A DWT Based Differential Relaying STATCOM Integrated Wind Fed Transmission Line

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Abstract- This paper presents the differential relaying scheme protection of transmission line in a Static Synchronous Compensator (STATCOM) integrated wind fed single circuit line. The Discrete Wavelet Transform (DWT) and Discrete Fourier Transform (DFT) approaches are used for classification and detection of fault in the transmission line. The STATCOM is placed at mid-point of the transmission line and wind farm acts as receiving end grid substation. The advantages of this scheme is that db4 mother wavelet is utilized for better accuracy of fault detection and because of differenetial relaying the synchronisation error is less which is neglected while computation of fault studies. The process starts with extracting the current signal (i.e, A, B and C) from the current transformer placed at sending and receiving end of the transmission line synchronously. The spectral energy (SE) content of each phase current signal at both end of transmission line is computed using DWT and DFT approach during the fault. The Differential Spectral Energy (DSE) of current signal (i.e spectral energy of current signal measured at sending end minus spectral energy of current signal measured at receiving end) is used to register the fault pattern. This scheme is very accurate, effective and simple for fault classification and detection of transmission line.

Keywords Single Circuit transmission line, Discrete Wavelet Transform (DWT), Differential Spectral Energy (DSE), Static Synchronous Compensator (STATCOM), Wind-farm, Fault Inception Angle (FIA)

1. Introduction

Power system disturbances [1] are considered to be very transitory and non-stationary in nature. If this disturbance sustain for long duration, it may cause damage not only to the equipment associated nearby but also affect the end user. To protect the equipment and isolate the faulty part from the healthy system is an important issue to discuss. Therefore, the protection engineer must have some means to clear the fault at an earliest possible of time. Therefore, fault analysis using signal processing approach is an important area of research to find the solution during the fault.

Numerous approach like Fourier transform, Fast Fourier Transform [2], short time fourier transform [3] and S-transform [4] have been used since a decade. The above approaches are some demerit regarding time information loss, fixed window size and fault analysis accuracy of non-stationary signal. The soft computing approach like artificial fuzzy neural network [5], extended Kalman filtering with SVM [6] takes long time to process for training, testing, noise and filtering for the fault analysis. However, integrating the wind farm [7] to the grid poses special complication and challenges to the protection system. The complexity increases while integrating the most versatile FACT's device integrated to the wind-farm [8]. However an alternative solution is addressed for enhancing the operation of SCIG (squirrel cage Induction generator) based wind farm connected to network [9] using QSTDC (quasi static time domain simulation). But this solution is not able to provide the different types fault occurred by varying the parameters of the line. Protection of transmission line in an offshore wind farm is also discussed [10] using FCIP (fault component integrated power) [11] but it unable to address the study of fault detection and classification at different parameter condition of the line including wind speed. However the DFIG based wind farm is popularly implemented because of its high performance [12]. As the power output of the generator is nonlinear to wind speed, therefore wind farm cannot contribute to the grid when the wind speed is beyond the rated limit. For this reason the placement and sizing of FACT's integrated DFIG based wind farm is required to enhance the voltage stability [13].

As a result the transmission system connects such farms will be easy to maintain the voltage limit. However the protection system turn out to be more complex and difficult to analyse the fault in a conventional relaying scheme using distance relay [14] which is discussed and the issue of tripping the signal based on impedance of the line. During the fault this impedance changes which develop an error due to the result of under reach/over reach problem. The combined approach of decision tree and fuzzy rule based differential relaying approach including UPFC is discussed [15]. However this approach is unable to address the different condition of fault parameters of the line. Travelling wave theory [16] approach has been utilized for power system fault classification but it offers high frequency contaminated signal. Combined approach of ANN and fuzzy [17]-[18] for classification and detection of fault in transmission system fails to achieve precise results due to inaccuracies and takes long time to process. Thus, the motivation behind this work is to analyze a fast algorithm based approach which takes less time to process in a effective and accurate manner. The Discrete wavelet transform (DWT) approach [19]-[23] provides accurate result because of its variable window sizing and flexible in operation. The selection of mother wavelet [21] is also an important factor incase of DWT approach. The merit of this approach is that local analysis of larger signal can be performed where the other signal processing approach fails to accomplish. The signal can be decomposed into scaled and shifted version of mother wavelet. The analysis like Multi Resolution [23] find suitable for the signal features having low frequency with sharp spike, impulse component related to fault. Further it is also used for the reduction of harmonic and noise and ignoring the high pass output, when signal reconstruction is at accurate standards of threshold. The Static Synchronous Compensator (STATCOM) [24]-[26] based voltage source converter is preferred because voltage is controlled for the required reactive current flow at every bus. It is also utilized to control the reactive power (VAR) compensation, transient stability, dynamic stability and voltage stability. It can supply dynamic VAR with immediate requirement during system fault for voltage compensation. Daubechies mother wavelet has various types of filter coefficients like Db4, Db6, Db8, and Db10 etc. Out of this db4 wavelet is most suitable for power transient application study for its high accuracy. Our study system is processed with the lhelp of db4 wavelets at a sample frequency of 2 kHz. This 2 kHz sample frequency is considered to be high enough to capture the transient signal. Fig. 1 depicts the three stage wavelet decomposition tree which is discussed in three different stages of frequency content. In 1st stage, a1 (0–1kHz), d1 (1–2kHz), in 2nd a2 (0–0.5 kHz), d2 (0.5–1kHz) in 3rd a3 (0–0.25kHz), d3 (0.25–0.5 kHz) of approximate and detail coefficient have been decomposed with different frequency content. In 3rd stage, a3 contains harmonics of fundamental current frequency (50 Hz), 3rd (150Hz) and 5th (250 Hz) signal. The 3rd level reconstructed signal (A3) of phase currents (A, B and C) at each substation are obtained from the approximate coefficient (a3) of individual phases. Using DFT the rms values of each fundamental current (A, B and C) are computed from both the end bus.

