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Research paper

A Discrete Wavelet Transform based STATCOM Compensated Transmission Line

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Abstract

This paper describes the Discrete Wavelet transform (DWT) applied for classification and detection of fault with respect to the position of the Static Synchronous Compensator (STATCOM). STATCOM is positioned at mid-point of the transmission line. The reactive power injection or absorption (i.e shifting phase voltage with respect to bus voltage) depends upon the apparent impedance during the fault. The current signals of each phase are retrieved from both sending and receiving end of three phase transmission line synchronously. It starts processing through DWT to acquire spectral energy (SE) content of each phase current signals from both end of the transmission line. Differential spectral energy (DSE) of each phase current signals (i.e SE of current signal recovered from sending end minus SE of current signal recovered at receiving end) of transmission lines is used to record the fault configuration.

Keywords: *DWT; SE; DSE; Fault Inception Angle (FIA); Normal Source impedance (NSI)*

1. Introduction

The STATCOM [1] based voltage source converter is preferred because it's ac output voltage is controlled in transmission or distribution system for the required reactive current flow for any bus voltage, which is generally adjusted to serve as a voltage source for converter. It is used to control the voltage compensation, reactive power (VAR) compensation, transient stability, dynamic stability and voltage stability. It can supply dynamic VAR with immediate required during system fault for compensation of voltage. Hence, it causes over reaching or under reaching of distance relay [4]. The performance of power system is affected by faults on transmission line, which results interruption of flow. Hence, early recognition and exact assessment of fault detection and classification care faster in maintenance and restoration of supply resulting an enhanced economy and consistency of power supply. Fourier transform (FT) is generally unable for analysis of non-stationary signals because of its coefficients which does not give any inherent time information. So, it is being applicable in the analysis of stationary signal but it fails to analyze the problem like power system and power quality disturbances occurred in the power system. The Short Time FT (STFT) overcomes time location problem, but it does not give any idea regarding multiple resolution in time and frequency domain, which is essential for analyzing transient signal containing both high and low frequency components. The main demerit in STFT is of fixed size of window. Wide window gives good frequency resolution but bad time resolution because of smaller size of window. As the Window size becomes smaller and smaller, the frequency resolution decreases and time resolution increases. This paper proposes DWT based differential protection scheme for STATCOM [4] compensated single transmission line using fast frequency filtering DWT. This paper describes the consequence of STATCOM working under different situations and variable disturbance in parameters at the time of fault condition are considered while designing this protection scheme. The scheme proposes DWT based STATCOM-compensated differential relaying in single circuit line. DWT algorithm is discussed in part-2, protection of the scheme is described in part-3, simulation results are presented in part-3 and conclusion part is discussed in part-4.

2. DWT

Recently wavelet analysis have been applying in various domains like geophysics to telecommunication to biomedical engineering. Most of the work done in power quality area and analysis of power system disturbances like detection, classification and location of fault. The selection of wavelet [6]-[7] with typical features of multi-resolution have been applying in many research area of power system disturbance. Hence, it requires much attention for optimal choice of mother wavelet. It is also very difficult to perform with numerous mother wavelet and Daubechy'db_4 is one of them which gives better accuracy for simulation study. The Continuous WT signal x(t) is represented by

$$CWT(b,a) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t)\psi \frac{(t-b)}{a} dt \tag{1}$$

The mother wavelet is represented by

$$\psi_{a,b}(t) = \psi \frac{(t-b)}{a} \tag{2}$$

The translation and dilation parameters in the above equations are denoted as a and b. The process lasts decomposition upto third level represented in Figure-1. Computational algorithm is taken from paper [8]. The scheme is applied for 2 KHz sampling frequency, one cycle period gives 40 samples of base frequency 50 Hz. All the fundamental current obtained in [8] is recovered by utilizing DFT followed by applying DWT. Thus, DSE of P-phase ($DSE_{,P}$) is represented by

