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A Fault Detection and Classification Method for SC Transmission Line Using Phasor Measurement Unit Concept

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***Abstract*: In this paper, fault detection and classification for Series Compensated Line (SCL) using phasor measurement unit is presented. The algorithm presented in this paper uses the PMU synchronized measurements and not depends on the data to be provided by the electricity utility. The compensated line parameters and Thevenin's equivalent (TE) of the system at SCL terminals are calculated online, using three independent sets of pre-fault phasor measurements. The accuracy of fault location is performed with respect to fault location/position, types of fault, fault angle. The accuracy of the algorithm is simulated in MATLAB for 9-bus transmission system.**

***Keywords*: Phasor measurement unit (PMUs), series compensated lines, Fault location, Thevenin's equivalent.**

I. INTRODUCTION

The development of series compensation in power systems increases the transfer capacity, system stability, such that it can minimizes the amount of transmission lines for certain power transfer capability. Transmission lines are an important component of the power system and its protection is important to minimize the damages to the equipment due to short circuits. Protection of the power system relates to detection of fault means quick isolation of faulty line from the system, classification of faults relates to identifying the types of faults and finally fault location leads to quick repair and restoration of faulty lines in the system to improve the reliability and availability of power inorder to reduces the customers complaints.

Fault location on SCLs is considered as important factor for the manufacturer, operators and maintenance engineers because these are dispersed over a hundreds of kilometres and major connections between the supply and load centers. Especially Series compensated lines are considered as difficult for fault location because series capacitors on these lines are equipped with a Metal-Oxide Varistors for overvoltage protection. Phasor measurement units are used in the field of fault location, and PMU based fault location algorithm in [1] can be applied to any series FACTS compensated line as they independent from the series device model.

This paper presents a accuracy of fault location algorithm for series compensated line using synchronized phasor measurement unit, such that it does not need the data from the utility. The algorithms proposed in [2,3] are not sensitive to fault resistance and inception angle and it does not need the knowledge of equivalent system impendence such that they depends on the SC line parameters provided by the utility. This is the main advantage of the proposed algorithm over methods presented in [2,3]. The proposed algorithm requires three independent sets of pre-fault voltage and current phasor measurements at both ends of SCL. These parameters are used for the calculation of the respective Thevenins equivalents(TEs) and these parameters are also used to calculate the SCL parameters. The remaining concepts of this paper includes the concept of phasor measurement unit, online calculation of TEs using PMU, online measurements of SCL parameters, accutate fault location algorithm, simulation results followed by the conclusion.

II. INTRODUCTION TO PHASOR MEASUREMENT UNITS (PMUS)

Phasors are usually considered as a common tool of AC circuit analysis, representing the steady state waveforms of fundamental frequency component. Even though when a power system is not in steady state, phasors are useful in describing the behaviour of power system. Fig.1 shows the steady state waveform of nominal power frequency signal. By observing the waveform at the instant of time t=0, the steady state waveform may be represented by a complex number with a magnitude equal to the rms value and phase angle equal to angle a.

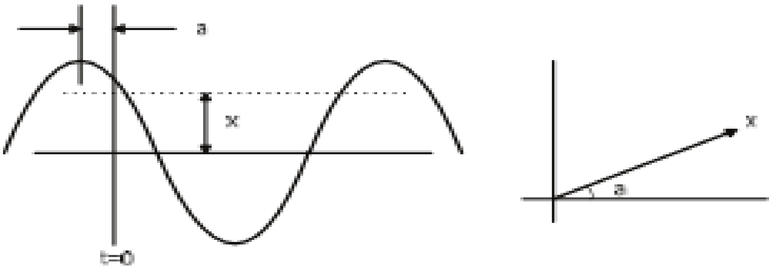


Fig.1 Phasor representation of sinusoidal waveform

In digital measuring system, samples of waveform for one nominal period are collected starting at t=0, then the fundamental frequency component of Discert Fourier Transform (DFT) is calculatedby using

$$X(t)=\frac{Xm}{\sqrt{2}}Xe^{j\emptyset}=\frac{Xm}{\sqrt{2}}(\cos\emptyset+j\sin\emptyset) \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where N is the total number of samples in one period, X is the phasor, and x_k is the samples of waveform. After obtaining the three phases of the phasors (Xa,Xb,Xc) a positive, negative and zero sequence phasors are obtained using the equation 3, When several voltages and currents in a power systems are measured and are converted to phasors If they are at a common reference point, it is easy to achieve in substation, where the sampling clock pulses can be placed to all the measuring systems. In order to measure common reference phasors, the task of synchronizing the sampling clock is not a trivial one. By using the Global Positioning System(GPS) satellite transmission, with the an error less than 1micro second.

