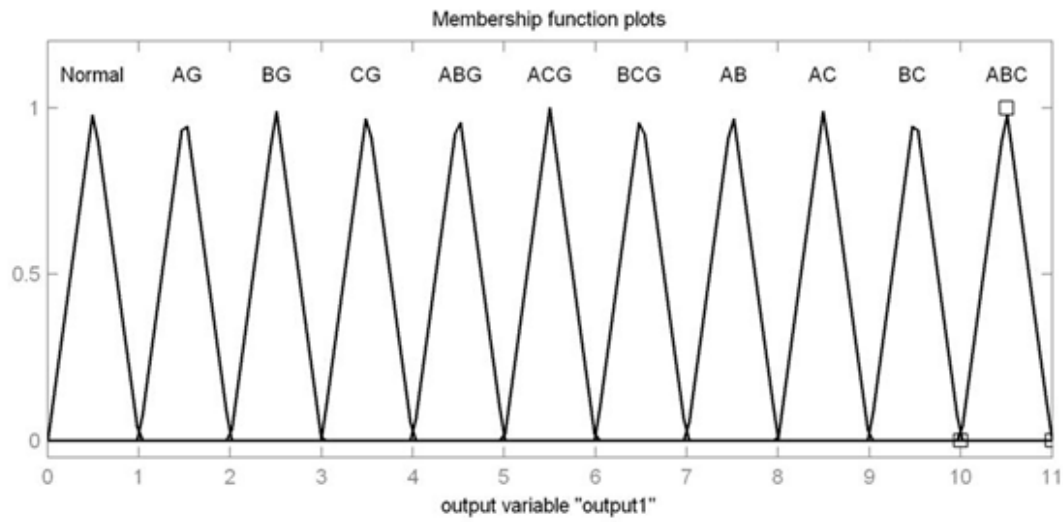

Figure 4. Triangle membership function of fuzzy system output.

Table (I). Fuzzy system rules.

Fault type	algorithm				
	m	ma	mb	mc	mg
normal	low	low	low	low	low
AG	high	high	low	low	high
BG	high	low	high	low	high
CG	high	low	low	high	high
ABG	high	high	high	low	high
ACG	high	high	low	high	high
BCG	high	low	high	high	high
AB	high	high	high	low	low
AC	high	high	low	high	low
BC	high	low	high	high	low
ABC	high	high	high	high	low

Table (II). Output membership function values.

Membership Function	A	B	C
Normal	0	0.5	1
AG	1	1.5	2
BG	2	2.5	3
CG	3	3.5	4
ABG	4	4.5	5
ACG	5	5.5	6
BCG	6	6.5	7
AB	7	7.5	8
AC	8	8.5	9
BC	9	9.5	10
ABC	10	10.5	11

Table (III) to (VIII) show wavelet singular values of three phase current signals and zero sequence current signal and also input indexes of fuzzy system in different conditions. As can be seen, the proposed method can detect and classify the fault correctly in different conditions such as fault resistance variation, different location of fault inception and power angle shift.

Table (III). Wavelet singular values of three phase current signals and fault detection index m in the fault inception 50 kilometers from relay placed with Rf = 25 and δ= 10.

Events	Phase	λ1	λ 2	λ 3	λ 4	λ total	m
Normal	a	174.7623	9.716462	4.19054	1.811521	562.191	0
	b	171.5065	9.908923	4.273725	1.84692		
	c	167.7779	10.1584	4.356529	1.88166		
SPTG	a	1637.367	89.06599	38.41888	16.59535	2173.725	1611
	b	198.6754	12.41449	5.293367	2.305604		
	c	157.1499	10.12629	4.390558	1.922455		
DPTG	a	1742.237	95.98659	41.38748	18.13283	3804.736	3242
	b	191.439	18.873	8.436007	4.033628		
	c	1548.811	82.65253	36.74038	16.00672		
TPTG	a	1816.068	100.4575	43.34808	18.71244	5715.038	5153
	b	1786.449	96.48169	43.12926	18.84633		
	c	1648.159	87.22592	39.02628	17.13377		
PTP	a	177.3763	9.82089	4.230186	1.827584	3369.928	2807
	b	1539.586	80.65091	36.44233	16.03936		
	c	1382.098	73.56139	33.48141	14.81354		

Table (VI). Wavelet singular values of three phase current signals and fault detection index m in the fault inception 300 kilometers from relay placed with Rf = 100 and δ= 20.

