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Hybrid Method for Transmission Line Fault Detection to Design a Protection Scheme

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Abstract- **This paper investigated a hybrid technique for transmission line fault identification to formulate a protection method. Currents on transmission line are analyzed using Stockwell transform (ST) and a matrix is computed. Statistical operations are performed on this matrix to compute Standard deviation fault index (SDFI), low value fault index (LFI), maximum value fault index (MFI), and sum fault index (SFI). Fault index (FI) is evaluated by multiplying the SDFI, LFI, MFI and SFI and also considering a weight factor (WF). This FI effectively detects the faults such as line to ground (LG), line to line (LL), line to line with ground (LLG), three phases fault (LLL) and three phases fault with ground (LLLG). Faults are categorized from each other using the number of phases which are faulty and a ground fault index (GFI). GFI is evaluated by processing the Zero sequence current (ZSC) by use of ST. Designed hybrid method performs better in comparison to a fault detection method using Discrete Wavelet transform (DWT). Study is performed by use of MATLAB software.**

Keywords- **Fault, Fault index, Ground Fault index, Stockwell transform, Transmission line.**

I. INTRODUCTION

Network of power system interconnects the generators with loads. Network considered to transmit bulk power from generating plants to load centers is known as transmission system and lines used in this system are called transmission lines. Transmission lines impacted by faults which result in malfunction and interrupt the supply of bulk power. If faulty transmission line is not taken out of system immediately after the fault event then cascade tripping of the power system may also take place affecting the supply of large area [1]. Recently, many methods have been published to detect the faults incident on a line using the signal processing and machine learning (ML)supported techniques. A technique for DWT for identification of faults in the availability of linear loads and dynamic loads is available in [2]. This has small fault categorization time but performance is reduced in the noisy conditions. A DWT based technique for detection of faults taken place on a Thyristor Controlled Reactor (TCR) equipped Transmission Line is reported in [3]. This method used the current fault index for fault recognition. In [4], authors formulated a transmission line detection technique in presence of solar energy generation using DWT. A ST based technique to detect faults on a power line feeding dynamic load is reported in [5]. It used combination of features taken from current and voltages. In [6], authors introduced method for study of faults occurred on transmission line having a series compensator where energy from wind power sources is available. A ST based technique for identification of fault on a line in the presence of solar power is available in [7]. Many fault identification methods are available in [8]-[11].

Descriptive review of approacheselaborated in above paragraph indicates that robust and intelligent fault detection techniques can be designed for transmission line protections. This is taken as research objectives and following are research contributions of this paper:-

- A hybrid method for transmission line fault detection to design a protection scheme using decomposition of current by ST is designed.
- Standard deviation fault index (SDFI), LFI, MFI, and sum fault index (SFI) are computed by statistical operations on the output matrix obtained by decomposition of current using ST.
- FI is evaluated by multiplication of SDFI, LFI, MFI and SFI and also considering a weight factor (WF).
- Faults are categorized from each other using number of faulty phases and a GFI. GFI is evaluated by analyzing ZSC using ST.
- Designed hybrid approachworks better compared to DWT based technique of fault detection.

Paper is formulated in 7 sections. Section-1 gives basic concepts of transmission line faults, research gaps, research contribution and structure of paper. Section-2 details the test transmission line considered for the study. Section-3 details the proposed ST based hybrid method for transmission line fault recognition. Section-4 elaborates the results of simulation for all the investigated faults and fault categorization. Section-5 details the performance comparative study and Section-6 concludes the research. Section-7 lists the references.

II.TEST TRANSMISSION LINE

Method of fault detection for formulation of transmission line protection scheme (TLPS) is validated on a two terminal power line connected among Bus-2 & Bus-3 in the test system elaborated in Fig. 1. Transmission line is operated on the 220kV voltage level. Total length of line used for study is 100km. Generators GEN-1 & GEN-2 are operated on 11 kV voltage level and directly connected to Bus-1 and Bus-4 respectively. Phase angle of GEN-1 voltage is kept 20° higher compared to phase angle of GEN-2 voltage. Hence, Generator GEN-1 is operating in the generating mode indicating a generating station and Generator GEN-2 is operating in motoring mode indicating a load. Hence, power on transmission line flows from Bus-2 to Bus-3. A utility transformer (UT-1) is placed between Bus-2 and Bus-1. Similarly, a utility transformer (UT-2) is placed between Bus-3 & Bus-4. Both transformers, UT-1 and UT-2 are rated at 220/11kV. Test system is operating at a frequency of 60Hz. Fault location point (FLP) is taken at center of transmission line. A current transformer (CT) is equipped near the Bus-2 of test line to capture current in real time conditions.