$$\begin{vmatrix} X1 \\ X2 \\ X0 \end{vmatrix} = \frac{1}{3}\begin{bmatrix} 1 & e^{j2\pi/3} & e^{j4\pi/3} \\ 1 & e^{j4\pi/3} & e^{j2\pi/3} \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} Xa \\ Xb \\ Xc \end{bmatrix} \quad \ldots\ldots\ldots\ldots.(2)$$

III. ONLINE THEVENIN'S EQUIVALENT CALCULATION USING PMU MEASUREMENTS

The importance of accurate fault location algorithm for series compensated line is concerned with online calculation of systems TEs at the terminals of the line. This is possible by PMUs as voltage and its angle , and current and its angle are provided at high rates of measurements per cycle. Three consecutive sets of voltage and current measurements are used to determine the TE at the two compensated line terminals as shown in Fig.2 and Fig.3.

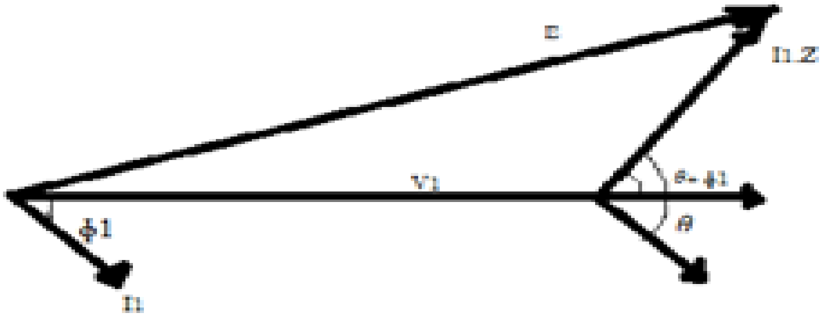


Fig 2: Phasor measurement for the 1st measurement

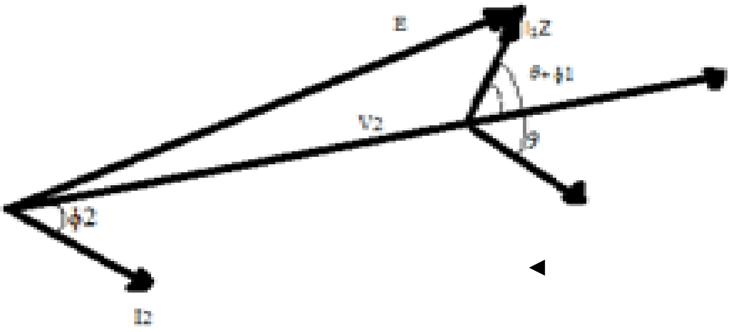


Fig.3 : Phasor measurement for 2nd measurement

From fig.2 and fig.3 we get

$$(r+\frac{P1-P2}{I1^2-I2^2})^2+\left(x-\frac{Q1-Q2}{I1^2-I2^2}\right){}^\wedge 2=\frac{V2^2-V1^2}{I1^2-I2^2}$$

$$+(\frac{P1-P2}{I1^2-I2^2}){}^\wedge 2+(\frac{Q1-Q2}{I1^2-I2^2}){}^\wedge 2 \quad \text{............(3)}$$

Where r and x are the resistance and reactance of the Thevenins impedence represented by Zth. P and Q are the real and reactive powers. From the equation 3, two measurements are obtained, and the third measurement is required which can be used with either of the measurements to produce one more circle, then by applying selection criteria [4] to determine the Z_{th}. The local V and I measurements at that node is given by equation 4 as,

$$V=E_{th}+Z_{th}.I \qquad \text{....................(4)}$$

IV. ONLINE MEASUREMENT OF SERIES COMPENSATED LINE PARAMETERS USING PMU

One more important factor of this algorithm is the online measurements of SCL parameters like series resistance and reactance, shunt admittance. Let us consider one line diagram of a series compensated line in fig.4. In most of the time Series compensated line is considered as a long line, therefore it isreprsented using distributed parameter model. The device (SC) is located at location R and it is a capacitor bank or Thyristor controlled power flow controller.

