International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 8, No. 4, December 2017, pp. 1804~1813
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v8i4.pp1804-1813 ❐ 1804

A Time-Frequency Transform Based Fault Detection and Classification of STATCOM Integrated Single Circuit Transmission

S.K Mishra[1], S.C Swain[2], L.N Tripathy[3]
[1,2]Department of Electrical Engineering, KIIT University
[3]Department of Electrical Engineering, BijuPatnaik University of Technology

Article Info

Article history:

Received Sep 17, 2017
Revised Nov 17, 2017
Accepted Nov 30, 2017

Keyword:

DSE
FDST
FDT
FIA
Rf
SE
SI
Single-circuit line

ABSTRACT

This paper discusses the time-frequency transform based fault detection and classification of STATCOM (Static synchronous compensator) integrated single circuit transmission line. Here, fast-discrete S-Transform (FDST) based time-frequency transformation is proposed for evaluation of fault detection and classification including STATCOM. The STATCOM is placed at mid-point of transmission line. The system starts processing by extracting the current signals from both end of current transformer (CT) connected in transmission line. The current signals from CT's are fed to FDST to compute the spectral energy (SE) of phase current at both end of the line. The differential spectral energy (DSE) is evaluated by subtracting the SE obtained from sending end and SE obtained from receiving end of the line. The DSE is the key indicator for deciding the fault pattern detection and classification of transmission line. This proposed scheme is simulated using MATLAB simulink R2010a version and successfully tested under various parameter condition such as fault resistance (Rf), source impedance (SI), fault inception angle (FIA) and reverse power flow. The proposed approach is simple, reliable and efficient as the processing speed is very fast to detect the fault within a cycle period of FDT (fault detection time).

Corresponding Author:

S.K Mishra,
Departement of Electrical Engineering,
KIIT University,
Kathajodi campus, Patia, Bhubaneswar, India.
Email: mishra29y@yahoo.com

1. INTRODUCTION

STATCOM [1] is one of the most important power controller FACTS (Flexible AC Transmission System) devices have been used in transmission as well as in distribution (DSTATCOM) system across many parts of the world because of its ease control of reactive power, voltage and flexible operation of power transmission capacity. To push the power limit with the existing transmission system, STATCOM is an alternative option in FACT's [2] family. It is primarily a shunt connected leading and lagging VAR control FACTS device based single circuit line and double circuit line [3] on Voltage Source converter (VSC) used to control VAR, enhances the transient, dynamic voltage stability. In addition to this it also performs both in generating or absorbing independently real and reactive power. STATCOM with advanced digital control technology and fast pulse control embedded system in superior power semiconductor switch with less cost is an emerging era to enhance power transmission capacity in the existing line. Though the occurrence of fault causes steady state and transient state disturbance in which fault loop is formed that affects the voltage and current parameter of the transmission line. There must be a strong relaying system which is to be properly addressed in order to mitigate the fault occurred in STATCOM integrated transmission line.

Therefore building an intelligent and fast fault monitoring system is essential for detecting and classifying the fault in the transmission line. Researchers have been developing many approaches to protect the equipment as well as restore the continuity of power during the fault. Therefore the system must be very accurate and fast acting to recognize the fault at an earliest possible of time to protect the costly equipment in the transmission line. Many approaches have been used for evaluating fault detection and fault classification such as signal processing, machine intelligence in learning, GPS communication system enabled to produce many researchers for analysis of fault, its location and faulty phase identification. The PMU application is gained wide spread attention in the analysis of fault in smart grid.

High performance based computing system like server cluster helps to process the system using distributed computing within a less time span which allows the system in smart grid. In case of conventional grid many different approaches are proposed.Earlier distance relay [4] is used to detect the fault because impedance of the line changes during the occurrence of fault but it unable to provide protection of whole transmission line as some errors may introduce while detecting the fault at near and far ends which causes over reaching/under reaching. The frequency signal in the current waveform or voltage waveform is thoroughly analyzed by means of travelling wave theory [5]. Fuzzy-neural network based scheme [6] is discussed but the problem in this if some neurons are missed during phasor data interpretation under training and testing process it may lead to error in fault detection process. In extended Kalman filtering [7] the problem of dissimilar filters are introduced which lead errorneous result and Machine intelligence mehod consumes more processing time.

Fourier transform, wavelet transform in particular DWT [8],[9] is somehow considered for study of fault analysis, however there are some problem which may introduce in the accuracy of the system, as it is very sensitive to noise and unable to address the harmonics clearly. S-transform and fast discrete S-transform which is modified form S-transform are the various signal processing technique used to compute fault detection, classification and location in the transmission line. Fault identification process using linear time-frequency analysis of distribution in VSI switch [10] is presented, however it unable to explain the fault detection time at different fault condition with respect to fault location. The matrix converter [11] approach is discussed in which it explain open circuit/short circuit condition at switching fault component but unable to detect the type of different shunt fault occurred in transmission line and its detection time. Fault current limiter is discussed in [12] which is used to improve the transient stability and unable to trace shunt faults except short circuit fault. An Adaline LMS control including DWT approach is presented [13] but it takes more prcessing time as the pulse is controlled by means of neural network. The DT (Decision tree) [14] approach consumes more processing time due to its burden. All the above approach discussed here involves without integration of STATCOM in transmission line.