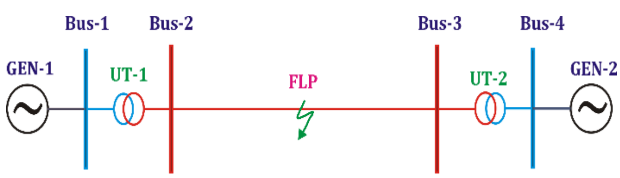

Fig. 1 Test transmission line

III. FAULT DETECTION METHOD

A hybrid transmission line protection scheme (TLPS) is designed by computing various features from current by application of ST. Current is continuously captured by CT installed near Bus-2 of the test line. Current (*i(t)*) is decomposed by use of ST and ST matrix (STM) is computed using the below relation [12]:-

$$STM = abs\left(\int_{-\infty}^{\infty} i(t)\frac{|f|}{\sqrt{2\pi}}e^{-\frac{f^2(\tau-t)^2}{2}}e^{-j2\pi ft}dt\right) \quad (1)$$

Where τindicates time of spectral localization & f indicates the Fourier frequency. The *g(t)* represents a window function. Various features are computed from STM. Standard deviations of STM indicates the Standard deviation fault index (SDFI) which is computed by below relation:-

$$SDFI = std(STM) \quad (2)$$

The *std* indicates the MATLAB command to compute standard deviation of a matrix. Minimum value of each column of STM indicates the low value fault index (LFI) which is computed by below relation:-

$$LFI = min(STM) \quad (3)$$

The *min* indicates the MATLAB command to compute minimum value of a column of a matrix. Maximum value of each column of STM indicates the maximum value fault index (MFI) which is computed by below relation:-

$$MFI = max(STM) \quad (4)$$

The *max* indicates the MATLAB command to compute maximum value of a column of a matrix. Summation of elements appearing in each column of STM indicates sum fault index (SFI). The SFI is evaluated by below demonstrated relation:-

$$SFI = sum(STM) \quad (5)$$

The *sum* indicates the MATLAB command to compute summation of elements appearing a column of a matrix. Fault index (FI) is evaluated taking the multiplicationof SDFI, LFI, MFI and SFI and also considering a weight factor (WF) as described below:-

$$FI = SDFI \times LFI \times MFI \times SFI \times WF \quad (7)$$

A fault index threshold (FTH) is considered equal to 70. Values of FI higher compared to FTH indicates faulty nature of phase.

A. *Ground Fault Index*

A ground fault index (GFI) is formulatedby decomposing the zero sequence current (ZSC) by the ST. ZSC (I_0) is computed from phase current using below relation:-

$$I_0 = \frac{I_1 + I_2 + I_3}{3} \quad (8)$$

The ZSC is decomposed using formulation of ST elaborated in equation (1) and matrix STMG is computed. Low ground fault index (LGFI) is evaluated by taking minimum values of each column of STMG as described below:-

$$LGFI = min(STMG) \quad (9)$$

Summation ground fault index (SGFI) is formulated by summing the all elements of each column of STMG as detailed below:-

$$SGFI = sum(STM) \quad (10)$$

The ground fault index (GFI) is formulated by multiplying the LGFI, SGFI and a ground weight factor (GWF) as detailed below:-

$$GFI = LGFI \times SGFI \times GWF \quad (11)$$

A fault index ground threshold (FIGH)of 10 is taken to identify ground presence with a fault. Values of GFI greater than FIGH indicates the fault availability with a fault. This is used to discriminate the LL fault from LLG fault.

IV. SIMULATION RESULTS

This section elaborates simulation results to detect the faults happening on a transmission line using designed TLPS. Proposed hybrid fault detection method has effectively detected faults like line to ground (LG), line to line (LL), line to line and ground (LLG), three phases fault (LLL) and three phases fault with ground (LLLG). Categorization of faults is also elaborated in this section. Results are discussed in below sections.

A. *Line to Ground Fault*

A LG fault is occurred at FLP of line at 0.1s and currents of all phases are recorded by CT installed on the line near Bus-2 which are shown in Fig. 2 (a). Currents of all phases are decomposed using the proposed hybrid method and SDFI, LFI, MFI, SFI and FI are computed for LG fault which are elaborated in Fig. 2(b), (c), (d), (e) and (f) in same sequence.