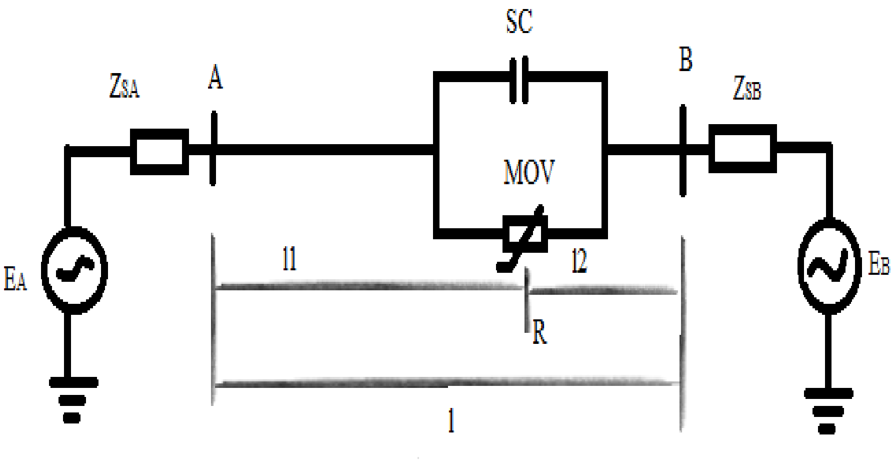


Fig.4: One line diagram of SCL

The following notations are used in the fig:

E_A, Z_{SA} : Thevenins equivalents of the system at terminal A E_B, Z_{SB} : Thevenins equivalents of the system at terminal B l_1, l2, l : Length of segment AR, length of segment BR, and total line length.

V. PROPOSED ALGORITHM

Any abnormal flow of current in power system components is called as a fault in the system. A fault is of a random nature and therefore considering the fault at both the ends of the SC unit shown in fig 5.

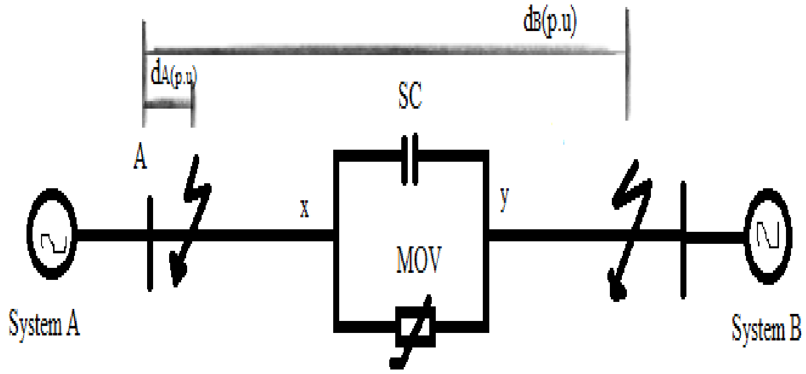


Fig 5: Faults on Series compensated line

The distance dA, dB in p.u can be obtained by eq.5 and eq.6 as:

