I J C T A, 8(5), 2015, pp. 2343-2349

A Cumulative Sum-Based Fault Classifier for Power System Relaying

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Abstract: This paper presents a fault classification technique for transmission lines based on Cumulative Sum (CUSUM) method. It analyses the current samples obtained through current transformer (CT) connected to the three phases lines and then identifies the fault type. A drift parameter is used to provide low pass filtering effect and its value will affect the performance of the proposed technique. Characteristic features of different fault types of faults are used to determine the fault type. The effectiveness of this algorithm is better than traditional methods used for fault classification. The results are carried out by using EMTP and MATLAB simulation of a 400KV power system. This technique is not affected by noises, system frequency deviation, harmonics and other uncertainties.

Index terms: Transmission lines, protection unit, digital relay, line protection, CUSUM.

1. INTRODUCTION

In recent times, the quality and continuity of electric power is the main concern of power utilities. Protection units are one of the main factor in getting good quality and continuity of electric power. It also plays an important role in preventing losses of utilities as well as end users. Now days, digital relays are being used for their sensitivity, accuracy and speed. The digital unit has to process the voltage or current data in order to detect, classify and locate the fault in the transmission lines. The power industry demands accurate detection and classification of the fault [2], [3]. After fault classification, the fault can be localised and maintenance work can be done on that particular location of transmission line in order to restore the previous steady state condition. Therefore, fault classification is considered to be an important process of digital protection units. A number of different techniques for fault classification are presented by many researchers from time to time. Some of the recent fault classification techniques are based on: (a) Neural Networks [4-11], (b) Wavelet transform [12-17], (c) Fuzzy-neural techniques [18-21]. The method based on neural networks requires a lengthy and difficult training process and method based on wavelet transform is very complicated. Fuzzy-neural based method provides better result in compare of other two techniques.

In this paper a new fault classifier is proposed which is based on CUSUM technique. Earlier a CUSUM based fault detector had been proposed in which, the author clearly shows that this technique is not affected by noises and other uncertainties [22]. Simulation studies have been carried out to show the performance of the proposed technique. Fault data are obtained through an EMTP model and fault classification is done by MATLAB program which make use of CUSUM method.

2. FAULT CLASSIFICATION BASED ON CUSUM

A 400 KV system is taken, as shown in Fig.1 and transmission line parameters are as follows:

I. Line Length = 128 KM

II. Source voltages:

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- Source 1: $V_1 = 400$ KV
- Source 2: $V_2 = 380\ \angle$□δ KV, where δ is the power angle.

III. Source impedance: (Both sources)

- Positive sequence impedance = 1.74 + j0.3958
- Zero sequence impedance = 2.4146 + j0.5975

IV. Transmission line parameter.

- Positive sequence impedance = 2.51+ j0.0056
- Zero sequence impedance = 13.62 + j0.0172

V. Sampling Time = 1ms.

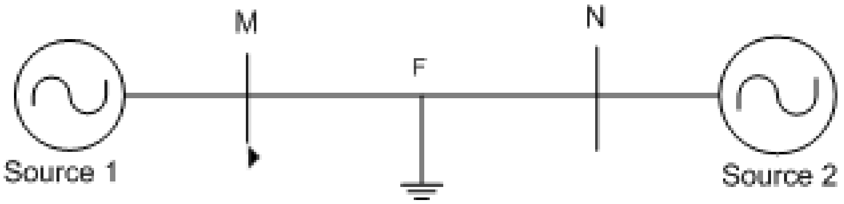

Figure 1: Test Power System.

Post fault data's are processed through the proposed algorithm. The prerequisite for fault classification is that, the fault should be detected first. This technique is able to classify the fault within a half cycle. The ten faults can be classified by using four indices which are S_a, S_b, S_c and S_g. The calculation of these indices is as follows:

Normalised current output obtained through CT is processed in digital unit of a distance relay.