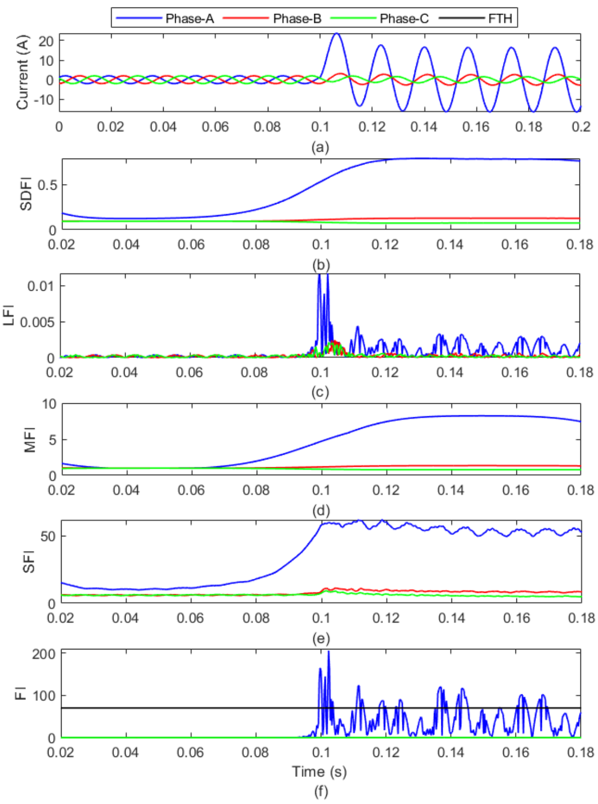

Fig. 2 LG fault (a) Current waveforms (b) SDFI (c) LFI (d) MFI (e) SFI (f) FI

Fig. 2(a) elaborates that current of phase-A has raised at 0.1s and current of phases-B & C retain the same value. Fig. 2(b) elaborates that SDFI of phase-A has increased at 0.1s and SDFI of phases-B & C retain the same value which indicates faulty nature of phase-A and healthiness of phases-B&C. Fig. 2(c) elaborates that LFI of phase-A has increased at 0.1s and LFI of phases-B & C retain the same value which indicates faulty nature of phase-A and healthiness of phases-B&C. Fig. 2(d) elaborates that MFI of phase-A has increased at 0.1s and MFI of phases-B & C retain the same value which indicates faulty nature of phase-A and healthiness of phases-B&C. Fig. 2(e) demonstrates that SFI of phase-A isenhanced at 0.1s and SFI of phases-B & C retain the same value which indicates faulty nature of phase-A and healthiness of phases-B&C. Fig. 2(f) demonstrates that FI of phase-A has enhanced at 0.1s and becomes higher than FTH and FI of phases-B & C retain the same value which is below FTH. This indicates faulty nature of phase-A and healthiness of phases-B&C.

B. *Line to Line Fault*

A LL fault is occurred at FLP of power line at 0.1s and currents of all phases are recorded by CT installed on the line near Bus-2 which are shown in Fig. 3 (a). Currents of all phases are decomposed using the proposed hybrid method and SDFI, LFI, MFI, SFI and FI are computed for LL fault which are elaborated in Fig. 3(b), (c), (d), (e) and (f) in same sequence.