1.1 Future Prospect of Wind farm:

Grid integrated wind-farms are developed increasingly to meet the growing power demand across many parts of the world. The percentage share of wind farms from the renewable energy sources are rising daily because of clean source. The pollution and global warming are also increasing day to day because of fossil fuel plant. The most important point is that the reliability increases when wind-farm acts as a grid substation. Assuming that the wind farm is located at a place where continuous supply of wind is available throughout the year. The frequency variation as well as voltage fluctuations may happen due to such speed variation. This problem can be solved to the greater extent by means of control arrangement using power electronics devices, provided at every generating unit of wind farm. Generally, the power output of each generating unit has the characteristics of non-linear relationship related to wind speed. Sometimes wind speed is beyond to its limits at that situation farm cannot act as a grid. Under such condition the voltage become under or over voltage, due to change of low or high wind speed at that situation some group of turbines may be considered for trip while the others may be operated to cater the load demand. The transmission system that connects such farms will be exposed to such a continuously controlled wind speed changing environment. Hence the protection to this system is a challenging task and becomes more complex with different wind speed. When STATCOM and wind-farms are acting together in the transmission system the transmission line turn out to be more complex and conventional relaying approach fails to analyse the fault. The conventional protection schemes are based on fault signal component of fundamental frequency. This frequency component does not provide the adequate information necessary for discriminating internal as well as external fault. So, the motivation behind this scheme is to implement differential relaying based DWT approach in a STATCOM integrated wind fed transmission line. This approach is very simple and accurate for detection and classification of fault under different parameter variation and wind speed of the wind farm connected to the line. The Section-2 of the paper discusses the modelling analysis of STATCOM and DFIG based wind farm. Section-3 describes the simplicity formulation of DWT approach. Section-4 describes about the spectral energy based protection scheme. Section-5 discusses the simulation result. Section-6 deliberately address the conclusion part of the scheme.

2. STATCOM and DFIG Modelling

The STATCOM nodelling anlysis is referred [28-30]. Similarly, DFIG based wind farm modelling is referred [31-35].

3. Discrete Wavelet Transform

Power system disturbance signals are non-stationary and transitory in nature. Fourier Transform (FT) is ideal for the calculation of steady state signal of 50Hz and its harmonics. It is unable to process the signal with sharp changes and discontinuities. So, FT fails to detect the signal which is highly non stationary and noisy. The WT offers a choice of wavelets, which can be applied very well to non-stationary signal. It has the special quality of orthogonally, which is used for perfect reconstruction and decreases the computational time by numerically filtering out unwanted noisy frequency information. The wavelet analysis technique is used to reconstruct transient signals using less number of wavelet coefficients. By using three stage wavelet decomposition approach approximate coefficient (a_3) is evaluated. The phase current is computed from the reconstructed signal. The fundamental current of rms value is obtained by using DFT and referred [28]. The amplitude and phase of each fundamental current rms value is evaluated using the expression as.

$$I(k) = |I(k)| \tan^{-1}\left(\frac{\operatorname{Im} I(k)}{\operatorname{Re} I(k)}\right) = A + JB \qquad (1)$$

Where, Im *I(k)* and Re *I(k)* are imaginary and real value of *I(k).* Aand B are real and imaginary parts of fundamental current. The amplitude of each phase current is expressed as

$$|I(k)| = \sqrt{(A^2 + B^2)} \qquad (2)$$

The Spectral energy (*SE*) of each phase is calculated at sending and receiving end by the expression as

$$SE_P = |I(k)|^2 \qquad (3)$$

Where, P is phase (A, B and C)
Differential Spectral Energy of each phase (DSE_P) is calculated by considering the difference of SE_p from the sending and receiving end of the line and is expressed as

$$DSE_P = SE_{s.e,P} - SE_{r.e,P} \qquad (4)$$

4. Proposed Protection Scheme

The system is structured by considering the A.C grid acts as substation-1 and the bus is represented as B-S. Substaion-2 acts as wind farm and the bus as B-4 which is depicted in Fig.2(a). The STATCOM is placed at midpoint of the transmission line length of 400km. Three fault points are considered for the study of fault analysis to distinguish internal and external fault of transmission line. Internal fault occurs in the section between B_S and B_3. The external fault occurs in the section between B_3 and B_4 of the Fig. 2(a). Let V_s and V_r be the voltages at sending end bus B_S and receiving end bus B_4 respectively and *Zs, Zr* be the impedance of sending end and receiving end respectively. The transmission lines consist of four subsections i.e, Z_{l1}, Z_{l2}, and Z_{l3} and Z_{l4}.