Current samples $m_{ak,}$ $m_{bk,}$ m_{ck} and m_{gk} are used and four sets of two complementary signals are formed as follows:

For phase A:

$$m_{ak}(1) = m_{ak} \tag{1}$$

$$m_{ak}(2) = -m_{ak} \tag{2}$$

For phase B:

$$m_{bk}(1) = m_{bk} \tag{3}$$

$$m_{bk}(2) = -m_{bk} \tag{4}$$

For phase C:

$$m_{ck}(1) = m_{ck} \tag{5}$$

$$m_{ck}(2) = -m_{ck} \tag{6}$$

For Ground:

$$m_{gk}(1) = m_{gk} \tag{7}$$

$$m_{gk}(2) = -m_{gk} \tag{8}$$

Where, m_{gk} is equal to $m_{ak} + m_{bk} + m_{ck.}$

By processing these eight signals the two sided CUSUM test is expressed as:

$$A_k = \max\,(A_{k\text{-}1} + m_{ak}(1) - v_1, 0\ ) \tag{9}$$

$$A_k{*} = \max\,(A{*}_{k\text{-}1} + m_{ak}(2) - v_1, 0\ ) \tag{10}$$

$$B_k = \max\,(B_{k\text{-}1} + m_{bk}(1) - v_1, 0\ ) \tag{11}$$

$$B_k{*} = \max\,(B{*}_{k\text{-}1} + m_{bk}(2) - v_1, 0\ ) \tag{12}$$

$$C_k = \max\,(C_{k\text{-}1} + m_{ck}(1) - v_1, 0\ ) \tag{13}$$

$$C_k{*} = \max\,(C{*}_{k\text{-}1} + m_{ck}(2) - v_1, 0\ ) \tag{14}$$

$$G_k = \max\,(G_{k\text{-}1} + m_{gk}(1) - v_2, 0\ ) \tag*{(13)}$$

$$G_k{*} = \max\,(G{*}_{k\text{-}1} + m_{gk}(2) - v_2, 0\ ) \tag*{(14)}$$

Where $A_{k,}$ $A_k{*}$, $B_{k,}$ $B_k{*}$, $C_{k,}$ $C_k{*}$, G_k and $G_k{*}$ are the test statistics and v_1 and v_2 are the drift parameters.

In steady state condition the maximum value of normalised current signal is 1 and maximum value of normalised ground current signal is 0. So ideally the values of drift parameter v_1 and v_2 are 1 and 0 respectively but practically these values are set, slightly higher than ideal values due to the presence of noises and other uncertainties.

$$S_a = \max\,(A_{k,}\ A_k{*}\ ) \tag{15}$$

$$S_b = \max\,(B_{k,}\ B_k{*}\ ) \tag{16}$$

$$S_c = \max\,(C_{k,}\ B_k{*}\ ) \tag{17}$$

$$S_g = \max\,(G_{k,}\ B_k{*}\ ) \tag{18}$$

The characteristics features of different type of fault are determined in terms of S_a, S_b, S_c and S_g.

- For a-g fault Sa > p1, Sb ≤ p1, Sc ≤ p1 and Sg > p2.
- For b-g fault Sa ≤ p1, Sb > p1, Sc ≤ p1 and Sg > p2.
- For c-g fault Sa ≤ p1, Sb ≤ p1, Sc > p1 and Sg > p2.
- For a-b-g fault Sa > p1, Sb > p1, Sc ≤ p1 and Sg > p2.
- For b-c-g fault Sa ≤ p1, Sb > p1, Sc > p1 and Sg > p2.
- For c-a-g fault Sa > p1, Sb ≤ p1, Sc > p1 and Sg > p2.
- For a-b fault Sa > p1, Sb > p1, Sc ≤ p1 and Sg ≤ p2.
- For b-c fault Sa ≤ p1, Sb > p1, Sc > p1 and Sg ≤ p2.
- For c-a fault Sa > p1, Sb ≤ p1, Sc > p1 and Sg ≤ p2.
- For a-b-c fault Sa > p1, Sb > p1, Sc > p1 and Sg ≤ p2.

Where, p_1 and p_2 are the threshold values. These threshold values depend upon many factors such as: drift parameters values, magnitude of fault current, low frequency noises, dc offset, interharmonics, frequency deviation, sampling rate, changing of loads.

3. ALGORITHM ASSESSMENT

The proposed algorithm is tested on the three phases current data obtained from simulation. A sampling rate of 1kHz has been chosen. A three phase transmission line (400KV, 50Hz) connecting two system as shown in Fig.1 has been taken for testing the proposed method. Fault of different types are simulated under various condition and assessment of algorithm is carried out. The load angle ‘δ’ and fault resistance is varied for different simulations. Different types of fault are simulated where a fault is initiated at 0.1 and the corresponding test statistics are shown in Fig.2-Fig.5. It can be clearly seen from these figures that for different types of fault, the faulted phases indices are varying and other phases maintains a zero value index. The values of S_a, S_b, S_c and S_g corresponds to different condition are given in Table1-2. On the basis of these values, the fault type can be determined. It can be observed from the Table1-2 that fault can be easily classified if these values are processed through the logic given above for classify the ten types of fault.