Therefore, a strong motivation behind the proposed scheme is to develop an algorithm which provides fast processing of discrete S-transform (FDST) including STATCOM. S-Transform (ST) has been used for transmission line protection [15], [16] for fault detection and classification due to its superior properties of localizing the imaginary and real spectrum independently because of its moving and scalable localizing property of Gaussian window. FDST [17] is used for frequency selection approach suitable for the analysisof non-stationary signals that considerably reduce the computational complications by evaluating the maximum energy content obtained from frequency component of the respective phase. The paper is divided into different sections. Apart from the Section-1, introduction part is discussed earlier. Section-2 describes FDST formulation. Section-3 discusses DSE based approach of differential relaying scheme. Section-4 discusses the simulation results and discussion obtained from different types of fault condition. Section-5 discusses the conclusion part of the proposed scheme.

2. FDST Signal Processing

FDST is a fast processing discrete S-transformation analysis and used to evaluate different frequency component from non-stationary current using decision tool mechanism by numerically filtering from unwanted frequency information. The FDST algorithm is referred from the literature [17]. S-spectrum of *S(k,n)* signal is a complex quantity represented in equation 1.

$$S(k,n) = A(k,n)e^{i\theta(k,n)} \tag{1}$$

Where, $A(k,n) = |S(k,n)|$ is magnitude of S-spectrum and phase is represented by $\mathrm{Re}(S(k,n))$ and $\mathrm{Im}(S(k,n))$ value the real and imaginary values of $S(k,n)$ expressed in equation 2.

$$\theta(k,n) = \tan^{-1}\frac{\text{Im}(S(k,n))}{\text{Re}(S(k,n))} \quad (2)$$

Spectral Energy (SE_p) of P-phase is represented in equation 3,

$$SE_P = |S(k,n)|^2 \quad (3)$$

(3)

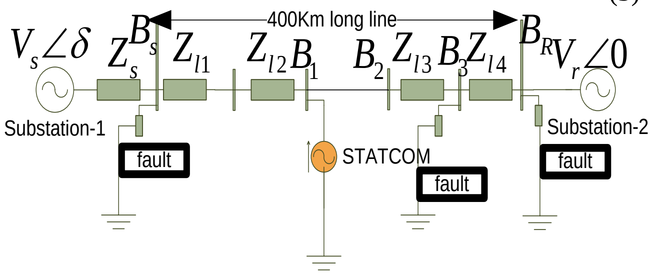

Figure 1. Proposed schematic diagram including the STATCOM placed at mid-point of the transmission line

3. Proposed Protection Scheme

The proposed diagram of the scheme including STATCOM is depicted in Figure1. The scheme consists of two 400kV substation placed at both end of line, which is having 1500 MVAcapacity.The voltage, impedance and bus of both end of sending and receiving terminals are represented as V_s,V_r,*Zs*, *Zr*, B-S and B-R respectively. The whole transmission line comprises of four different subsection Z_{l1}, Z_{l2}, Z_{l3} *and* Z_{l4} placed at 100km distance from one another. The positive and zero sequence of resistance and inductance are represented in ohm per km and in henry per km such as R1=0.01537, R0=0.04612, L1=0.8858×10^{-3} and L0=2.654×10^{-3} respectively. Parameters of the two grid substations shown in proposed scheme are Vs=400kV, δs= 12^0 and Vr =400kV, δr= 0^0 of 50Hz frequency. STATCOM of 100MVA capacity is shunt connected through transformer 15kV/400kV to the transmission line. Figure 2 depicts schematic diagram of proposed relaying scheme. The different parameters mentioned below are tested for simulation study.

- Fault resistance variation (Rf): 0 to 100Ω
- Fault Inception Angle (FIA) variation : 0^0, 45^0,90^0
- Reverse power flow
- Source impedance (SI) variation