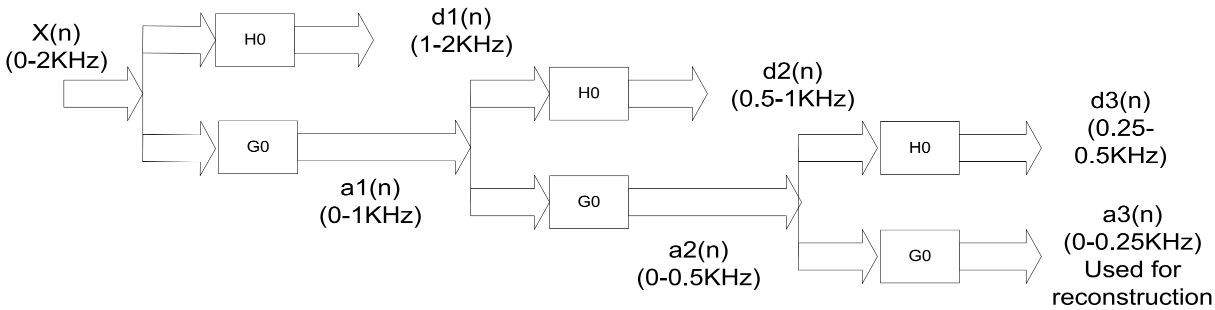

Fig. 1. Three stage wavelet decomposition tree

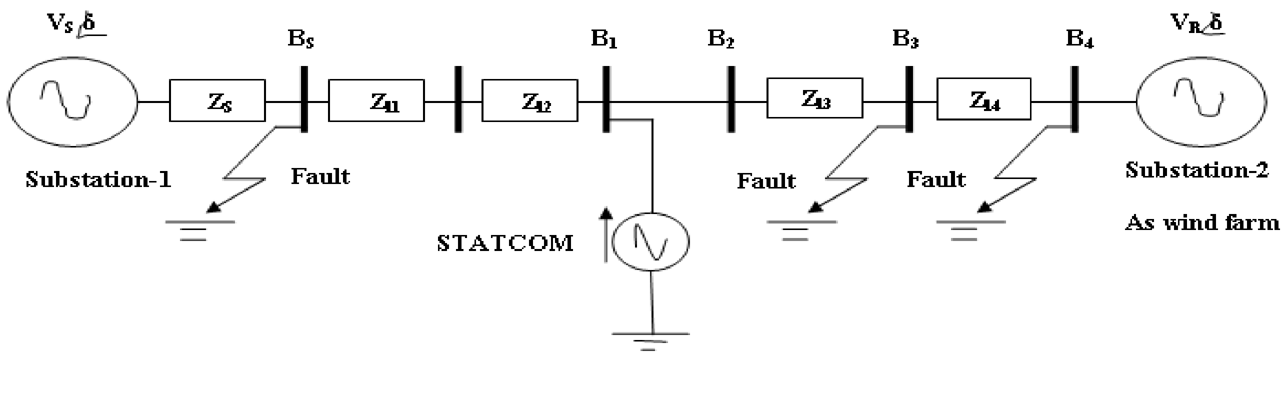

Fig. 2(a). Simulated transmission system

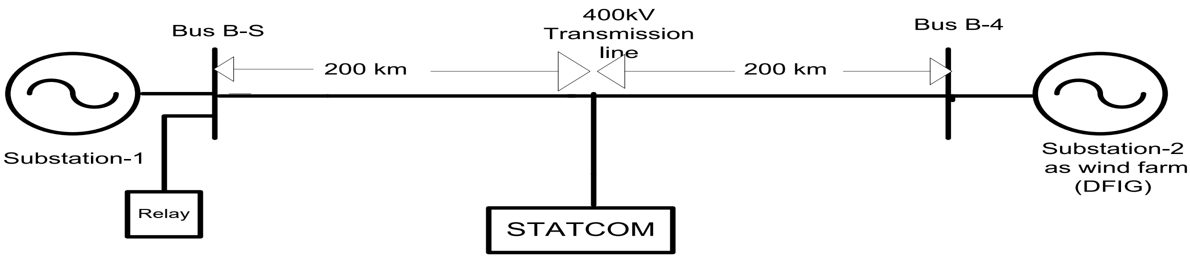

Fig. 2(b). Schematic diagram of proposed scheme

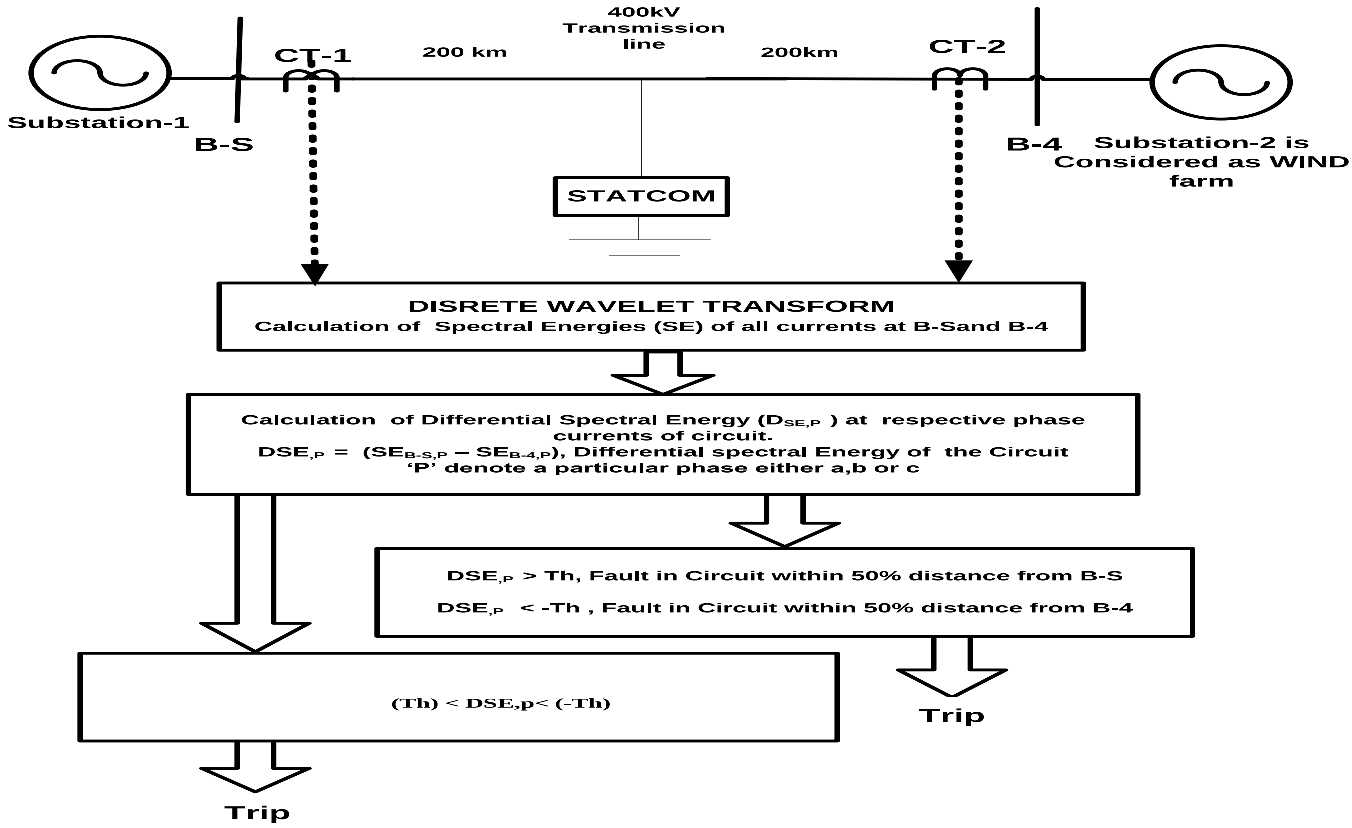

Fig. 3. Proposed relaying scheme

The voltage of wind farm, which is connected at receiving end, is stepped up to 400kV by using step up transformer. Fig. 2(b) depicts the schematic diagram of proposed scheme. Fig. 3 depicts the flow chart of the proposed relaying scheme.