Events	Phase	λ 1	λ 2	λ 3	λ 4	λ total	m
Normal	a	221.6889	12.48825	5.378162	2.324549	717.348	0
	b	220.7337	12.52315	5.40749	2.337307		
	c	213.4931	12.99237	5.573529	2.407247		
SPTG	a	224.4627	14.68879	6.325471	3.106521	958.490	241
	b	224.1464	12.45004	5.974916	3.078262		
	c	414.4604	29.73896	13.91632	6.141365		
DPTG	a	524.7664	28.91888	12.31609	5.80809	1319.811	602
	b	225.4531	13.26013	6.540175	3.197953		
	c	447.4945	31.51587	14.23834	6.301365		
TPTG	a	563.282	31.04837	13.31437	5.65444	1765.670	1048
	b	561.6719	37.62854	18.08826	6.734747		
	c	471.3811	34.01841	16.33352	6.514214		
PTP	a	590.7944	34.95975	15.69841	6.202857	1368.550	651
	b	442.4928	25.75174	11.93319	4.553489		
	c	215.0087	13.11525	5.613489	2.426387		

Table (V). Wavelet singular values of three phase current signals and fault detection index m in the fault inception 550 kilometers from relay placed with Rf = 200 and δ= 30.

Events	Phase	λ 1	λ 2	λ 3	λ 4	λ total	m
	a	277.4283	15.74067	6.77438	2.927786		
	b	278.0822	15.66378	6.766179	2.924785		
Normal	c	268.0235	16.31112	6.999187	3.023032	900.665	0
SPTG	a	289.1238	18.10909	8.367329	3.75239	997.001	97
	b	346.3608	23.4812	10.64165	4.965671		
	c	263.5341	16.96197	7.959804	3.743429		
DPTG	a	365.4644	19.52638	9.326707	4.139409	1088.085	188
	b	349.7305	22.96131	10.70838	4.839981		
	c	273.6247	16.48003	7.714833	3.568422		
TPTG	a	363.8418	19.36752	8.438075	3.69426	1169.563	269
	b	359.8853	25.99547	12.77326	5.6121		
	c	325.2641	26.63894	12.65744	5.394448		
PTP	a	380.2013	21.79115	10.15384	4.407359	1060.355	160
	b	317.4954	18.65828	8.740717	3.846379		
	c	268.6862	16.3258	7.018217	3.032982		

Table (VI). Wavelet singular values of three phase current signals, zero sequence current signal and fault lassification indexes in the fault inception 50 kilometers from relay placed with Rf = 25 and δ= 10.

Events	λ a	λ b	λ c	λ z	ma	mb	mc	mg	Fuzzy Logic Output
Normal	190.48	187.54	184.17	0.00	7.48	4.54	1.17	0.00	0.5011
AG	1781.45	218.69	173.59	373.98	1598.45	35.69	9.41	373.98	1.501
BG	197.29	1723.31	232.34	398.90	14.29	1540.31	49.34	398.90	2.501
CG	229.60	193.26	1608.83	323.06	46.60	10.26	1425.83	323.06	3.501
ABG	1895.98	1888.95	215.19	287.76	1712.98	1705.95	32.19	287.76	4.5
ACG	1897.74	222.78	1684.21	354.04	1714.74	39.78	1501.21	354.04	5.5
BCG	206.67	1814.18	1751.65	334.22	23.67	1631.18	1568.65	334.22	6.5
AB	1828.27	1662.76	185.78	0.01	1645.27	1479.76	2.78	0.01	7.499
AC	1549.32	189.61	1688.77	0.01	1366.32	6.61	1505.77	0.01	8.499
BC	193.25	1672.72	1503.95	0.01	10.25	1489.72	1320.95	0.01	9.499
ABC	1978.59	1944.91	1791.55	0.00	1795.59	1761.91	1608.55	0.00	10.5

Table (VII). Wavelet singular values of three phase current signals, zero sequence current signal and fault assification indexes in the fault inception 300 kilometers from relay placed with Rf = 100 and δ=20.