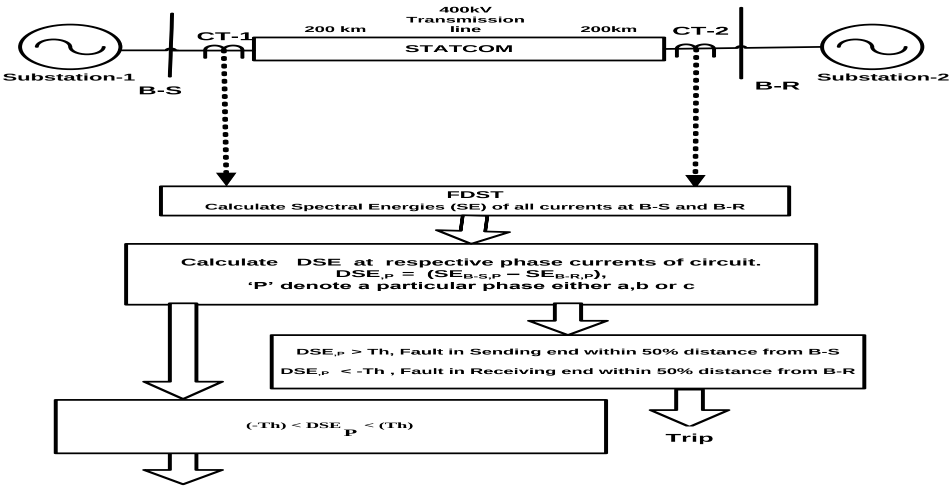

Figure 2. Schematic diagram of proposed relaying scheme

The differential spectral energy [19] of each phase (DSE_p) is formulated by

$$DSE_P = (SE_{B\text{-}S,P} - SE_{B\text{-}R,P}) \quad (4)$$

Here, P is phase-A, B or C.
The following conditions provide the information regarding detection and classification of fault in the transmission line.
$DE_{\text{-}P}$> +Th: fault is within 50% distance from B-S
DE $_P$<-Th: fault is within 50% distance from B-R
-Th<DE_P<+Th: fault is at an external end.
Threshold (Th) is selected after carrying out number of simulation at different types of fault condition. Here the Th is selected as 0.005 in our proposed system.The relaying theory is referred from the literature [20].

4. Result and Discussion

MATLAB R2010a SIMULINK version is used for modelling the proposed scheme. In order to provide complete protection of the scheme internal fault and external faults are considered.

4.1 Internal Fault:

All simulations are conducted at fault inception of 0.4s under different shunt fault condition.Figure 3 depicts A-G fault occurs at sending end bus (B-S) and A-G fault occurs at receiving end bus (B-R).This shows that A-G fault at B-S and A-G fault at B-R are 180 degree phase shift to each other. To test the effect of variation of Rf, number of simulations are tested at Rf values from 0Ω -100Ω at different fault condition. In Figure 4(a) ABC fault occurs at 150 km distance from B-S at Rf=1Ω, FIA=0^0 the DSE of all A,B and C phase current increases in +ve direction and crosses Th value at 0.005 and detects the ABC fault in 0.03s classified as ABC fault. So the fault detection time (FDT) requires 0.03s for ABC fault. Figure 4(b) depicts the frequency contour of ABC fault at 150km distance from B-S at Rf=1Ω and FIA=0^0. From this figure the frequency contours at time 0.4s successfully localizes the fault events just after the occurrence of fault. Figure 4(c) depicts ABC fault at 150km distance from Bus B-R (Bus-4), Rf=1Ω and FIA=0^0, the FDT takes 0.04s to cross Th value. Figure 4(d) depicts the frequency contour of ABC fault occurs at 150km distance from Bus B-R at Rf=1Ω and FIA=0^0.