4.1 Transmission Line Parameter:

Positive sequence impedance (Z1) of the line:
Z1=0.01537+j0.2783ohm/km
Zero sequence impedance (Z0) of the line:
Z0=0.04612+j0.8341142ohm /km

4.2 Source Parameter:
The sending end and receiving end voltage, angle are represented as Vs = 400kV, δs= $30^0$and Vr = 400kV, δr= $0^{0.}$

4.3 STATCOM and DFIG parameter:

The STATCOM, 100MVA is placed at central part of the transmission line length of 400km (200km from sending end). It is of 48-pulse VSI and connected through 2500μF DC capacitors and integrated to transmission line through a step up Δ/Y shunt transformer 15kV/400kV. It injects/consumes the reactive power into/from the transmission system and controls voltage to the point of common coupling. Doubly-Fed Induction Generator (DFIG) wind farm of 25kV, 40MW (2MW X 20 unit) is connected to 400kV through a step up transformer at receiving end side which acts as grid substation-2. DFIG is of wound rotor generator of induction type .It is designed by means of IGBT-based AC/DC/AC PWM converter. The stator winding connects to grid frequency 50 Hz and rotor is connected to the variable frequency via AC/DC/AC converter. The merit of using DFIG technology that it permits extracting maximum amount of energy from the wind at the time of low wind speeds by optimizing the speed of the turbine and reducing minimum amount of mechanical stresses develops at turbine during gusts of wind. The optimal speed of the turbine produces maximum output of mechanical energy at a particular wind speed which is proportional to given wind speed. When the the wind speed is lower than the rated speed like 5m/sec, 10 m/s then the rotor runs at a sub-synchronous speed. At very high wind speed it runs at hyper synchronous speed. The mentioned below points are considered for the analysis of fault detection and classification including different wind speed.

- Fault resistance (Rf) variation: 1 Ω, 50 Ω and 100Ω.
- Fault Inception Angle (FIA) variation: 0^0, 45^0,$90^{0.}$
- Different types of fault: AG, BG, CG, AB, BC, CA, ABG, BCG, CAG, ABC.
- Reverse power flow.
- Source impedance variation (SI variation- 30% and 50% increase of normal SI)
- Wind speed variation (5m/sec,10m/sec and 15 m/sec)

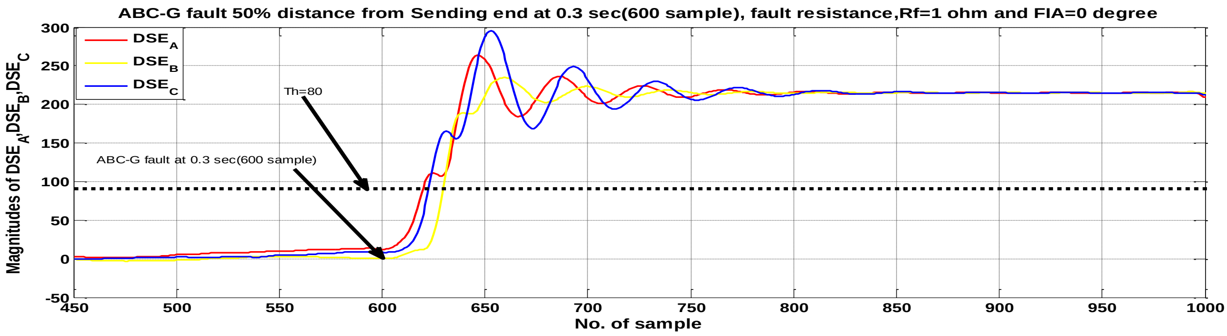

Fig. 4(a). ABC-G fault at 0.3sec from 100km distance (50% of total distance from STATCOM to sending Bus B-S), Rf=1Ω,FIA=0^0 and wind speed=15m/sec

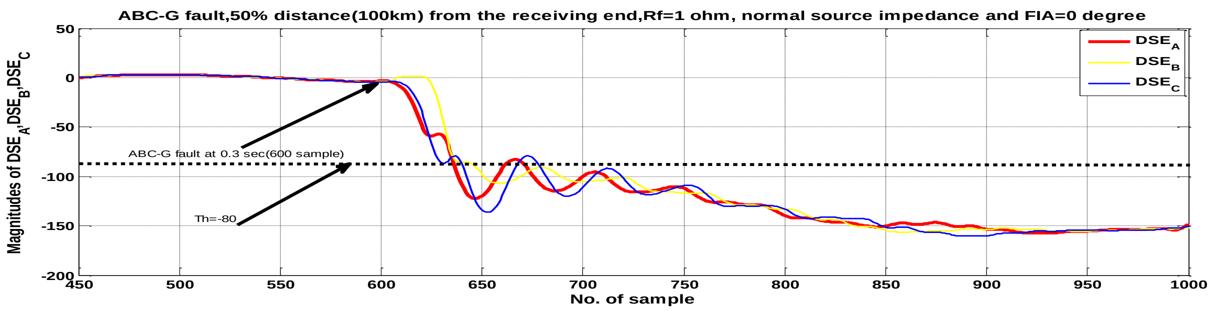

Fig. 4(b). ABC-G fault at 0.3sec at receiving bus B-4, 50% distance (100km from wind farm (i.e, bus B-4) to STATCOM, Rf=1Ω, FIA=0^0 and wind speed=15m/sec

Table 1: Energy variation of Current signal at different fault condition, distance of 100 km(50%) from B-S and a distance of 100 km(50%) from B-4 at Rf= 1Ω and FIA=0^0 with wind speed=15m/sec

Fault	Current: Threshold setting at SE Th= 80			Current: Threshold setting at RE Th=80			Fault classification
Type	A	B	C	A	B	C	
AG	***156.85***	5.88	5.03	***82.61***	63.45	50.50	A- phase
ABG	***181.68***	***189.13***	24.53	***99.87***	***126.50***	44.41	AB-phase
BCG	17.16	***201.51***	***203.32***	57.28	***127.21***	***121.31***	BC-phase
ABC	***205.35***	***212.52***	***207.27***	***102.21***	***103.25***	***106.86***	ABC-phase

The differential spectral energies is expressed as

$$DSE_{,P}=(SE_{B-S,P}-SE_{B-4,P}) \quad (5)$$

Where, P is phase like A, B or C.