The values chosen for v_1, $v_{2,}$ p_1 and p_2 are 1.3, 0.2, 0 and 0 respectively. However these values can be varied according to the different system condition.

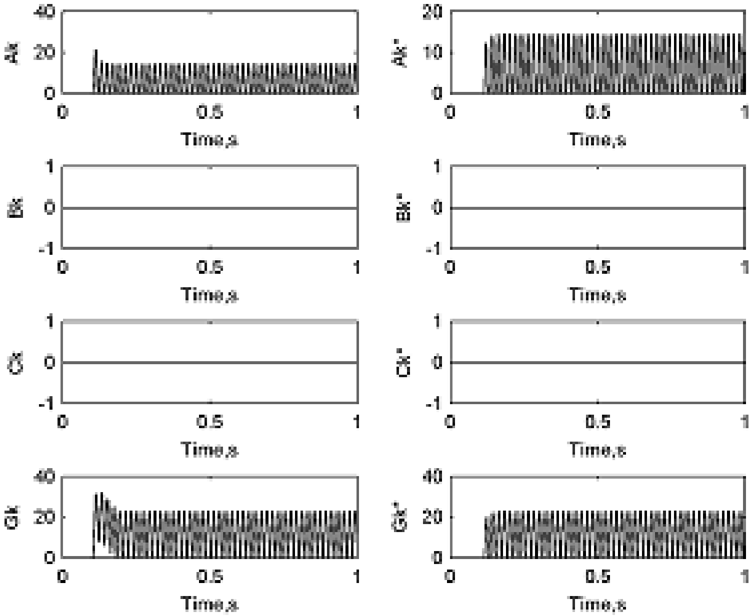

Figure 2: Fault Type: 'AG', fault location (d):0.4, fault resistance (Rf): 5Ω, fault inception angle (FIA):45°, δ 20°

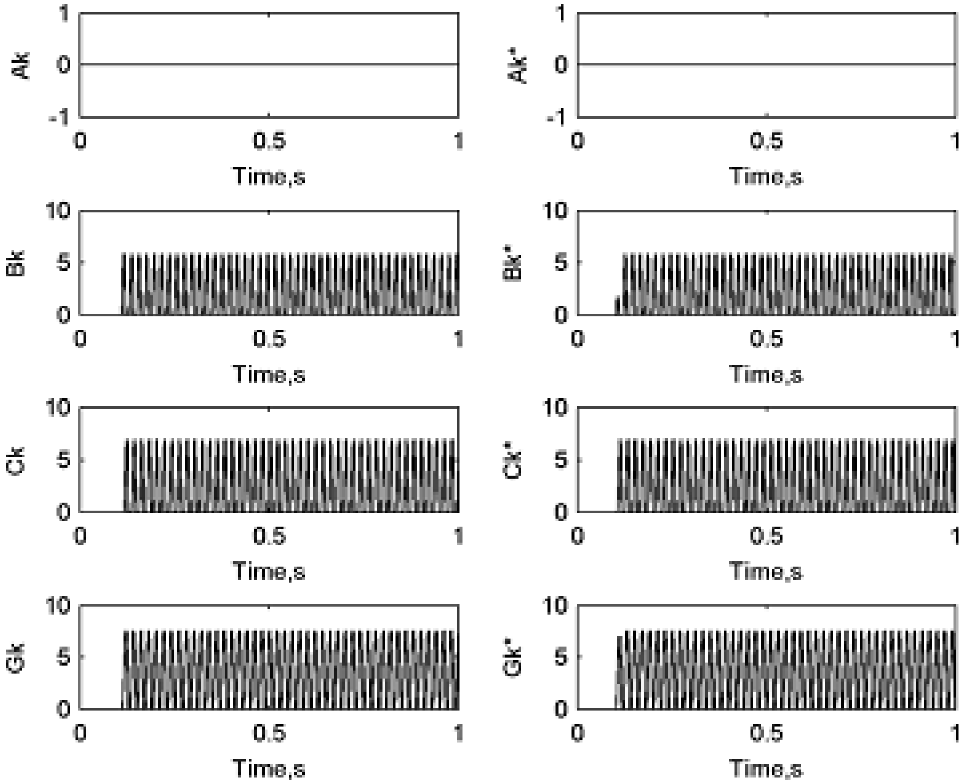

Figure 3: Fault Type: 'BCG', fault location (d):0.8, fault resistance (Rf): 50Ω, fault inception angle (FIA):25°, δ 10°