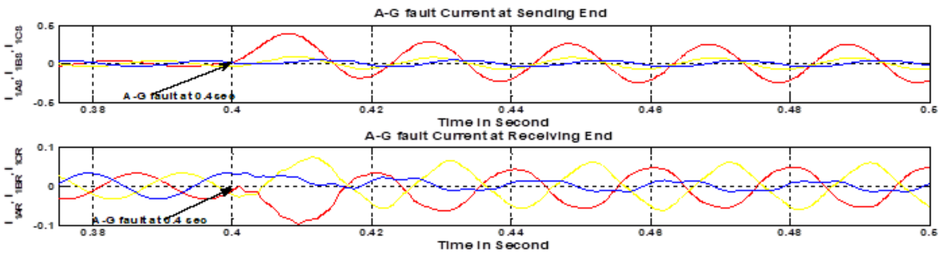

Figure 3. A-G fault at 100km from B-S and at 100km from B-4

4.2 Effect of fault resistance variation (Rf)

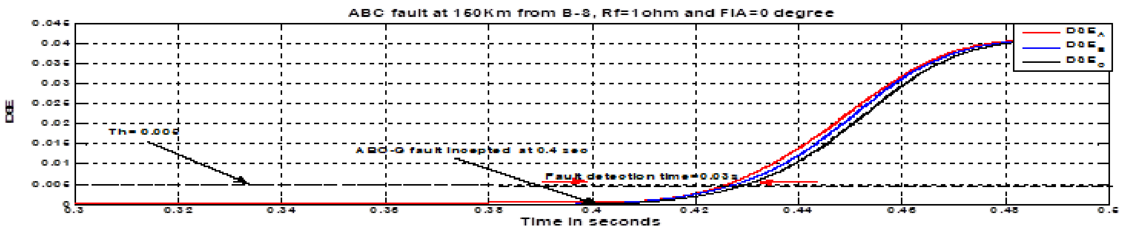

Figure 4(a). ABC fault at 150km distance from B-S, Rf=1Ω and FIA=0^0

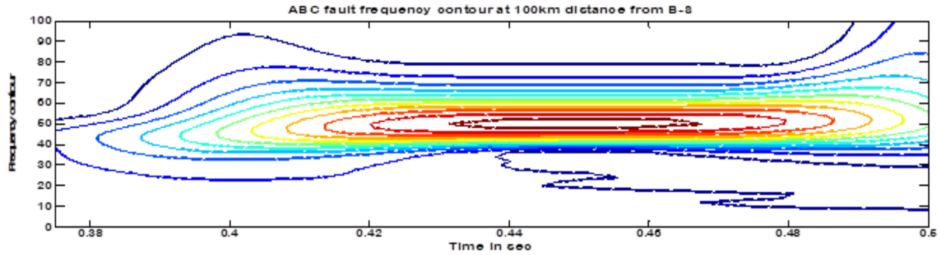

Figure 4(b). Frequency contour of ABC fault at 0.4 sec, Rf=1 Ω and FIA=0

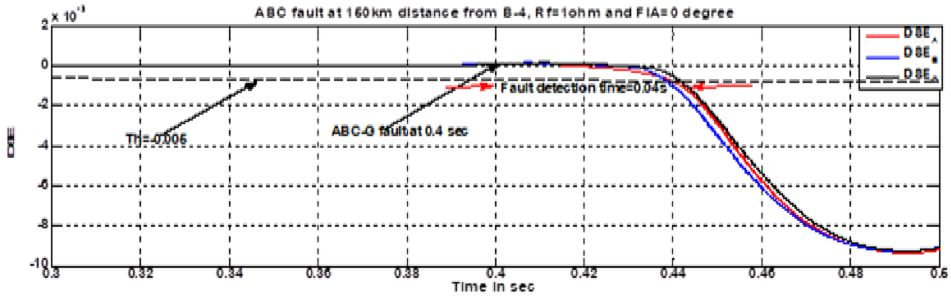

Figure 4(c). ABC fault at 150km distance from Bus B-R (Bus-4), Rf=1Ω and FIA=0^0

Figure 4(e) depicts three different values of Rf=1Ω, 50Ω and 100Ω, FIA=0^0 and it shows that DSE of A-phase current increases in +ve direction and crosses Th value at 0.005. FDT for each three different values of Rf (1Ω, 50Ω and 100Ω) takes time in 0.04s, 0.042s and 0.044s respectively for 100km distance from B-S. Thus the system works fine in all the values of Rf from 0Ω to 100Ω at any location of transmission line. Table 1 depicts the variation of Rf at three different values such as 1Ω, 50Ω and 100Ω at FIA=0^0 the FDT in s and distance in km from B-S is presented under differet types of fault condition.

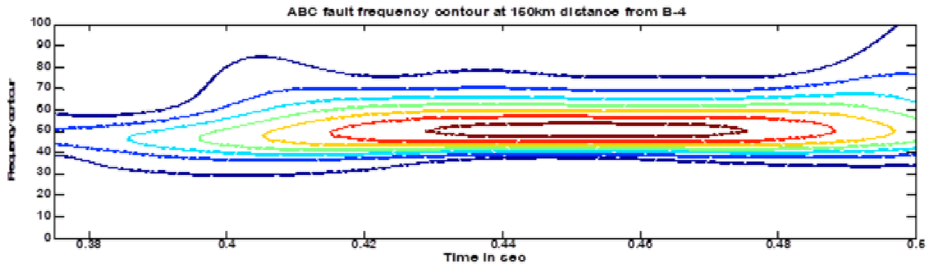

Figure 4(d). Frequency contour of ABC fault at 150km distance from B-R, Rf=1Ω and FIA=0^0

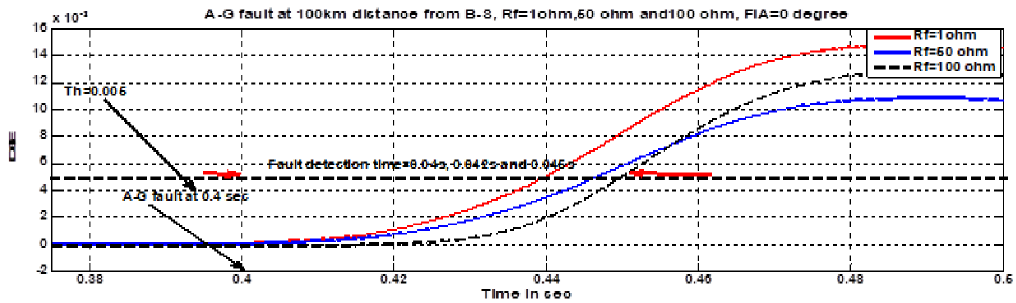

Figure 4(e). A-G fault at 100km distance from B-S at Rf=1Ω, 50Ω and 100Ω, FIA=0^0

Table 1. Variation of Rf from 1Ω - 100Ω at FIA=0^0, Fault detection time (FDT) and distance in km from B-S

Type of fault	Rf=1 Ω FDT and distance from B-S	Rf=50Ω FDT and distance from B-S	Rf=100Ω FDT and distance from B-S	Fault classification
A-G	0.04s, 100km	0.042s,100km	0.044s,100km	A-phase
A-G	0.04s,350km	0.045s,350km	0.045s,350km	A-phase
AB-G	0.03s,200km	0.04s,200km	0.04s,200km	AB-phase
BC-G	0.04s,10km	0.04s,10km	0.04s,10km	BC-phase
ABC	0.03s,150km	0.035s,150km	0.034s,150km	ABC-phase

4.3 Effect of the Fault Inception Angle (FIA):

To test the effectiveness and performance of the system, Figure 5(a) depicts B-G fault occurs at 200km distance from B-S, at Rf=1Ω and FIA=45^0. The FDT takes 0.05s and is detected as well as classified as B-G fault. Figure 5(b) depicts the frequency contour of B-G fault at Rf=1Ω, NSI and FIA=45^0 which localizes the fault at 0.4s. The figure shows that the fault is detected and classified in FDT 0.03s in case of FIA at 45^0 and FDT 0.05s in case of FIA at 90^0. Thus it is concluded that the FDT takes less time incase of lower value of FIA and vice-versa. Table 2 presents the variation of FIA from 0^0 to 90^0 at Rf=1Ω respect to FDT and distance in km from B-S under different types of fault.