$$dA=dFA.\left(\frac{l1}{l}\right) \qquad ....(5)$$

$$dB=\left(\frac{l1}{l}\right)+(1-dFB)\left(\frac{l2}{l}\right) \qquad ....(6)$$

The flow chart of Accurate fault location algorithm is shown in fig.6

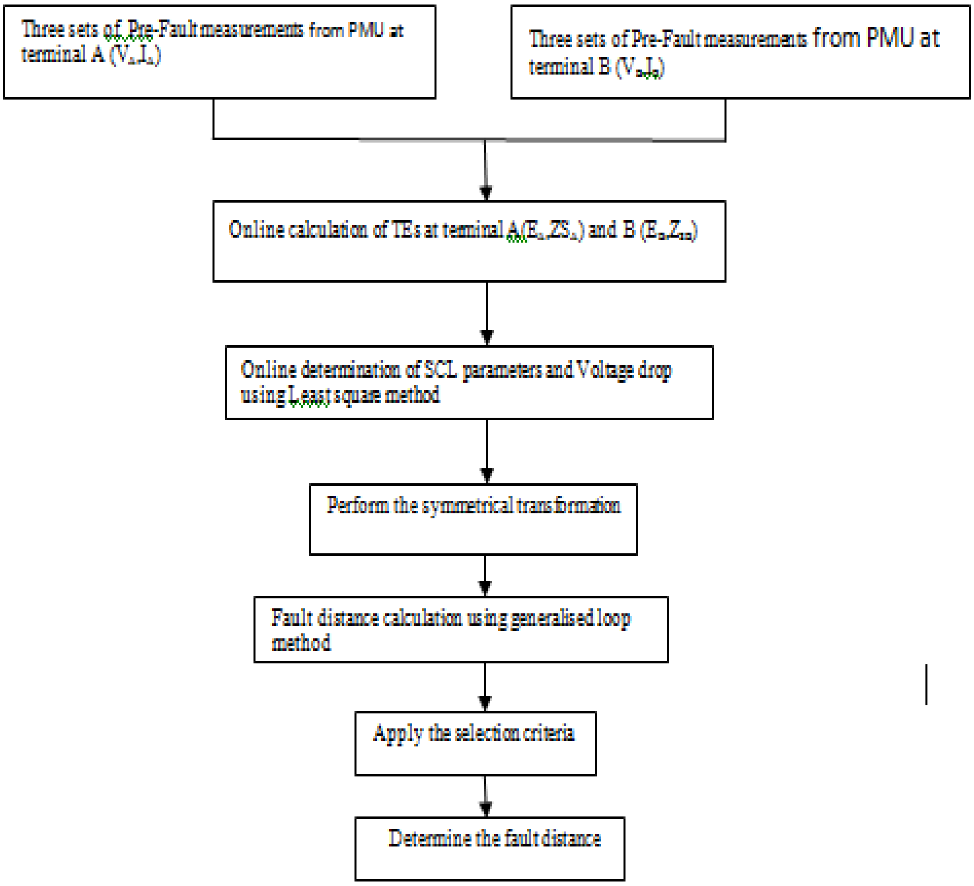


Fig.6 : Flow chart of accurate fault location algorithm

VI. SIMULATION RESULTS

The single line diagram for 9 bus transmission line, is considered for the analysis of fault location accuracy for series compensated line in MATLAB.

The line is compensated at 50% degree of compensation. The three-phase voltage and current signals are sampled at a frequency of 50Hz, by using the equation 2, obtain the voltage and current phasors. In this, the percentage error(eq.7) is used to measure the accuracy of the fault location algorithm and is obtained as

$$\%\ \text{Error} = \left[\frac{Actual\ fault\ location - Estimated\ fault\ location}{Total\ line\ length}\right] \times 100 \qquad \ldots\ldots\ldots..(7)$$

A. Influence of fault type and fault location :

In order to test the accuracy of the algorithm, different type of faults with different fault location is considered for the simulation and the results are tabulated in Table I –III. These results are shown in fig 7-8, it is observed that the proposed algorithm is very accurate irrespective of fault type and its location.