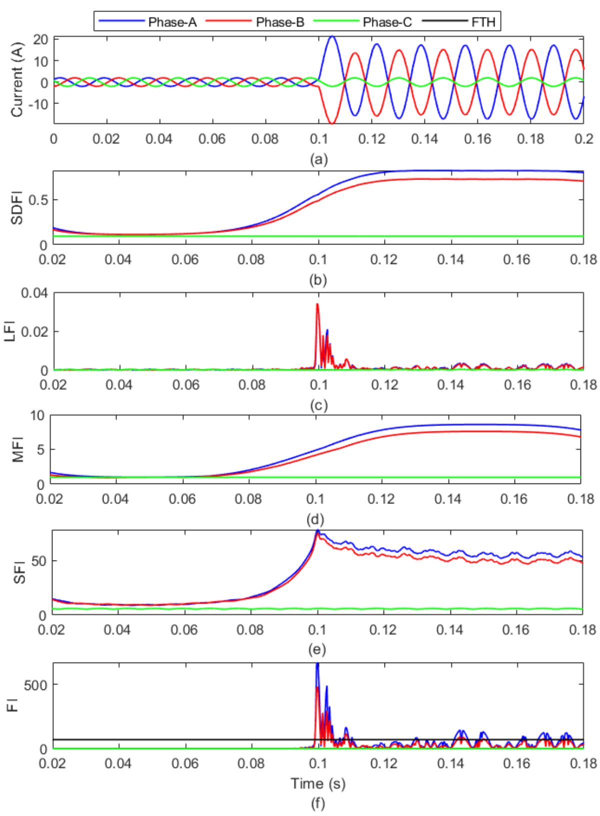

Fig. 3 LL fault (a) Current waveforms (b) SDFI (c) LFI (d) MFI (e) SFI (f) FI

Fig. 3(a) elaborates that current of phases-A&B is increased at 0.1s and current of phase-C retains the same value. Fig. 3(b) elaborates that SDFI of phases-A&B has raised at 0.1s and SDFI of phase-C retains the same value which demonstrates that phases-A&B are faulty and healthiness of phase-C. Fig. 3(c) elaborates that LFI of phases-A&B has enhanced at 0.1s and LFI of phase-C retains the same value which elaborates faulty nature of phases-A&B and healthiness of phase-C. Fig. 3(d) elaborates that MFI of phases-A&B has enhanced at 0.1s and MFI of phase-C retains the same value which demonstratesthat phases-A&B are faulty and healthiness of phase-C. Fig. 3(e) demonstrates that SFI of phases-A&B has enhanced at 0.1s and SFI of phase-C retains the same value which demonstratesthat phases-A&B are faulty and healthiness of phase-C. Fig. 3(f) demonstrates that FI of phases-A&B has enhanced at 0.1s and becomes higher than FTH and FI of phase-C retain the same value which is below FTH. This indicates faulty nature of phases-A&B and healthiness of phase-C.

C. Line to Line and Ground Fault

A LLG fault is occurred at FLP of power line at 0.1s and currents of all phases are recorded by CT installed on the line near Bus-2 which are shown in Fig. 4 (a). Currents of all phases are decomposed using the proposed hybrid method and SDFI, LFI, MFI, SFI and FI are computed for LLG fault which are elaborated in Fig. 4(b), (c), (d), (e) and (f) in same sequence.