Events	λ a	λ b	λ c	λ z	ma	mb	mc	mg	Fuzzy Logic Output
Normal	241.88	241.00	234.47	0.00	7.88	7.00	0.47	0.00	0.5011
AG	537.75	243.37	237.92	85.06	303.75	9.37	3.92	373.98	1.501
BG	247.84	540.94	240.56	96.79	13.84	306.94	6.56	398.90	2.501
CG	248.58	245.65	464.26	75.41	14.58	11.65	230.26	323.06	3.501
ABG	596.71	598.14	242.15	65.74	362.71	364.14	8.15	287.76	4.5
ACG	571.81	248.45	499.55	83.79	337.81	14.45	265.55	354.04	5.5
BCG	246.35	580.79	508.85	74.48	12.35	346.79	274.85	334.22	6.5
AB	647.66	484.73	236.16	0.01	413.66	250.73	2.16	0.01	7.499
AC	426.30	242.88	555.97	0.01	192.30	8.88	321.97	0.01	8.499
BC	244.19	587.30	404.84	0.01	10.19	353.30	170.84	0.01	9.499
ABC	613.30	624.13	528.25	0.00	379.30	390.13	294.25	0.00	10.5

Table (VIII). Wavelet singular values of three phase current signals, zero sequence current signal and fault classification indexes in the fault inception 550 kilometers from relay placed with Rf = 200 and δ=30.

Events	λ a	λ b	δ λ c	λ z	ma	mb	mc	mg	Fuzzy Logic Output
Normal	302.87	303.44	294.36	0.00	8.87	9.44	0.36	0.00	0.5011
AG	381.15	300.73	305.63	18.17	87.15	6.73	11.63	373.98	1.501
BG	319.35	385.45	292.20	22.89	25.35	91.45	1.80	398.90	2.501
CG	300.61	312.29	354.02	17.21	6.61	18.29	60.02	323.06	3.501
ABG	398.46	388.24	301.39	16.66	104.46	94.24	7.39	287.76	4.5
ACG	384.16	310.68	364.83	22.20	90.16	16.68	70.83	354.04	5.5
BCG	310.44	400.21	359.50	17.65	16.44	106.21	65.50	334.22	6.5
AB	416.55	348.74	295.06	0.00	122.55	54.74	1.06	0.01	7.499
AC	350.75	297.94	402.26	0.00	56.75	3.94	108.26	0.01	8.499
BC	301.77	420.78	353.12	0.00	7.77	126.78	59.12	0.01	9.499
ABC	395.34	404.27	369.95	0.00	101.34	110.27	75.95	0.00	10.5

c. Response time

Response time of the proposed algorithm under various type of fault such as SPTG, DPTG, TPTG and PTP is shown in figures (5) to (8), respectively. As can be seen, the speed of algorithm is acceptable and can detect and classify the fault in less than half a cycle.

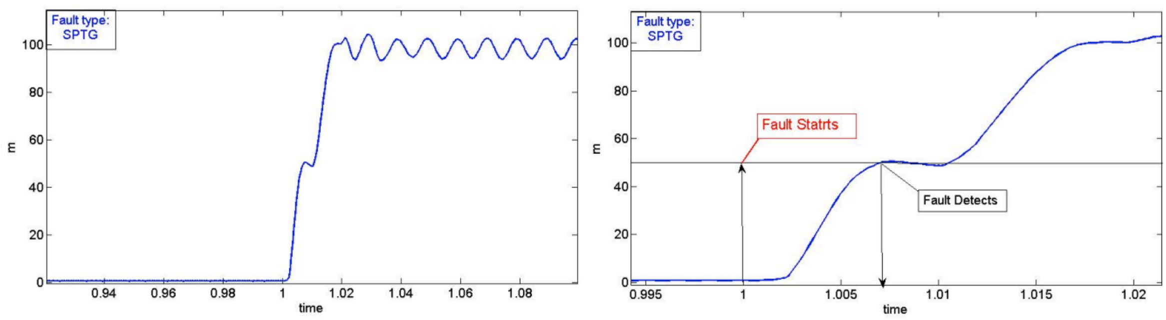

Figure 5. Fault detection index for SPTG fault.