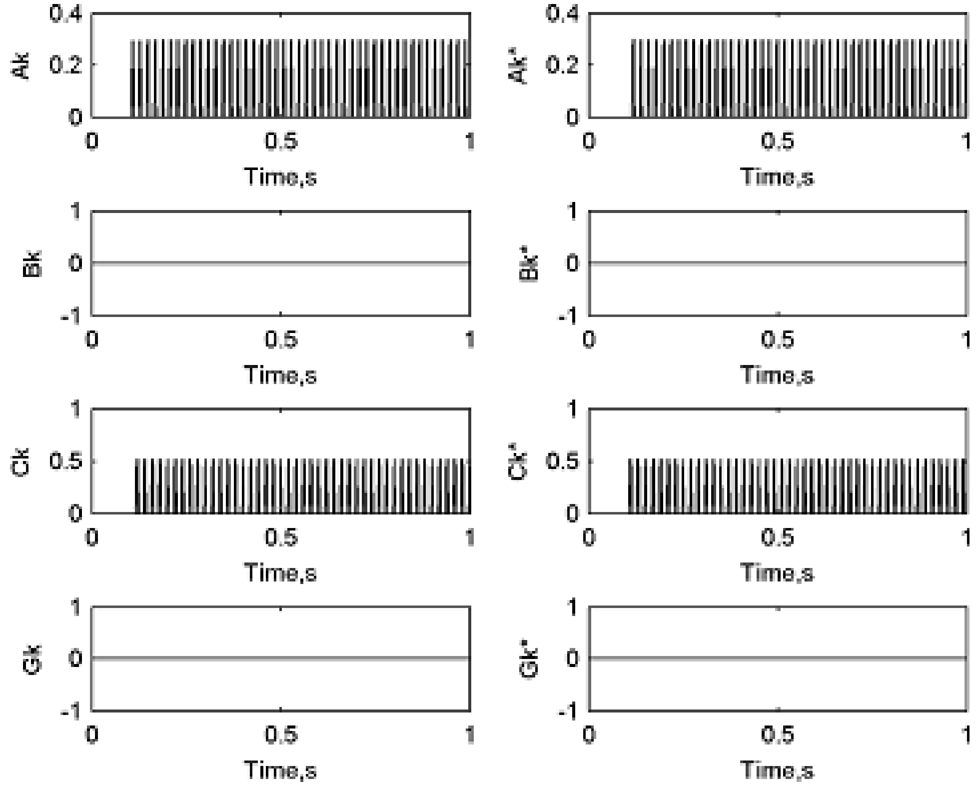

Figure 4: Fault Type: 'CA', fault location (d):0.5, fault resistance (Rf): 80Ω, fault inception angle (FIA): 10°, δ 30°