$$DSE_P = SE_{B-S,P} - SE_{B-4,P} \tag{3}$$

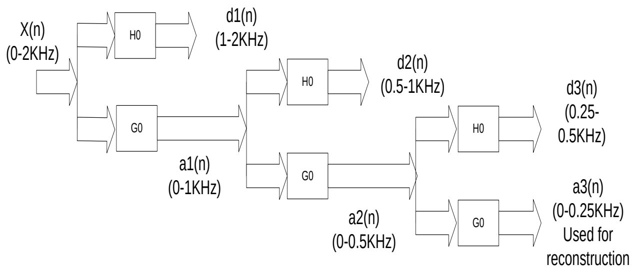

Fig. 1: Three Level Wavelet Decomposition Tree

3. Proposed Protection Scheme

Fig. 2 depicts the simulated transmission system. It consists of substations at both end of line having voltage of 400Kv, 50Hz and 1500 MVA. V_s , *Zs* and V_r, *Zr* be the sending and receiving end voltage and source impedance respectively and δ is the phase angle difference between them .i.e. $\delta = \delta_S - \delta_r = 12^0 - 0^0 = 12^0$. The scheme consist of four subsections i.e, Z_{l1}, Z_{l2}, Z_{l3}, Z_{l4}. B_s and B_4 are the sending and receiving end bus respectively. Fig. 3 shows the flow chart of the proposed protection scheme.

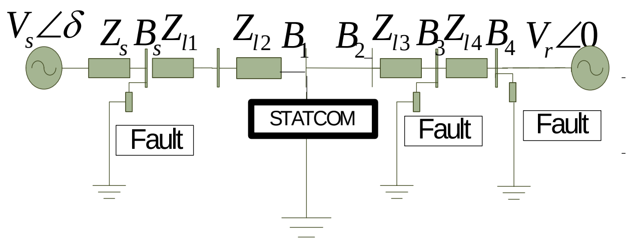

Fig. 2: Simulated Transmission System with STATCOM at mid-point of transmission line.

Positive and Zero Sequence impedance parameter of the transmission line are Z_1=0.01537+j0.2783ohm/Km and Z0=0.04612+j0.8341142ohm/Km. STATCOM is connected through shunt transformer 15Kv/400Kv Δ/Y and it injects or consumes VAR to transmission system for regulating the voltage at the point of common coupling. Following points are tested extensively for fault detection in the proposed scheme.

- Fault resistance (Rf) variation
- Fault inception angle (FIA) variation
- Different Shunt fault: AG, BG, CG, AB, BC, CA, ABG, BCG, CAG, ABC
- Source impedance (SI) variation
- Phase reversal

The following conditions are used for fault detection and classification.
Condition-1: $DSE_{,P}$ >+Th : Fault is within fifty percent distance of total length of line 400 Km from B_s
Condition-2: DSE_p <-Th : Fault is within fifty percent distance of total length of line 400 Km from B_4
Condition-3: (-Th <DSE_P <+Th): Fault is at an external zone.

Threshold Th value is selected as ±20 after successfully carrying out for different simulation studies.

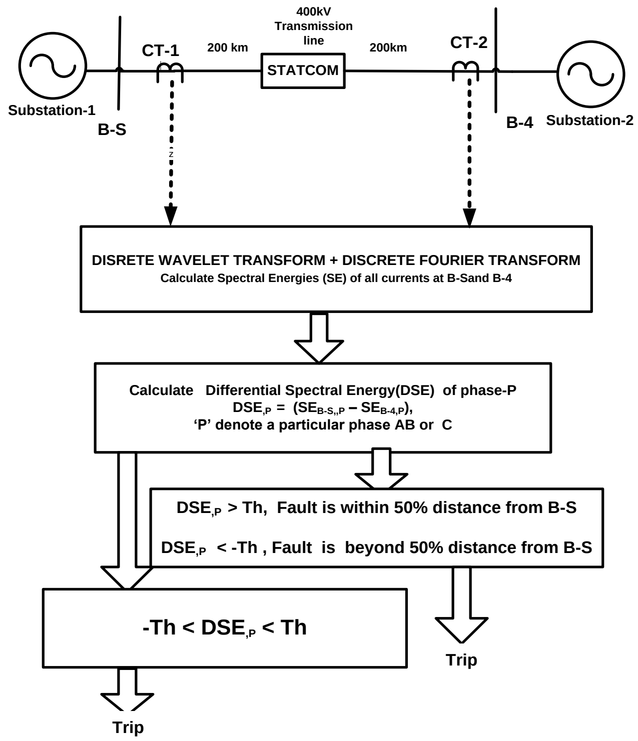

Fig. 3: Flow chart of proposed protection Scheme

4. Simulation Result

SIMULINK Model is utilised for modelling proposed system. Fig. 4 represents the A-G fault at B_s and B_4. All faults analysis are carried out at 0.3 sec or 600[th]sample period time. Table represents two types of condition. Condition-1 signifies as fault at a distance 100Km (within 50% distance) from B_s and condition-2 signifies fault at a distance 300Km (away from 50% distance) from B_s.