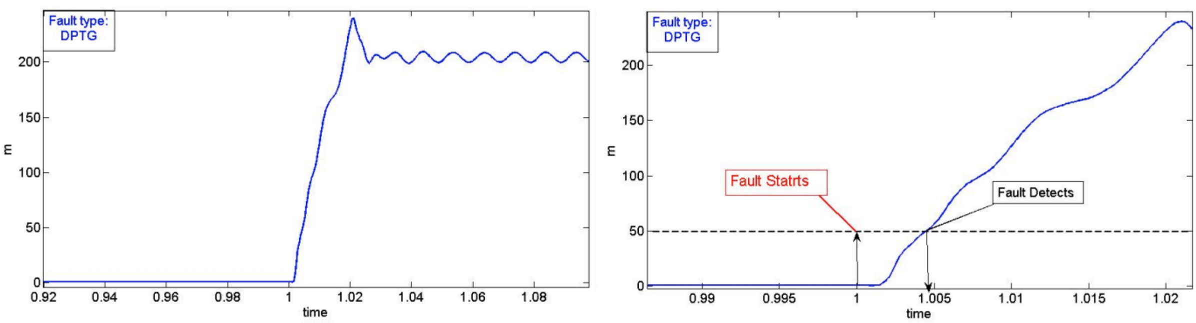

Figure 6. Fault detection index for DPTG fault.

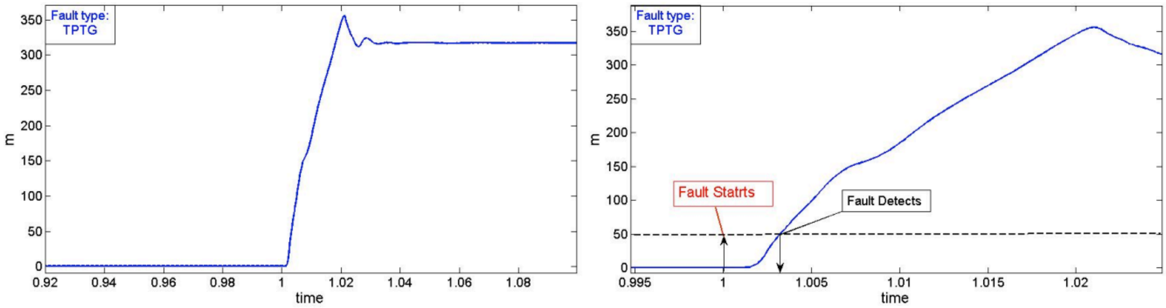

Figure 7. Fault detection index for TPTG fault.

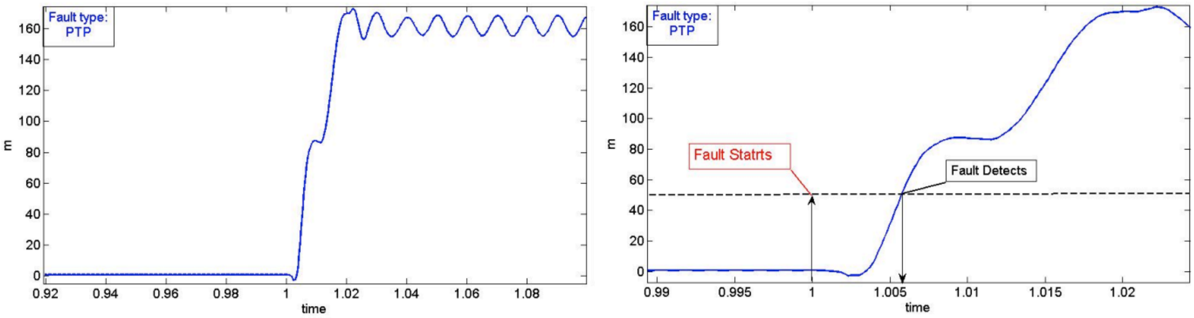

Figure 8. Fault detection index for PTP fault.

4. CONCLUSİON

In this paper, a method based on a combination of wavelet singular value and fuzzy logic is presented for fault detection and fault classification in power transmission line. The results show that the proposed indexes for fuzzy logic are sensitive to variation and as is mentioned, this method is robustness to parameter variation such as fault type, fault inception location, fault resistance and power angle, and can properly detect fault. The proposed algorithm has proven to be a convenient and rapid method for fault detection and fault classification in different conditions and is able to detect and classify the fault and determine the sound phase from faulty phase in less than 10 milliseconds after fault inception.