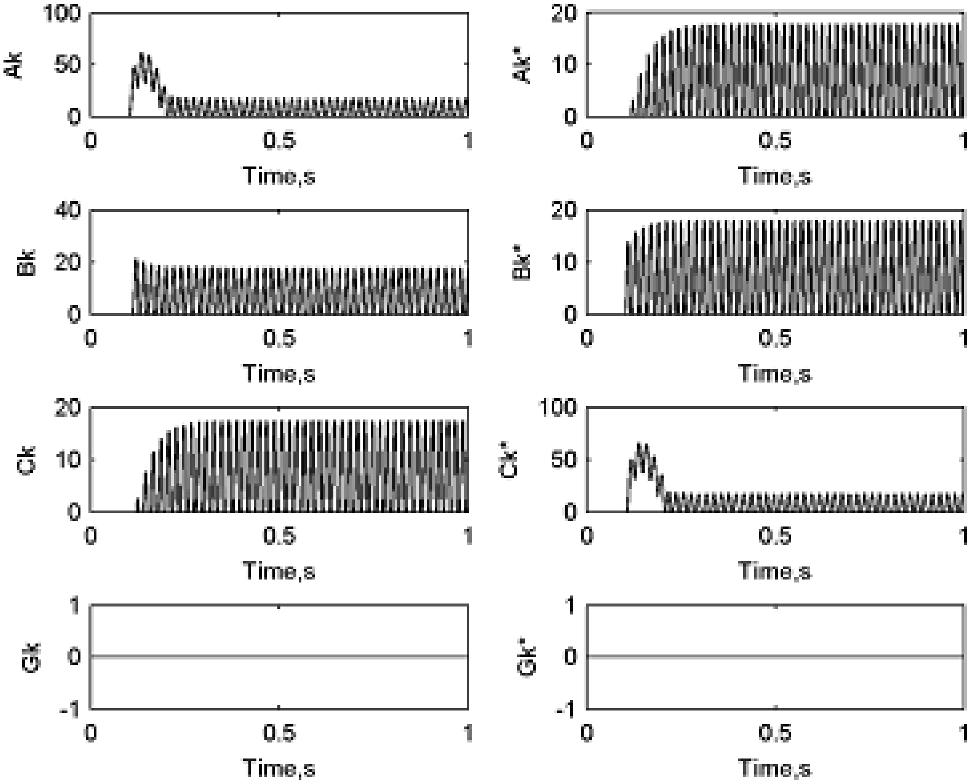

Figure 5: Fault Type: 'ABC', fault location (d):0.6, fault resistance (Rf): 0.1Ω, fault inception angle (FIA): 20°, δ 20°

Table 1
Simulation results in case of ground fault

Fault Type	Fault condition: d, Rf, FIA, δ	S_a	S_b	S_c	S_g
a-g	0.1, 5Ω, 20°, 20°	46.14	0	0	66.248
	0.5, 80Ω, 75°, 25°	1.3425	0	0	3.1502
	0.9, 50Ω, 15°, 15°	1.3425	0	0	3.0938
b-g	0.2, 45Ω, 20°, 30°	0	4.81	0	8.333
	0.4, 10Ω, 85°, 10°	0	51.02	0	63.22
	0.8, 50Ω, 45°, 20°	0	1.8386	0	3.3792
c-g	0.1, 50Ω, 45°, 15°	0	0	10.2557	14.9805
	0.5, 100Ω, 0°, 30°	0	0	0.4137	1.5523
	0.9, 40Ω, 90°, 10°	0	0	5.4849	6.7801
a-b-g	0.3, 30Ω, 45°, 20°	10.1411	13.78	0	16.30
	0.4, 200Ω, 90°, 10°	1.8091	2.09	0	4.08
	0.8, 55Ω, 5°, 30°	0.4438	0.6214	0	1.3657
b-c-g	0.2, 75Ω, 30°, 15°	0	6.69	7.86	10.77
	0.5, 150Ω, 75°, 30°	0	0.445	0.069	0.6417
	0.9, 15Ω, 15°, 10°	0	15.87	18.91	15.84
c-a-g	0.1, 0.1Ω, 90°, 30°	26.2989	0	40.8673	107.2
	0.5, 150Ω, 75°, 30°	0.0573	0	0.0159	0.5805
	0.8, 50Ω, 40°, 10°	6.9595	0	5.88	8.51

Table 2
Simulation results in case of phase fault.

Fault Type	Fault condition: d, Rf, FIA, δ	S_a	S_b	S_c	S_g
a-b	0.1, 50Ω, 45°, 30°	3.8928	3.4136	0	0
	0.5, 150Ω, 0°, 20°	0.2003	0.1937	0	0
	0.9, 50Ω, 15°, 15°	36.46	32.76	0	0
b-c	0.2, 0.1Ω, 30°, 10°	0	205.20	197.51	0.37
	0.4, 75Ω, 15°, 30°	0	0.965	0.5955	0
	0.8, 100Ω, 80°, 20°	0	0.17	0.044	0
c-a	0.15, 0.1Ω, 90°, 10°	68.37	0	74.23	0
	0.6, 50Ω, 45°, 30°	0.6943	0	1.2965	0
	0.9, 10Ω, 0°, 20°	34.64	0	37.35	0
a-b-c	0.1, 30Ω, 10°, 10°	37.01	37.75	37.67	0
	0.5, 50Ω, 45°, 30°	2.27	2.38	2.24	0
	0.9, 80Ω, 75°, 20°	0.3538	0.3568	0.3119	0

4. CONCLUSION

In this paper a new fault classification technique has been proposed for digital relaying. Large variations in location of fault, inception angle, fault resistance and load angle are simulated and types of fault are identified in each condition. The results prove the validity of the proposed technology. The value of drift parameters and thresholds should be set optimally. The threshold value depends upon many factors such as dc offset, harmonics, noises etc. Simplicity and accuracy are the two attractive features of the proposed technique.

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