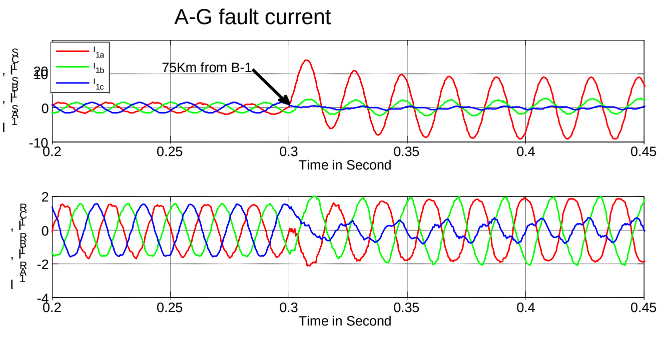

Fig. 4: L-G (A-G) fault current at B-1 and B-2.

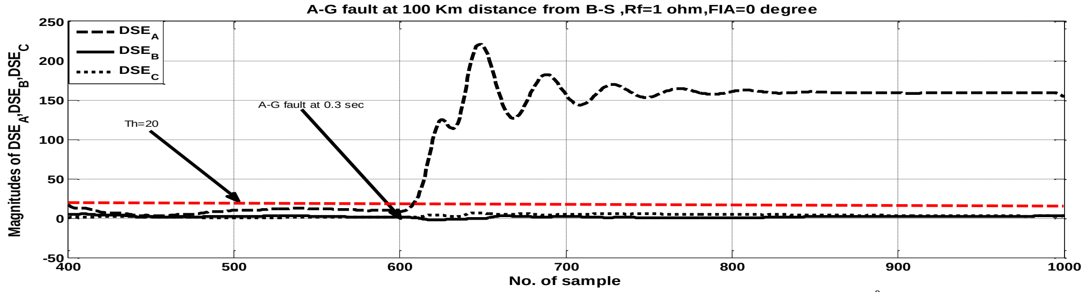

Fig. 5(a): A-G fault at sending end fault distance 100km from B_s , R_f=1Ω, FIA=0^0

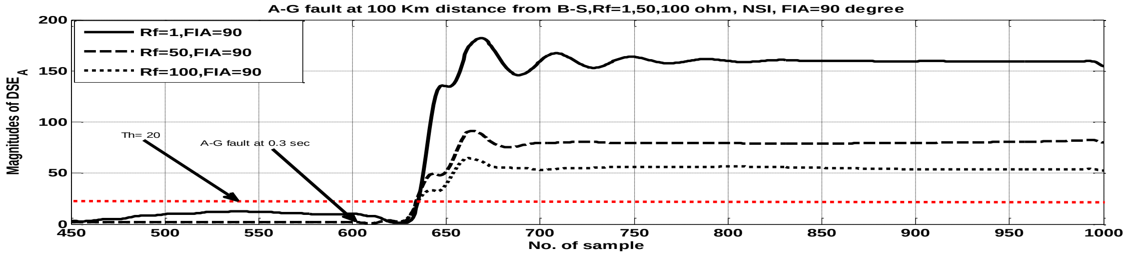

Fig. 5(b): A-G fault at 100 Km distance from B_s Rf= 1Ω, 50 Ω and 100 Ω, FIA=0 degree

4.1. Rf Variation

Fig. 5(a) represents A-G fault takes place at 100Km distance from B_s .DSE amplitude of A-phase current grows upward direction and crosses Th in a cycle period of time but remaining two phase B and C fail to cross Th. It confirms fault is in A phase. Fig. 5(b) A line to ground (A-G) fault takes place by varying the Rf values from 1, 50 and 100 ohm works fine up to 100 ohm in a cycle of time. In this table condition-1 and condition-2 is specified. Condition-1 is for 100Km distance from B_s and Condition-2 is for 300Km distance from B_4. Table 1, Table 2 and Table 3 represents various energy content of circuit-1, Rf= 1ohm, Rf=50 ohm and Rf=100 ohm and FIA=0^0 respectively. The higher values of different types of fault which is more than the threshold represents the faulty phase and other phases are healthy phase.