REFERENCE

[1] A. G. Phadke,"Computer Relaying for Power Systems", New York:Wiley, 1988.

[2] Cecati, Carlo, and Kaveh Razi. "Fuzzy-logic-based high accurate fault classification of single and double-circuit power transmission lines." In *Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), 2012 International Symposium on*, pp. 883-889. IEEE, 2012.

[3] He, Zhengyou, Ling Fu, Sheng Lin, and Zhiqian Bo. "Fault detection and classification in EHV transmission line based on wavelet singular entropy." *Power Delivery, IEEE Transactions on* 25, no. 4 (2010): 2156-2163.

[4] He, Zhengyou, Xian Wu, and Qingquan Qian. "Automatic fault detection for power system using wavelet singular entropy." In *Intelligent Mechatronics and Automation, 2004. Proceedings. 2004 International Conference on*, pp. 433-437. IEEE, 2004.
[5] Dubey, Rahul, and Subhransu Ranjan Samantaray. "Wavelet singular entropy-based symmetrical fault-detection and out-of-step protection during power swing." *IET Generation, Transmission & Distribution* 7, no. 10 (2013): 1123-1134.
[6] de Souza Gomes, André, Marcelo Azevedo Costa, Thomaz Giovani Akar deFaria, and Walmir Matos Caminhas. "Detection and Classification of Faults in Power Transmission Lines Using Functional Analysis and Computational Intelligence." (2013): 1-1.
[7] Al-Kababjie, M. F., F. Al-Durzi, and N. H. Al-Nuaimi. "A fault detection and classification using new distance relay." In *Renewable Energies and Vehicular Technology (REVET), 2012 First International Conference on*, pp. 237-243. IEEE, 2012.
[8] Freitas, Walmir, Wilsun Xu, Carolina M. Affonso, and Zhenyu Huang. "Comparative analysis between ROCOF and vector surge relays for distributed generation applications." *Power Delivery, IEEE Transactions on* 20, no. 2 (2005): 1315-1324.
[9] Chanda, D., N. K. Kishore, and A. K. Sinha. "Application of wavelet multiresolution analysis for classification of faults on transmission lines." In *TENCON 2003. Conference on Convergent Technologies for the Asia-Pacific Region*, vol. 4, pp. 1464-1469. IEEE, 2003.
[10] Samantaray, S. R. "A systematic fuzzy rule based approach for fault classification in transmission lines." *Applied Soft Computing* 13, no. 2 (2013): 928-938.
[11] Mahanty, R. N., and P. B. Gupta. "A fuzzy logic based fault classification approach using current samples only." *Electric power systems research* 77, no. 5 (2007): 501-507.
[12] Jayabharata Reddy, M., and D. K. Mohanta. "A wavelet-fuzzy combined approach for classification and location of transmission line faults." *International Journal of Electrical Power & Energy Systems* 29, no. 9 (2007): 669-678.
[13] Srinivasan, Dipti, Ruey Long Cheu, Young Peng Poh, and Albert Kim Chwee Ng. "Automated fault detection in power distribution networks using a hybrid fuzzy–genetic algorithm approach." *Engineering Applications of Artificial Intelligence* 13, no. 4 (2000): 407-418.
[14] Mufti, Muid, and George Vachtsevanos. "Automated fault detection and identification using a fuzzy-wavelet analysis technique." In *AUTOTESTCON'95. Systems Readiness: Test Technology for the 21st Century. Conference Record*, pp. 169-175. IEEE, 1995.
[15] S. G. Mallat, "A theory for multiresolution signal decomposition: The wavelet representation," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 1, no. 7, pp. 674–693, Jul. 1989.
[16] Cadzow, James A. "SVD representation of unitarily invariant matrices." *Acoustics, Speech and Signal Processing, IEEE Transactions on* 32, no. 3 (1984): 512-516.
[17] Ferrero, Alessandro, Silvia Sangiovanni, and Ennio Zappitelli. "A fuzzy-set approach to fault-type identification in digital relaying." IEEE Trans. Power Delivery, Vol.10, pp. 169-175, jan 1995.