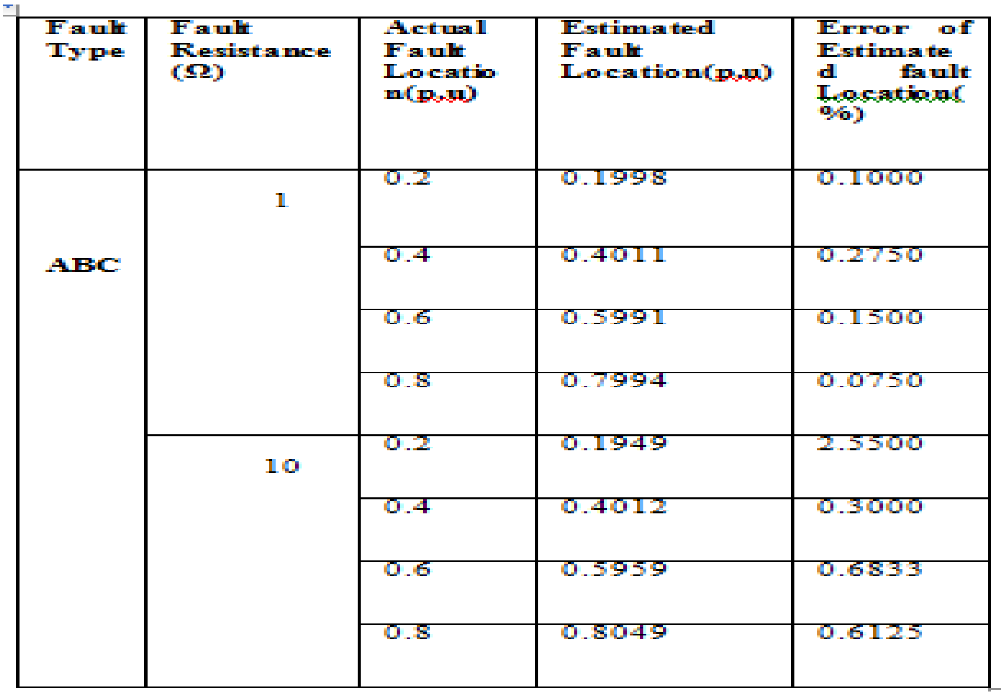
Table I: Fault location estimation for LG fault

Fault Type	Fault Resistance(Ω)	Actual Fault Location(p.u)	Estimated Fault Location(p.u)	Error of Estimated fault Location(%)
AG	10	0.2	0.1994	0.3000
		0.4	0.3992	0.2000
		0.6	0.6027	0.4500
		0.8	0.7999	0.0125
	100	0.2	0.1991	0.4500
		0.4	0.3999	0.02500
		0.6	0.6093	1.5500
		0.8	0.7954	0.5750
BG	10	0.2	0.2021	1.0500
		0.4	0.4081	2.0250
		0.6	0.5950	0.8333
		0.8	0.7956	0.5500
	100	0.2	0.2019	0.9500
		0.4	0.3998	0.0500
		0.6	0.5986	0.2333
		0.8	0.7945	0.6875
CG	10	0.2	0.2075	3.7500
		0.4	0.3956	1.1000
		0.6	0.5912	1.4667
		0.8	0.8013	0.1625
	100	0.2	0.1981	0.9500
		0.4	0.3998	0.0500
		0.6	0.6012	0.2000
		0.8	0.8016	0.2000

Table II: Fault location estimation for LLG fault

Fault Type	Fault Resistance(Ω)	Actual Fault Location(p.u)	Estimated Fault Location(p.u)	Error of Estimated fault Location(%)
ABG	5	0.2	0.2016	0.8000
		0.4	0.4057	1.4250
		0.6	0.5907	1.5500
		0.8	0.7989	0.13750
	50	0.2	0.2016	0.8000
		0.4	0.4056	1.4000
		0.6	0.5909	1.5833
		0.8	0.7981	0.2375
BCG	5	0.2	0.2038	**1.9000**
		0.4	0.4062	**1.5500**
		0.6	0.5955	**0.7500**
		0.8	0.7966	**0.4250**
	50	0.2	0.2038	**1.900**
		0.4	0.4062	**1.5500**
		0.6	0.5953	**0.7833**
		0.8	0.7964	**0.4500**
CAG	5	0.2	0.2001	0.0500
		0.4	0.4046	1.1500
		0.6	0.6011	0.1833
		0.8	0.7981	0.2375
	50	0.2	0.2002	0.1000
		0.4	0.4045	1.1250
		0.6	0.6018	0.3000
		0.8	0.7991	0.1225

Table III: Fault location estimation for Three phase fault



Fault Type	Fault Resistance (Ω)	Actual Fault Location(p.u)	Estimated Fault Location(p.u)	Error of Estimated fault Location(%)
ABC	1	0.2	0.1998	0.1000
		0.4	0.4011	0.2750
		0.6	0.5991	0.1500
		0.8	0.7994	0.0750
	10	0.2	0.1949	2.5500
		0.4	0.4012	0.3000
		0.6	0.5959	0.6833
		0.8	0.8049	0.6125