Fig. 3 depicts the flow chart of proposed relaying scheme. Three different cases are considered below for giving information regarding internal and external fault at sending and receiving end bus with different fault distance. The sending end faults are simulated at sending end substation and receiving end faults are simulated at receiving end substation. It gives the clear idea regarding detection and classification and distinguishing internal and exteral fault.

Case 1: DSE_P>Th: The fault is in phase, P at sending end Side (Internal fault) and distance of fault is within 50% from the sending end bus B-S.

Case 2: DSE_P<-Th: The fault is in phase, P at receiving end Side (Internal fault) and distance of fault is within 50% from the receiving end bus B-4.

Case 3: (-Th <DSE_P<Th): It indicates an external fault occurs.
The threshold value (Th=±80) is same for both at sending and receiving end only the difference of sign. The Th=+80 is for the occurence of fault within 50% distance from sending end and Th=-80 is for the fault within 50% distance from the receiving end. The Th value is evaluated after carrying out number of simulation at different distance of the line under critical condition of the line parameter. The fault distances like 25% (50km), 50% (100km) and 75% (150km) from both end of the transmission lines are considered for simulation study. The variation of Rf from 1Ω to 100Ω, variation of FIA from 0^0 to 90^0 , variation of source impedance (SI) from normal value of SI then increase of 30%, 50% of normal value of SI, reverse power flow and wind speed are also considered for simulation study. All these parameter variations are simulated at both end of the line to study the accuracy and effectiveness of the scheme. Fig. 4(a) and Fig. 4(b) depicts the ABC-G fault occurs at sending and receiving end at 0.3sec (600th sample), Rf = 1Ω and FIA=0^0 at 50% distance (100 km) from sending bus B-S and 50% distance (100 km) from receiving bus B-4 respectively. It is observed from the Fig. 4(a) that differential energy of A, B and C phase current i.e, DSE_A, DSE_B and DSE_C are rising in positive direction and crosses the Th=+80 and isssue the alarm signal to trip the circuit breaker. Similarly, Fig. 4(b) depicts the DSE_A, DSE_B and DSE_C are rising in negative direction and crosses the Th =-80 to issue the signal to trip circuit breaker.

5. Simulation Result and Discussion

The R2010a MATLAB SIMULINK model is utilised for transmission system including STATCOM and wind. The number of internal and external fault under various parameter conditions are simulated. The scheme is validated for different internal and external fault. Table 1 presents the energy variation of current signal at different type of fault both at sending and receiving end, Rf=1Ω and FIA=0^0. The sending and receiving end fault current at bus (B-S) and bus (B-4) for L-G, LL-G, LLL-G fault at 0.3 sec (600 sample) are considered at different faulted condition.

5.1 Fault Classification

The following table justifies the variation of differetial spectral energy. The left half of the following table presents the occurence of fault at 50% (100km) distance from the total distance of 200km (i.e, sending end bus to STATCOM) and the right half of the table presents the occurence of fault at 50% (100km) distance of 200km from STATCOM to receiving end bus. This bold italic value of DSE for the particular phase signifies fault classification of that particular phase. Thus the scheme is highly accurate and effective for classifying different type of fault like L-G, LL-G, LLL-G, LLL fault.

5.2 Fault resistance (Rf)

The DSE value changes every time with respect to fault time. To verify the performance of the system the Rf is changed from 0Ω to 100 Ω. Fig. 5 depicts the comparative analysis of A-G fault at different value of Rf=1Ω, 50Ω and 100Ω. In all such Rf value DSE_A of A phases are rising in positive direction and crosses Th value of +80. Thus the fault is detected in all such Rf value and remains within 40 sample. Further it shows that the amplitude of DSE_A are higher in case of lower resistance (Rf=1Ω) and lower in case of higher resistance (Rf=100Ω). It proves that the proposed scheme works fine at all the values of Rf from 1Ω to 100Ω and more trustworthy against any type of internal faults. Table 2 presents the energy variation of current signal at different type of fault both at sending and receiving end, Rf=100Ω and FIA=0^0.

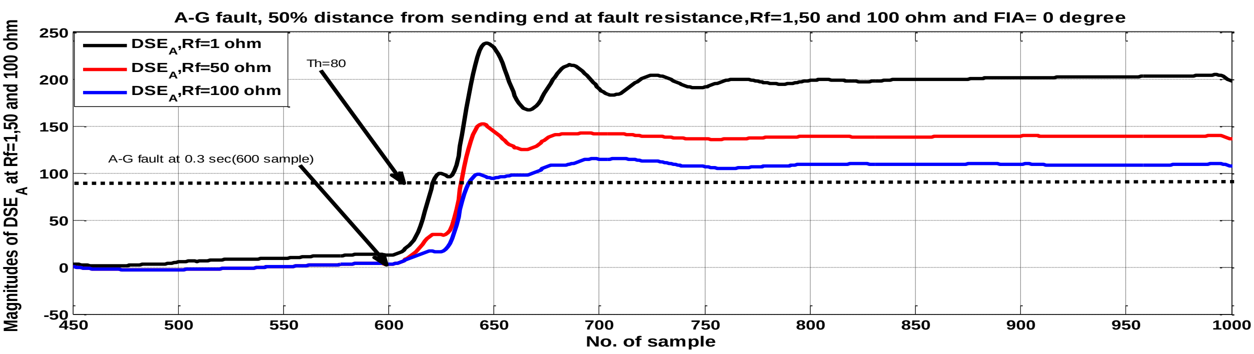

Fig. 5. A-G fault at 0.3 sec from B-S, fault at 100km (50%) distance from bus B-S at different values of Rf=1Ω, 50Ω and 100Ω, FIA=0^0 and wind speed=15m/sec.

Table 2: Energy variation of Current signal at different type of fault, distance of 100 km (50%) from B-S and at a distance of 100 km (50%) from B-4 receiving bus of Rf= 100Ω, FIA=0^0 and wind speed=15m/sec

Fault Type	Current: Threshold setting at SE Th=80			Current: Threshold setting at RE Th= 80			Fault classification
	A	B	C	A	B	C	
ABG	***113.08***	***108.11***	5.24	***94.39***	***79.91***	59.11	AB-phase
BCG	0.26	***103.08***	***112.28***	40.47	***84.70***	***83.94***	BC-phase
CAG	***117.04***	2.52	***114.24***	***83.34***	66.49	***99.36***	CA-phase
ABCG	***106.78***	***105.77***	***106.18***	***118.45***	***116.02***	***117.85***	ABC-phase

5.3 Source Impedance (SI)

To test the effect of SI variation, the number of simulations are carried out like normal source impedance (NSI) and 30%, 50% to 100% increase at Rf=1Ω and FIA=0^0. Fig. 6(a) depicts B phase fault occurs at 25% distance from B-S, the magnitude of $DSE_{,B}$ crosses Th value to detect the fault and it becomes higher as compared to 30% increase of SI.