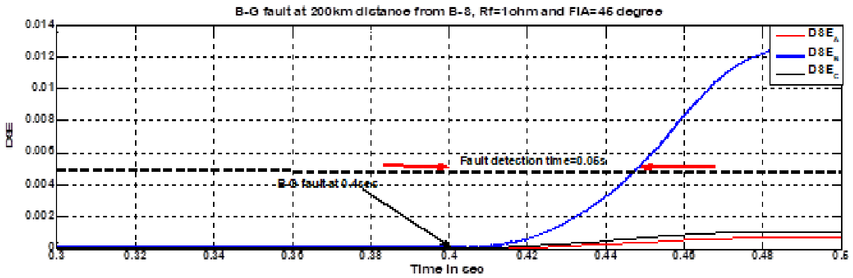

Figure 5(a). B-G fault at 200km from B-S at Rf=1Ω, FIA=45^0

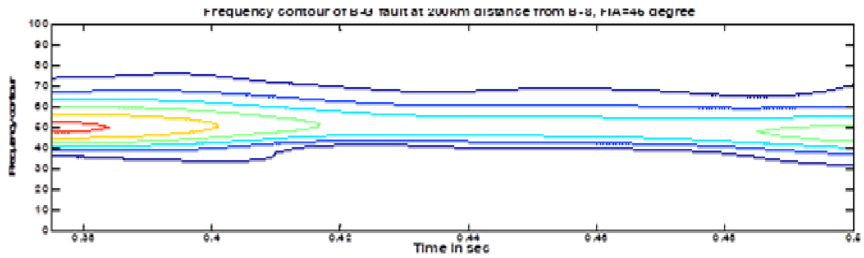

Figure 5(b). Frequency contour of B-G fault from B-S at 0.4s, Rf=1Ω, NSI and FIA=45^0

Table 2. Variation of FIA (0^0, 30^0, 45^0 and 90^0) at Rf =1Ω, fault distance in km from B-S

Fault Type	FIA=0^0 FDT and distance	FIA=30^0 FDT and distance	FIA=45^0 FDT and distance	FIA=90^0 FDT and distance	classification
B-G	0.035s, 200km	0.04s,200km	0.05s,200km	0.055s,200km	B-phase
CA-G	0.03s,100km	0.035s,100km	0.04s,100km	0.045s,100km	CA phase
A-G	0.25s,90km	0.03s,90km	0.03s,90km	0.05s,90km	A-phase
ABC-G	0.02s,90km	0.025s,90km	0.03s,90km	0.035s,90km	ABC phase

4.3 Effect of Variation in Source Impedance (SI):

To study the effect of SI, Normal SI (NSI) and increasing NSI from 5% to 30% of NSI. The number of simulations are considered for different types of fault at different values of %age increase of NSI. Figure 6(a) depicts AB-G fault at 50km distance from B-S, Rf=1Ω, 30% increase of NSI, FIA=0^0. Figure 6(b) depicts the frequency contour of AB-G fault occurs at 50 km distance from B-S, Rf=1Ω, SI=30% increase of NSI and FIA =0^0. It shows that the frequency contours successfully localizes the fault events at 0.4s. Thus, this increase of SI is allowed for any system to study the fault to classify and detects in an accurate manner. Table 3 depicts the variation of SI (5%, 10%, 15%, 20%, 25% and 30% increase of NSI) at Rf =1Ω, FDT and distance in km from B-S under different types of fault.

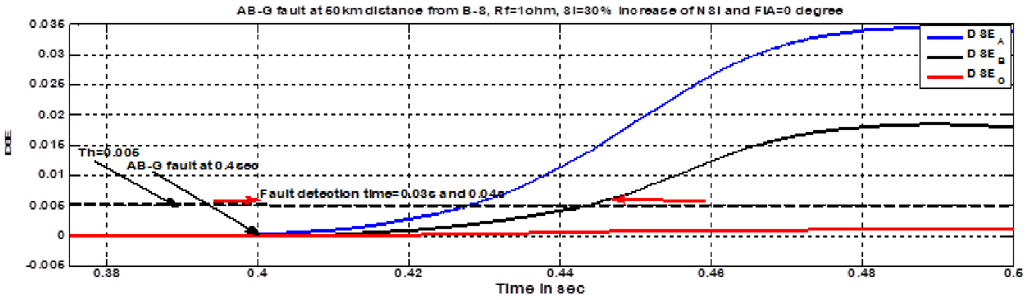

Figure 6(a). AB-G fault at 50Km distance from B-S, Rf=1Ω,SI= 30% increase of NSI, FIA =0^0