Table 1: Energy variation of Current at Rf= 1Ώ and FIA=0^0

Type of Fault	Condition-1			Condition-2		
	A	B	C	A	B	C
A-G	**93.0**	13.0	13.0	**-116.2**	-5.243	-1.819
AB-G	**104.24**	**104.24**	14.24	**-133.9**	**-136.9**	-13.899
BC	-1.629	**108.8**	**104.0**	15.69	**-132.0**	**-148.9**
ABC-G	**103.89**	**103.89**	**103.89**	**-114.3**	**-111.3**	**-123.39**

Table 2: Energy variation of Current at Rf=50Ώ and FIA=0^0

Type of Fault	Condition-1			Condition-2		
	A	B	C	A	B	C
A-G	**54.532**	8.4945	6.5859	**-24.053**	-8.09	3.67
AB-G	**51.299**	**67.0892**	3.9388	**-23.119**	**-20.54**	13.77
BC	-1.361	**79.3498**	**93.016**	14.7733	**-31.54**	**-65.3**
ABCG	**88.208**	**88.6054**	**88.081**	**-51.640**	**-51.95**	**-48.9**

Table 3: Energy variation of Current at Rf =100Ώ and FIA=0^0

Type of Fault	Condition-1			Condition-2		
	A	B	C	A	B	C
AB-G	**52.9083**	**68.7903**	4.3541	**-12.252**	**-15.707**	13.5807
BC-G	2.8003	**52.4112**	**68.1788**	11.7808	**-30.95**	**-30.746**
CA-G	**68.3042**	3.5402	**52.0809**	**-22.414**	12.8600	**-22.607**
ABC	**57.8673**	**57.9005**	**57.3105**	**-21.238**	**-21.177**	**-21.642**

4.2. Variation of FIA

Fig. 6 represent the AB-G fault at 100 km distance from B_s and Rf= 10Ω, NSI, at different values of FIA= 45^0 and 90^0 . It clears from the figure that, the fault time in FIA=45^0 is somewhat less as compared to FIA=90^0 The DSE of A and B-phase crosses the Th value within a cycle of time period. Thus, FIA variation is achieved with high degree of accuracy. Table 4 and Table 5 depicts the energy variation of current at Rf=1ohm, FIA=45 degree and FIA=90 degree respectively.

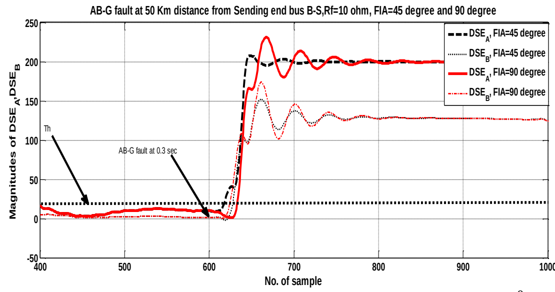

Fig. 6: AB-G fault at 50Km distance from Bs Rf= 10Ω , FIA=45^0 and 90^0

Table 4: Energy variation of Current at Rf =1Ώ and FIA=45^0

Type of Fault	Condition-1			Condition-2		
	A	B	C	A	B	C
AB-G	**83.45**	**84.79**	5.6529	**-71.7653**	**-72.207**	-12.3807
BC-G	5.7982	**78.1235**	**79.8692**	-12.438	**-80.578**	**-84.632**
CA-G	**84.482**	5.7831	**78.9852**	**-81.414**	7.9082	**-82.579**
ABC	**87.873**	**84.529**	**87.7421**	**-82.858**	**-81.787**	**-82.4821**

Table 5: Energy variation of Current at Rf =1Ώ and FIA=90^0

Type of Fault	Condition-1			Condition-2		
	A	B	C	A	B	C
A-G	**98.48**	7.5385	5.6529	**-101.358**	-2.0784	-5.3847
BC-G	7.6942	**97.5476**	**99.9862**	-2.8571	**-99.852**	**-98.2749**
CA-G	**99.529**	3.8531	**98.5873**	**-100.473**	6.9812	**-99.129**
ABC	**101.387**	**105.596**	**103.121**	**-98.834**	**-99.707**	**-102.841**

4.3. SI Variation

To test the effect of variation of SI, Fig. 7 represents A-G fault at 75Km distance from B_s , Rf=20 ohm, Source impedance, SI= NSI and 30% increase of NSI (Normal SI), Rf=1 ohm and FIA=0^0. Table 6 depicts the energy variation of current signal at SI= 30% increase to NSI, Rf= 1Ώ and FIA=0^0 which clearly describes the fault detection and classification of different types of fault.