Similarly, Fig. 6(b) depicts the comparative study of NSI and 30% increase of NSI. In all the figures it is found that, the fault is detected within 40 samples. Table 3 presents the result of energy variation takes place at different type of fault at sending and receiving end substation.

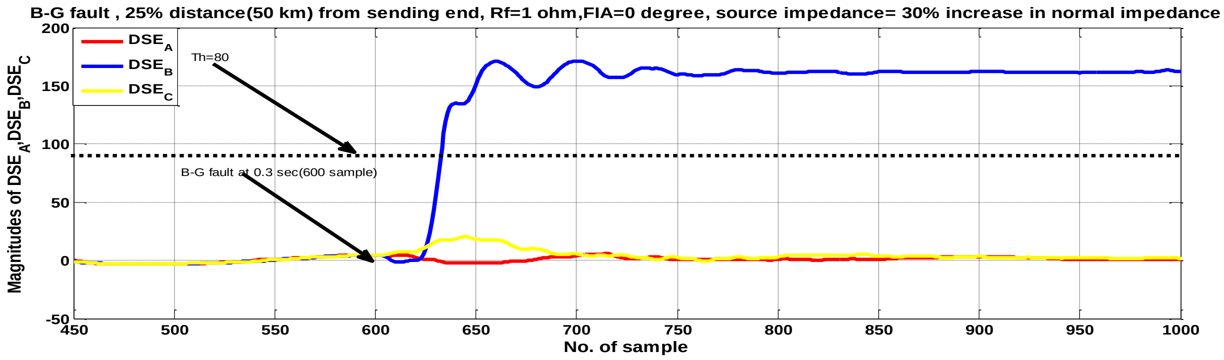

Fig. 6(a). B-G fault, 25% distance(50km) from sending bus(B-S) at 0.3 sec, SI = 30% increase of normal SI, Rf = 1Ω, FIA =0^0 and wind speed=15m/sec

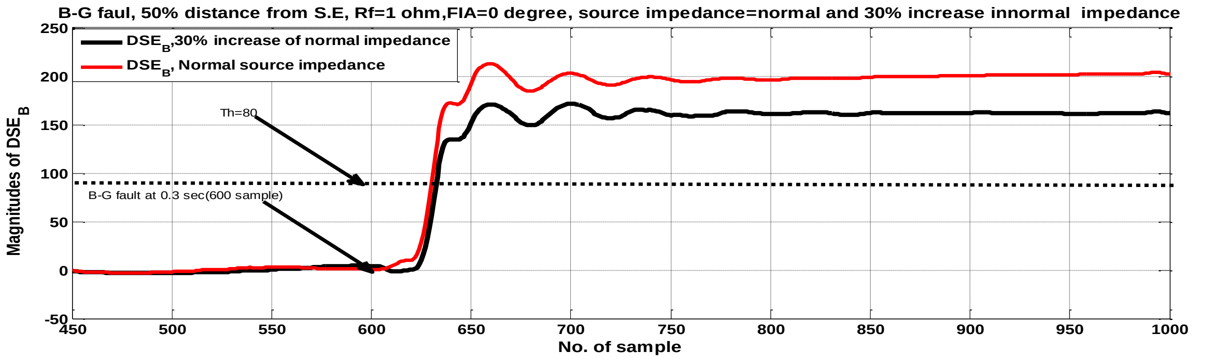

Fig. 6(b). A comparative study of B-G fault at 100km (50%) distance from bus B-S at 0.3 sec, Rf = 1Ω, FIA =0^0, SI=normal SI, 30% increase of SI and wind speed=15m/sec

Table 3: Energy variation of different type of fault, distance of 100 km (50%) from bus (B-S) and bus (B-4) at Rf= 1Ω, FIA=0^0, 30% increase in SI and wind speed=15 m/sec

Type of Fault	Current: Threshold setting at SE Th=80			Current: Threshold setting at RE Th= 80			Fault classification
	A	B	C	A	B	C	
AG	***156.95***	5.43	5.50	***84.14***	62.33	50.45	A-phase
ABG	***183.16***	***189.32***	23.98	***102.43***	***46.01***	128.02	AB-phase
BCG	15.64	***204.90***	***202.83***	87.75	***109.12***	***52.33***	BC-phase
ABCG	***208.04***	***226.31***	***234.23***	***101.28***	***104.44***	***110.58***	ABC-phase

5.4 Fault Inception Angle (FIA)

Fig. 7 depicts the A-phase fault comparison between two different FIA=45^0 and 90^0 at 100km distance from B-S, Rf=1Ω and wind speed=15m/sec. It is observed that both the waveform of FIA=45^0 and FIA=90^0 crosses the Th value and remains within 40 sample to detect the fault. Table 4 presents the different energy content at different values of FIA=45^0 with wind speed=15m/sec.