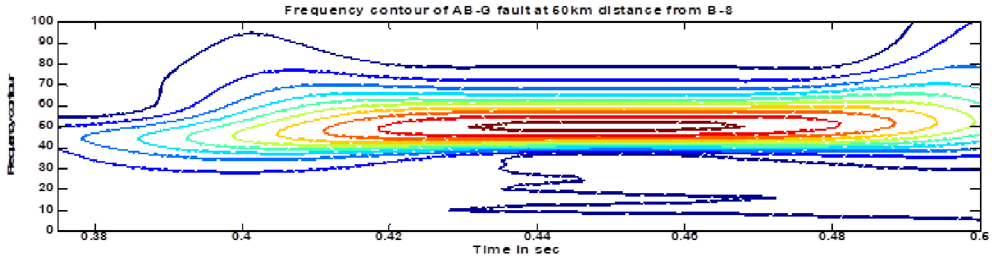

Figure 6(b). Frequency contour of AB-G fault at 0.4 sec, Rf=1Ω, SI= 30% increase of NSI, FIA=0^0

Table 3. Variation of SI (5%, 10%, 15%, 20%, 25% and 30% increase of NSI) at Rf =1Ω, fault distance in km from B-S

Fault type	SI=5% +NSI, FDT, distance	SI=10% +NSI, FDT, distance	SI=15% +NSI, FDT, distance	SI=20% +NSI, FDT, distance	SI=25% +NSI, FDT, distance	SI=30%+NSI, FDT, distance
A-G	0.03s,10km	0.03s,10km	0.032s,10km	0.032s,10km	0.04s,10km	0.04s,10km
AB-G	0.02s and 0.025s,50km	0.02s and 0.03s,50km	0.02s and 0.035s,50km	0.03s and 0.035s,50km	0.03s and 0.035s,50km	0.03s and 0.04s,50km
AB-G (B-4)	0.025s and 0.03s,50km	0.025s and 0.03s,50km	0.025s and 0.03s,50km	0.03s and 0.035s,50km	0.04s and 0.042s,50km	0.04s and 0.044s,50km
ABC	0.03s,399km	0.03s,399km	0.035s,399km	0.035s,399km	0.04s,399km	0.04s,399km

4.4. Effect of phase reversal:

The phase reversal is critical issue while studying fault detection and classification. The effectiveness of the system is also tested using reverse power flow under different types of fault. Figure 7(a) depicts the ABC fault occurs at 70km from B-S, at Rf=1Ω, FIA =0^0, with phase reversal. The DSE of all three phase current A-phase, B-phase and C-phase crosses the Th value in 0.04s to detect and classify the fault. Figure 7(b) depicts the frequency contour of ABC fault. Thus, it is concluded that the system works fine in phase reversal. Table 4 presents the reverse power flow at Rf =1Ω, FIA=0^0, FDT and distance in km from B-S under different types of fault. Table 5 presents the distance variation with respect to FDT from B-S at Rf =1Ω and FIA=0^0.

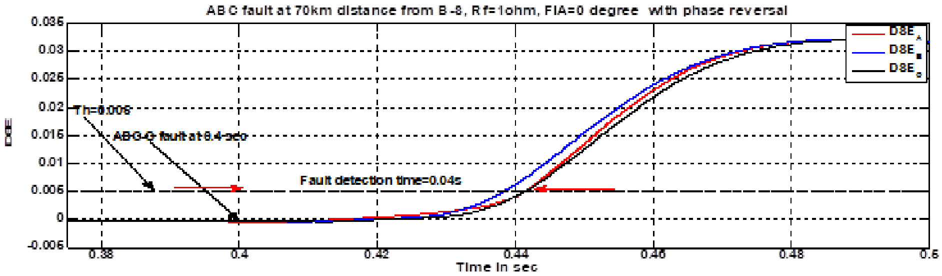

Figure 7(a). ABC fault at 70km distance from B-S, Rf=1 Ω,FIA=0^0 with phase reversal

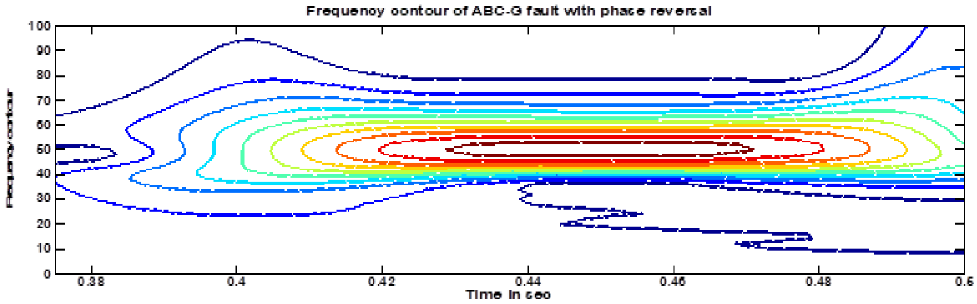

Figure 7(b). Frequency contour of ABC fault at 70km from B-S,Rf=1Ω, NSI, FIA =0^0 with phase reversal

Table 4. Reverse power flow at Rf =1Ω, FIA=0^0, fault distance in km from B-S

Fault Type	FDT in Reverse power flow from B-S, distance	FDT in Reverse power flow from B-4 distance	classification
C-G	0.035s,100km	0.035s,100km	C-phase
AB-G	0.03s and 0.04s,70km	0.025s and 0.038s,70km	AB-phase
BC	0.04s,150km	0.045s,150km	BC-phase
ABC	0.04s,70km	0.04s,70km	ABC-phase