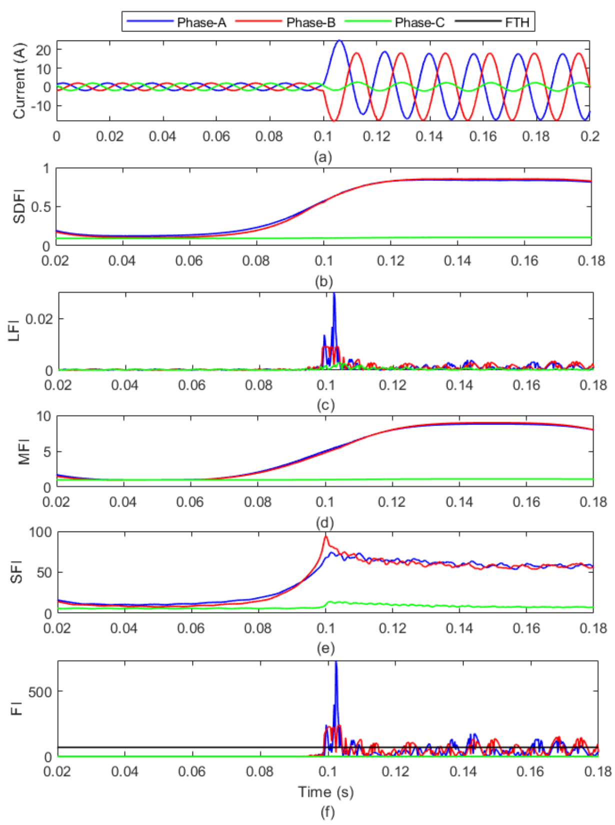

Fig. 4 LLG fault (a) Current waveforms (b) SDFI (c) LFI (d) MFI (e) SFI (f) FI

Fig. 4(a) elaborates that current for phases-A&B has enhanced at 0.1s and current of phase-C retains the same value. Fig. 4(b) elaborates that SDFI of phases-A&B has enhanced at 0.1s and SDFI of phase-C retains the same value which elaboratesthat phases-A&B are faulty and healthiness of phase-C. Fig. 4(c) elaborates that LFI of phases-A&B has enhanced at 0.1s and LFI of phase-C retains same value which demonstratesthat phases-A&B are faulty and healthiness of phase-C. Fig. 4(d) elaborates that MFI of phases-A&B has enhanced at 0.1s and MFI of phase-C retains the same value which demonstratesthat phases-A&B are faulty and healthiness of phase-C. Fig. 4(e) elaborates that SFI of phases-A&B is increased at 0.1s and SFI of phase-C retains the same value which demonstrates that phases-A&B are faulty and healthiness of phase-C. Fig. 4(f) elaborates that FI of phases-A&B has increased at 0.1s and becomes higher than FTH and FI of phase-C retain the same value which is below FTH. This indicates that phases-A&B are faulty and healthiness of phase-C.

D. Three Phase Fault

A LLL fault is occurred at FLP of power line at 0.1s and currents of each phase are captured by CT installed on the line near Bus-2 which are shown in Fig. 5 (a). Currents of all phases are decomposed using the proposed hybrid method and SDFI, LFI, MFI, SFI and FI are computed for LLL fault which are elaborated in Fig. 5(b), (c), (d), (e) and (f) respectively.

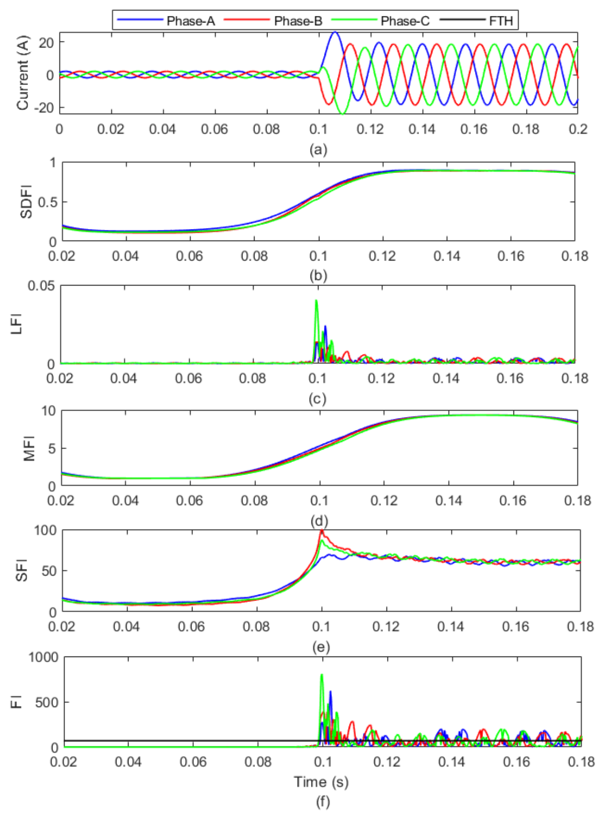

Fig. 5 LLL fault (a) Current waveforms (b) SDFI (c) LFI (d) MFI (e) SFI (f) FI

Fig. 5(a) elaborates that current of eachphase areenhanced at 0.1s. Fig. 5(b) elaborates that SDFI of eachphase has increased at 0.1s which indicates faulty nature of all phases. Fig. 5(c) elaborates that LFI of all phaseshas increased at 0.1s which elaborates faultiness of eachphase. Fig. 5(d) elaborates that MFI of all phases has increased at 0.1s which demonstrates faultiness of eachphase. Fig. 5(e) elaborates that SFI of eachphase is enhanced at 0.1s which indicates that all phases are faulty. Fig. 5(f) elaborates that FI of eachphase isenhanced at 0.1s becomes higher than FTH. This elaboratesfaultiness of eachphase.

E. Three Phase to Ground Fault

A LLLG fault is occurred at FLP of power line at 0.1s and currents of each phaseare captured by CT equipped on line at Bus-2 which is shown in Fig. 5 (a). Currents of all phases are decomposed using the proposed hybrid method and SDFI, LFI, MFI, SFI and FI are computed for LLLG fault which are demonstrated in Fig. 5(b), (c), (d), (e) and (f) in same order.