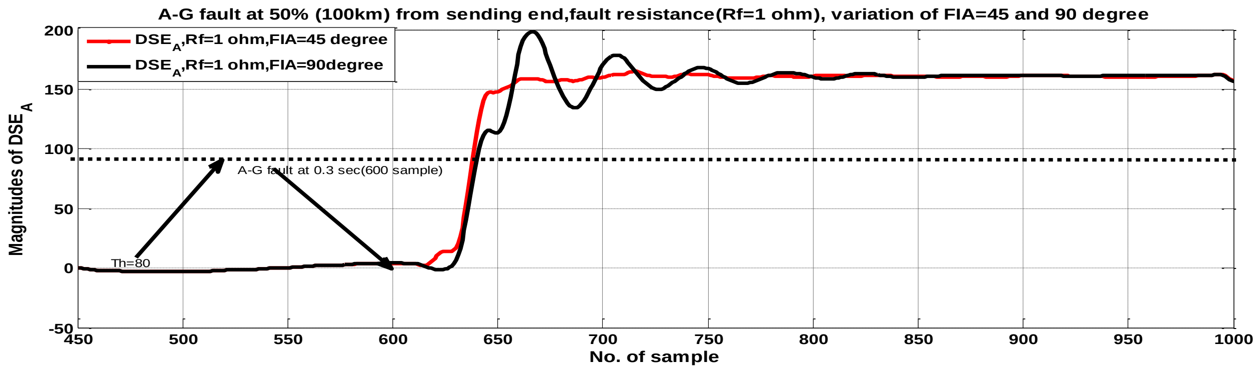

Fig. 7. A-Phase fault, distance 50% from B-S, Rf = 1Ω and FIA =45^0 and 90^0 and wind speed=15m/sec

Table 4: Energy variation of different fault, distance of 100 km (50%) from B-S and distance of 100km from B-4 at Rf= 1Ω and FIA=45^0, wind speed=15m/sec.

Type of Fault	Current: Threshold setting at SE Th= 80			Current: Threshold setting at RE Th=80			Fault classification
	A	B	C	A	B	C	
AG	***161.09***	33.08	71.02	***99.60***	48.86	39.95	A-phase
BCG	73.67	***237.02***	***222.52***	67.25	***108.89***	***56.97***	BC-phase
ABG	***201.78***	***233.35***	88.23	***100.49***	***83.92***	52.31	AB-phase
ABCG	***210.35***	***244.82***	***231.92***	***102.79***	***114.41***	***113.29***	ABC-phase

5.5 Phase Reversal

Fig. 8 depicts AB-G fault occurs at 50% distance (100km) from B-S at Rf =1Ω and FIA=0^0, phase reversal with wind speed=15m/sec. The DSE_A and DSE_B rises towards positive direction and able to detect the fault within 40 samples.

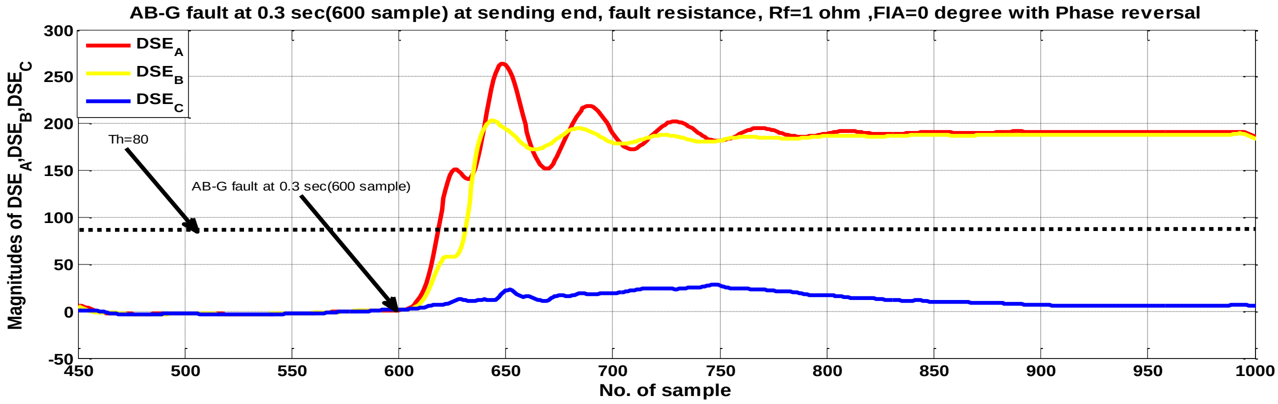

Fig. 8. AB-G fault at 0.3 sec, 50% distance (100km) from B-S at Rf=1Ω and FIA=0^0 with phase reversal, wind speed=15m/sec

5.6 Wind Speed

The differential relay is more accurate to justify the performance of fault detection and classification in case of variation of wind speed. The different wind speed from 5m/sec to 15m/sec are considered for simulation study. Fig. 9(a) depicts the CA-G fault with wind speed=5m/sec. Similarly, Fig. 9(b) depicts the AB-G fault at the distance of 50% (100km) from B-S, at Rf =1Ω, NSI, FIA =0^0 and wind speed=15m/sec.

Table 5 presents the energy variation of different types of fault with phase reversal. In all the above figure it is found that the fault is detected with the variation of wind speed from 5m/sec to 15m/sec and all such faults are detected within 40 samples per cycle to cross the threshold value (Th) which is equivalent to 20msec cyclic period of time.

Table 5: Energy variation of different types of fault at a distance of 100km from B-S and 100km from B-4, Rf= 1Ω and FIA=0^0 with phase reversal and wind speed=15m/sec

Fault Type	Current: Threshold setting at SE Th= 80			Current: Threshold setting at RE Th=80			Fault classification
	A	B	C	A	B	C	
BG	2.17	***158.62***	7.78	7.21	***157.09***	26.98	B-phase
ABG	***191.93***	***179.32***	18.74	***84.62***	***160.38***	37.18	AB-phase
BCG	9.25	***189.86***	***206.13***	65.69	***189.30***	***89.94***	BC-phase
ABCG	***219.40***	***211.22***	***237.26***	***84.83***	***191.91***	***107.77***	ABC-phase