Table 5. Distance variation with respect to FDT from B-S at Rf =1Ω and FIA=0^0

Fault Type	100km, FDT	200km, FDT	300km, FDT	Classification
B-G	0.03s	0.03s	0.04s	B-phase
BC-G	0.03s	0.035s	0.04s	BC-phase
AB	0.035s	0.035s	0.04s	AB-phase
ABC	0.04s	0.04s	0.04s	ABC phase

4.5 External fault

To test reliability further an external fault AB phase is made. Figure 8(a) depicts AB fault at 0.4s, it shows that the DSE of any of the A phase and B phase currents are unable to cross Th value (±0.05) neither in +ve direction nor in –ve direction. Thus it proves that the fault is an external fault. Figure 8(b) depicts frequency contour of AB fault which shows that the fault is effectively localize at inception of fault. Thus the fault is detected and classified in the analysis of an external fault. The proposed scheme clearly discriminates well to detect internal and external fault.

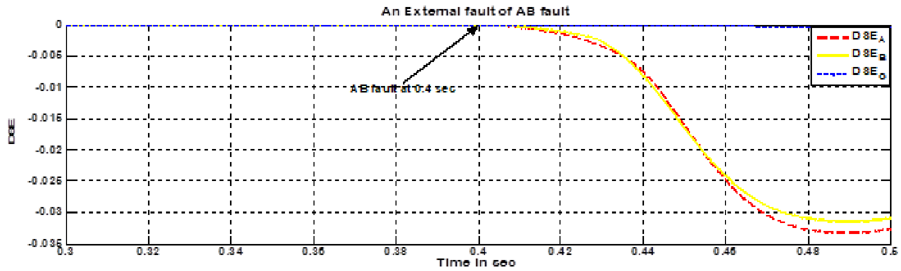

Figure 8(a). AB fault is at an external zone, Rf=1Ω, FIA =0^0

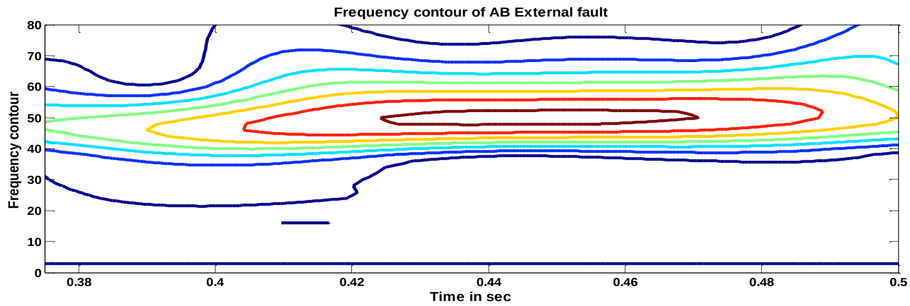

Figure 8(b). Frequency contour of an external end of AB fault, Rf=1 Ω,NSI, FIA=0^0

Table 6. A comparative study of DSE with Differential current scheme and Distance relaying scheme.

Fault condition with varying parameters.	Proposed algorithm of DSE scheme	Differential current scheme	Distance relaying scheme
Rf variation from 0 -100Ω	Not affected	Affected	[21] Relay under reach (-4.1%)/over reach (2%)
SI variation upto 50%	Not affected	Affected	[21] Relay under reach (-4%)/over reach (2%)
STATCOM variation (voltage and VAR regulator)	Affected in Small variation, but works fine	Affected	[21] STATCOM Relay under reach (-7.9%) and over reach (6.2%)
Reverse power flow	Not affected	Affected	Affected
Inter circuit fault	Not affected	Affected	Affected
External fault	Not affected	Affected	Affected

5. DISCUSSION

The differential relaying scheme of time-frequency transform based fault detection and classification of STATCOM integrated single circuit transmission line is proposed.Table 1-Table 5 depicts the variation of different parameter condition under different types of fault. It is seen that in all the case the fault is detected and classified accurately within a cycle of time period (20ms). In all these condition FDT with respect to distance of fault location from sending and receiving end bus under different types of faults have been considered. As enough literatures are not available to compare the proposed scheme, still a comparative analysis has been presented in Table 6. A comparative study of proposed algorithm of DSE scheme with respect to the existing approach [21] is presented. In this table different types of parameter variation such as fault resistance (Rf), Source Impedance (SI) upto 50%, STATCOM variation, reverse power flow, inter-circuit fault and external fault are considered. It is clearly understood that the proposed scheme of DSE scheme works fine and not affected under such variation compared to differential current scheme and distance relaying scheme. The distance relaying scheme performs to detect the fault but very often relay behaves under reach and over reach problem. It is observed that in all the exreme situation and critical condition of parameter variation such as Rf, SI, FIA and phase reversal, the proposed scheme works fine to address fault detection and classification.