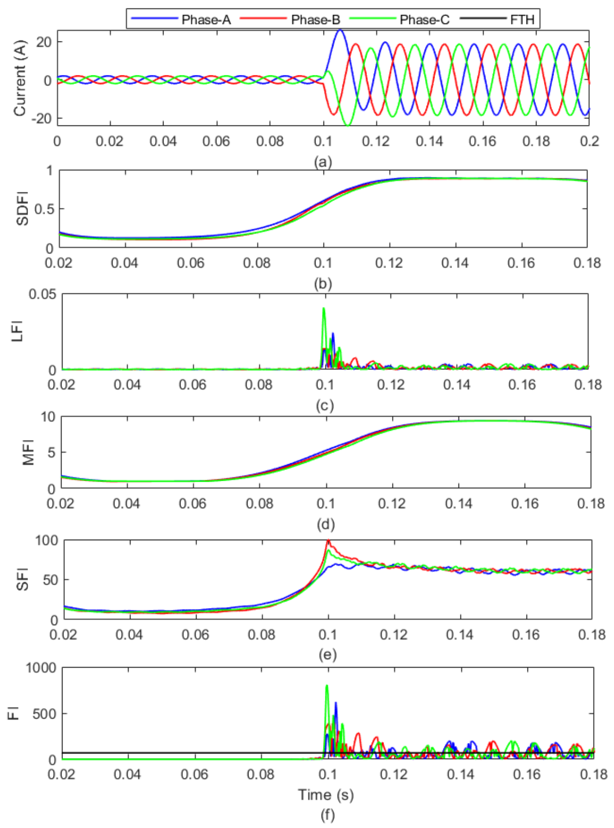

Fig. 6 LLG fault (a) Currents (b) SDFI (c) LFI (d) MFI (e) SFI (f) FI

Fig. 6(a) elaborates that current of each phase is enhanced at 0.1s. Fig. 6(b) elaborates that SDFI of each phase is enhanced at 0.1s which elaborates that all phases are faulty. Fig. 6(c) elaborates that LFI of all phases has increased at 0.1s which elaborates that all phases are faulty. Fig. 6(d) elaborates that MFI of all phases has enhanced at 0.1s which elaborates that all phases are faulty. Fig. 6(e) elaborates that SFI of all phases has enhanced at 0.1s which indicates elaborates that all phases are faulty. Fig. 6(f) elaborates that FI of all phases has enhanced at 0.1s becomes higher than FTH. This elaborates that all phases are faulty.

F. Fault Classification

All faults are categorized from one another checking number of faulty phases. LG fault has one faulty phase. LL and LLG have two faulty phases. LLL and LLLG have all phases faulty. The LL and LLG faults are categorized from one another by use of GFI demonstrated in Fig, 7. This is seen that, for LLG fault GFI has values greater than FIGH and for LL fault GFI has values smaller compared to FIGH. Similarly, GFI is effective to discriminate the LLL and LLLG faults from one another.

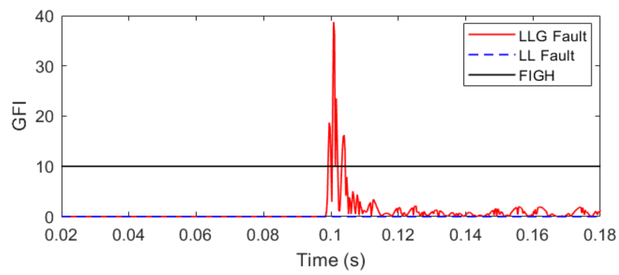

Fig. 7 GFI for LL and LLG fault

V. PERFORMANCE COMPARISON

Performance of proposed method is analyzed and compared with a fault detection technique using DWT reported in [13]. This is seen that FI used by DWT technique has very small variations for all fault types whereas proposed ST based hybrid method has wide range of FI for all faults. Hence, DWT based technique reported in [13] may categorize the faults wrongly specifically during the conditions of noise whereas designed method has good accuracy of fault classification even with all types of faults.

VI. CONCLUSION

This paper presented a hybrid method for transmission line fault detection to design a protection scheme using decomposition of current by ST. A FI is designed to detect faults like LG, LL, LLG, LLL and LLLG. The FI is computed from the SDFI, LFI, MFI, SFI and a weight factor (WF). This concluded that proposed ST based hybrid method effectively recognized the LG, LL, LLG, LLL and LLLG. This technique is also effective to recognize considering number of faulty phases and a GFI. Designed hybrid approach performs better compared to DWT based method of fault detection.

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