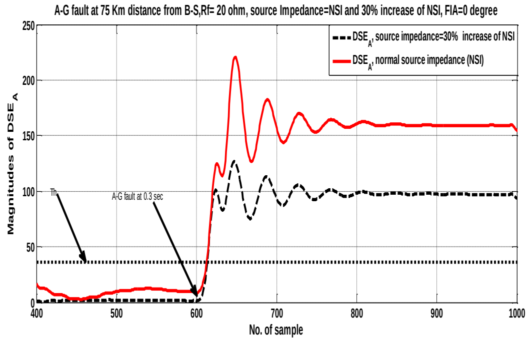

Fig. 7: A-G fault at 75 Km distance from B_s, Rf=20Ω, SI =NSI and 30% increase of NSI, FIA=0^0

Table 6: Energy variation of current signal at SI= 30% increase to NSI, Rf= 1Ώ and FIA=0^0

Type of Fault	Condition-1			Condition-2		
	A	B	C	A	B	C
A-G	**93.23**	8.22	-3.16	**-117.2**	5.27	-3.4
AB	**105.14**	**96.5**	-2.43	**-135.4**	**-135.7**	-11.8
BC	-1.54	**109.7**	**105.0**	15.687	**-133.8**	**-150.1**
ABC	**104.4**	**107.5**	**116.7**	**-113.7**	**-111.6**	**-127.2**

4.4. Variation of Phase reversal

To verify performance of the system, LLL-G fault takes place at 100 Km distance from $B_{s,}$ Rf=1 ohm, NSI, FIA =0^0 with phase reversal it is found that system works fine at different fault condition. Fig. 8 shows the three phase fault (ABC-G) occurs at, 50% distance from B-1of circuit-1, Fr=1Ώ, NSI, FIA =0^0 with phase reversal. Similarly, Table 7 depicts the energy variation of current signal Rf=11Ώ and FIA=0^0 with phase reversal

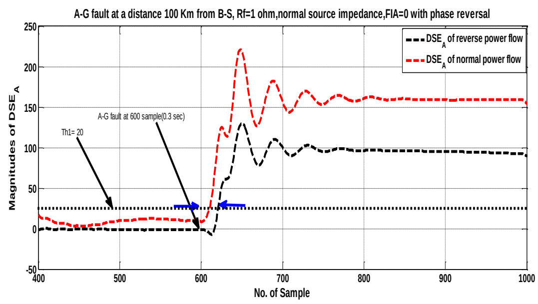

Fig. 8: LLL-G (ABC-G) fault, 100Km distance from B_s, Rf=1Ω, NSI, FIA =0^0 with phase reversal

Table 7: Energy variation of current signal Rf=11Ώ and FIA=0^0 with phase reversal

Type of Fault	Condition-1			Condition-2		
	A	B	C	A	B	C
A-G	**100.3**	-4.006	4.3882	**-110.4**	-14.79	-4.93
AB-G	**97.10**	**107.760**	-1.0733	**-144.6**	**-136.9**	-12.3
BC-G	-1.83	**93.26**	**116.54**	-14.86	**-148.7**	**-46.4**
ABC	**109.8**	**105.62**	**116.1863**	**-113.8**	**-116.8**	**-125.2**

4.4. Variation of External fault

An external fault of ABC-G takes place at R_f = 1Ω, FIA =0^0 and observed that DSE of all the three phase currents are within the threshold value and fail to cross.

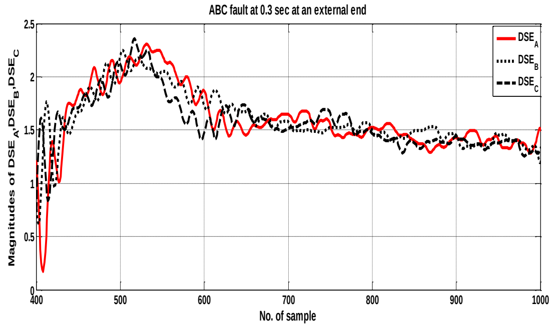

Fig. 9: ABC-G fault at an external zone, R_f = 1Ω,FIA =0^0

5. Conclusion

The DWT based relaying scheme for single circuit transmission line protection including STATCOM is proposed. The scheme is validated for classifying and detecting faults (internal as well as external) by varying Rf, FIA, SI and phase reversal. After numbers of simulations are conducted to justify the performance and accuracy of the system and it is found that the scheme works fine for any such variation. Thus the system is validated for any kind of such parameter change described above. It is concluded that the system is highly accurate for distinguishing detecting any types of fault.

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