6. CONCLUSION

A time-frequency transform based fault detection and classification of STATCOM integrated single circuit transmission line is proposed. The DSE based relaying differential scheme including fast signal processing FDST is used for analysis of different types of fault detection and classification at different parametric condition. DSE scheme is used either to issue or suppress the tripping signal. The frequency contour waveform shows the localization of fault occurs at 0.4s. The scheme is validated for detecting and classifying the different types of external and internal condition by varying theparameters such as Rf, SI, FIA and phase reversal. Therefore it is concluded that the proposed DSE scheme works fine under all such extreme and critical condition to detect both internal and external fault within a cycle of response time (20ms).

REFERENCES

[1] N. G. Hingorani and L. Gyugyi. Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems, New York: IEEE Press, 2000.
[2] S. R. Samantaray. "A Data-Mining Model for Protection of FACTS-Based Transmission Line", in *IEEE Transactions on Power Delivery,* 2013; 28 (2): 612-618
[3] L.N. Tripathy, S.R Samantray, P.K Dash. "A fast time–frequency transform based differential relaying scheme for UPFC based double-circuit transmission line", *International Journal of Electrical and Power Energy system,* 2016; 77(1): 404-417.
[4] Zhou X, Wang H, R.K Agarwal, P. Beaumont. "Performance of evaluation of distance relay as applied to a transmission system with UPFC", *IEEE Transaction on Power Delivery,* 2006; 21(3): 1137-1147.
[5] M.H.J. Boolen. "Traveling wave based protection of double circuit lines", *Proceedings of Institute of Electrical and Electronics Engineers C- Generation, Transmission and Distribution,* 1993*;* 140 (2): 37–47.
[6] P.K. Dash, A.K Pradhan, G.Panda. "A novel fuzzy neural network based distance relaying scheme", *IEEE Transaction on Power Delivery,* 2000; 15(3): 902-907.
[7] S. R. Samantaray, P. K. Dash. "High impedance fault detection in distribution feeders using extended kalman filter and support vector machine", *European Transaction on Electrical Power,* 2010; 20(3): 382-393.
[8] V. L. Pham, K. P. Wong. "Wavelet transform based algorithm for harmonic analysis of power system waveform", *proceeding on Institutionof Electrical Engineering, Generation, Transmission and Distribution,* 1999; 146(3): 249–254.
[9] Y. S Rao, G. Ravi Kumar, G. Keshab Rao. "A new approach for classification of fault in transmission line with combination of wavelet multi resolution analysis and neural networks", *International Journal of Power Electronics and Drive system,* 2017; 8(1): 505-512.
[10] M. F. Habban, M. Manap, A.R. Abdullah, M.H. Jopri, T. Sutikno. "An Evaluation of linear time frequency distribution Analysis for VSI switch faults identification", *International Journal of Power Electronics and Drive system,* 2017; 8(1): 1-9.
[11] S. Azimi and M.V. Amiri. "Concurrent Detection and Classification of faults in Matrix Converter using Trans-conductance", *International Journal of Power Electronics and Drive system*, 2014; 5(1): 93-100.
[12] S. Dhara, A. K. Shrivastav, P. K. Sadhu, A. Ganguly. "A fault current limiter circuit to improve transient stability in power system", *International Journal of Power Electronics and Drive system,* 2016; 7(3): 769-780.
[13] S. K. Mishra, L.N Tripathy, S.C Swain. "An Adaline LMS control and DWT approach based differential relaying STATCOM integrated line", *International Journal of Control Theory and Applications*, 2017; 10 (37): 281-296.
[14] M. K. Jena, S. R. samantray, L. N. tripathy. "Decision tree-induced fuzzy rule-based differential relaying for transmission line including unified power flow controller and wind-farms", in *IET Generation, Transmission and Distribution*, 2014; 8 (12): 2144-2152.
[15] P.K. Dash, S.R. Samantaray, G. Panda and B.K. Panigrahi. "Time– frequency transform approach for protection of Parallel transmission lines" *IET Generation, Transmission & Distribution*, 2007; 1 (1): 30-38.
[16] L.N. Tripathy, S.R Samantray, P.K Dash. "Sparse S-transform for location of faults on transmission lines operating with unified power flow controller", in *IET Generation, Transmission & Distribution*, 2015; 9(15): 2108-2116.
[17] L.N. Tripathy, S.R Samantray, P.K Dash. "A fast time-frequency transform based differential relaying scheme for UPFC based double circuit transmission line", in *International Joiurnal of Electrical Power & Energy System*, 2016; 77(1): 404-417.
[18] H. A. Darwish, A. M. I. Talab, a.H Osman, N. M Mansur, O. P. Mallik. "*Spectral energy differential approach for transmission line protection*", proceeding on PSCE, Atlanta: USA, 2006: 1931–1937.
[19] L.N. Tripathy, M. K. jena, S. R Samantray. "Differential relaying scheme for tapped transmission line connecting UPFC and wind farm", *International Journal of Electrical Power & Energy Systems*, 2014; 60 (2): 245-257.
[20] W. Elmore, Protective Relaying Theory and Applications, second ed., Marcel Dekker, Inc., New York, 2005.
[21] M. Khederzadeh, A. Ghorbani. "STATCOM modelling impacts on performance evaluation of distance protection of transmission lines", in *European Transaction on Electrical Power,* 2011; 21(3): 2063-2079.