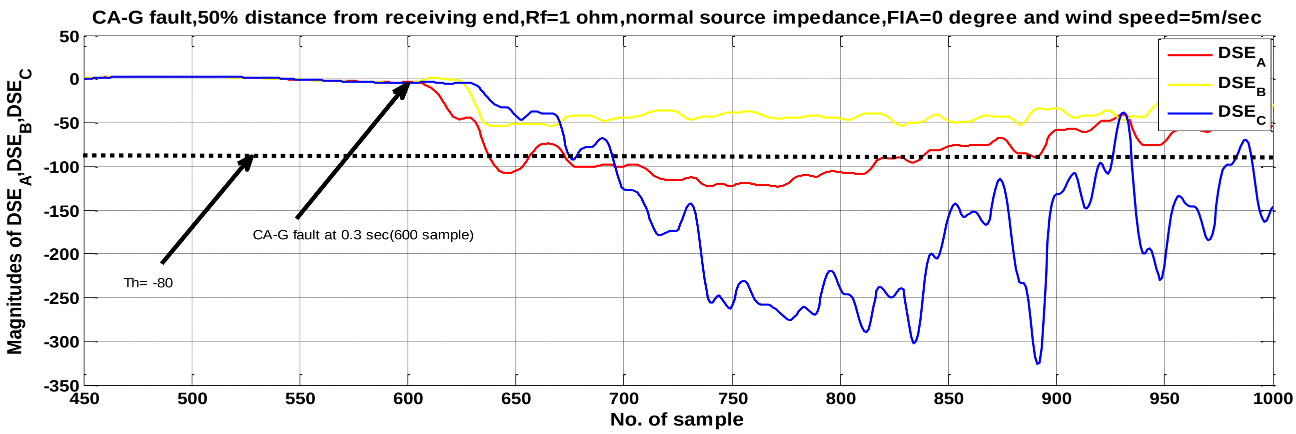

Fig. 9(a). CA-G fault at B-4 at 0.3 sec, distance 50% (100km)from wind farm, Rf = 1Ω normal SI, FIA =0^0 and wind speed=5m/sec

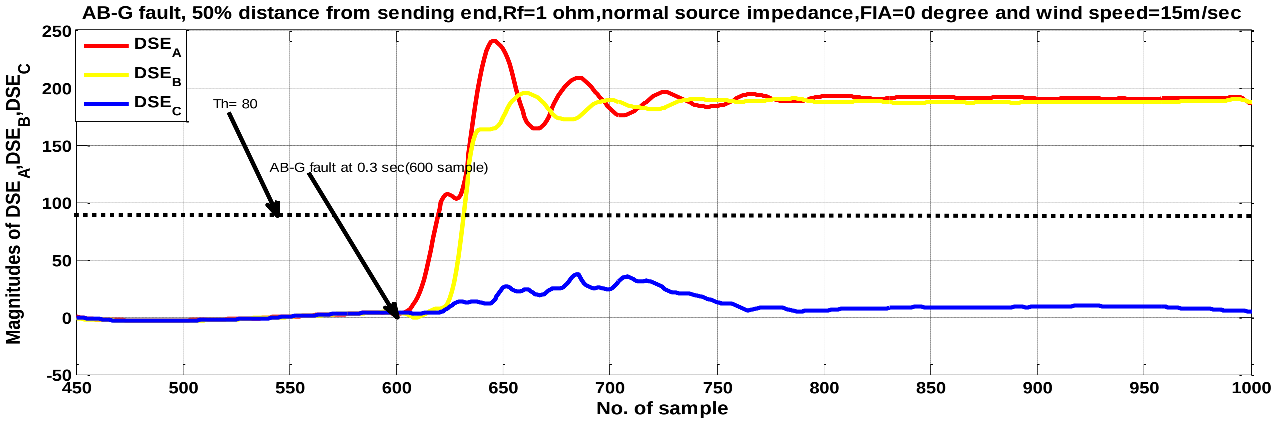

Fig. 9(b). AB-G fault at B-S at 0.3 sec, distance 50% (100km) from bus B-S, Rf = 1Ω normal SI, FIA $=0^0$ and wind speed=15m/sec

5.7 External Fault

In order to verify, the reliability and stability of the scheme, an external fault AB-G has been created between Z_{l3} to Z_{l4} section of the transmission line of Fig. 2(a). Fig. 10 depicts the AB-G fault at an external end at Rf = 1Ω and FIA $=0^0$. It is observed that the DSE of A and B phase are within the threshold limit and does not cross the Th value (+80 and -80) at any point of time. Hence, the relaying scheme is more accurate and highly efficient for analysis of an external fault

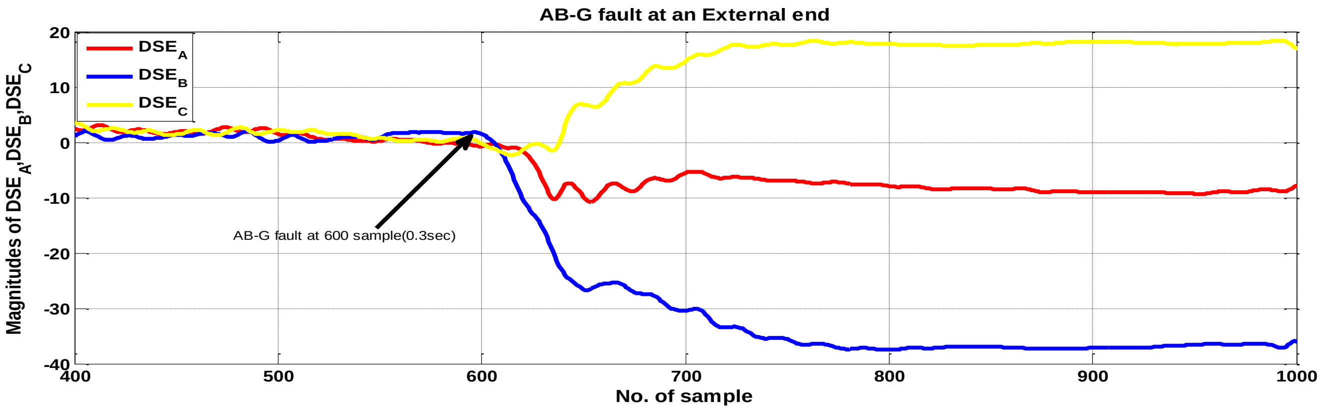

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Fig. 10. AB-G fault at 0.3 sec at an external end at Rf= 1Ω and FIA$=0^0$, wind speed=15m/sec

6. Conclusion

The differential relaying scheme based STATCOM integrated wind fed transmission line is proposed. The fault detection and classification using DWT of different types of fault including wind speed is discussed. The line parameters such as fault resistance, source impedance, fault inception angle, power reversal and wind speed variation are considered as parameter variation of the line. In all the above figure and table mentioned above it is observed that the fault is detected and classified in an accurate manner. The total protection of transmission line including internal and external fault is simulated to justify the performance of the system. The advantages of this scheme is highly effective, simple approach and requires less processing time to detect and classify the fault. From all the figure it is also found that the fault detection time remains within a cycle (20msec) period of time as all the shunt faults are detected within 40 samples per cycle which is equal to 20msec in a cyclic time period.

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