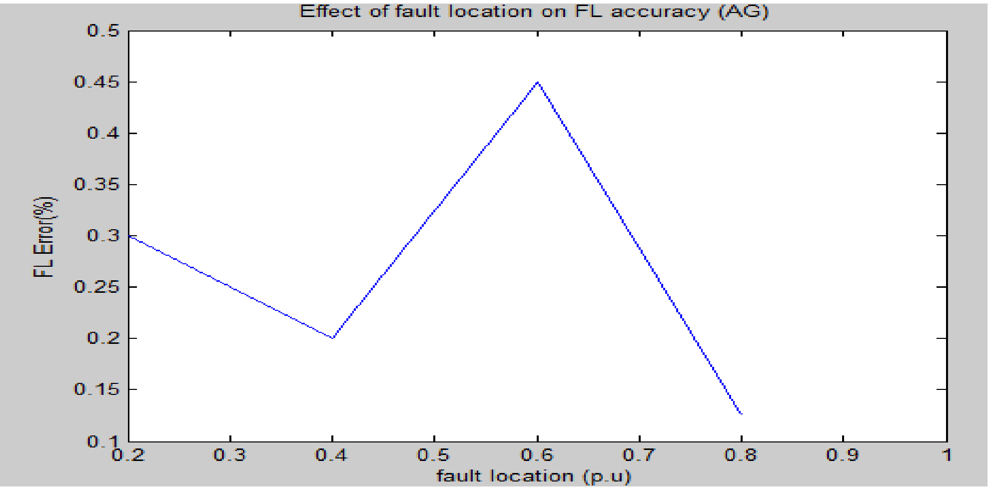


Fig 7: Effect of fault location on FL accuracy (AG)

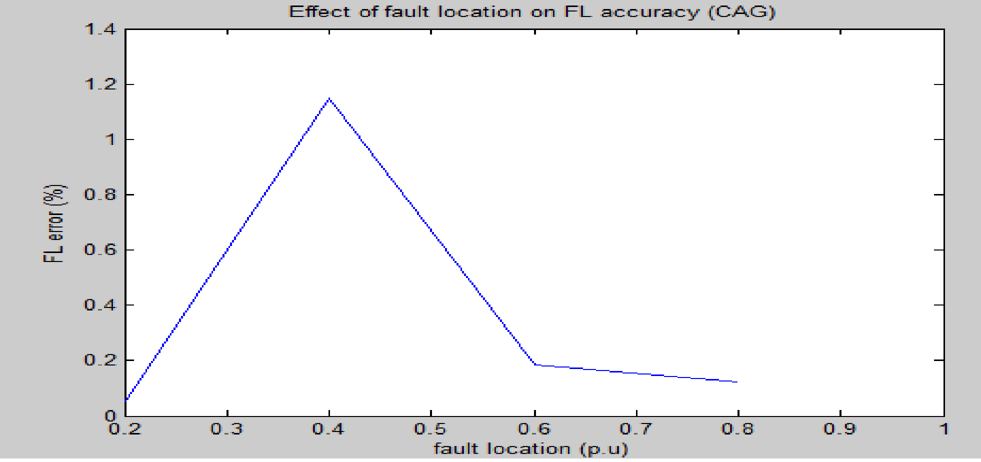


Fig 8: Effect of fault location on FL accuracy (CAG)

B. Effect of Fault Inception angle on the algorithms accuracy:

The algorithm accuracy for AG,,ABG,BC faults by the effect of the variation of the fault inception angle are shown in table IV ,by assuming that fault occur at a distance of 0.6 per unit from one terminal(a).

Table IV: Effect of Fault Inception angle on the algorithms accuracy

Fault Inception Angle(°)	Fault Type					
	AG		BC		ABG	
	Estimated FL(p.u)	Error of EFL(%)	Estimated FL(p.u)	Error of EFL(%)	Estimated FL(p.u)	Error of EFL(%)
0	0.5924	1.2667	0.5949	0.8500	0.5906	1.5667
30	0.5931	1.1500	0.5951	0.8167	0.5912	1.4667
45	**0.5935**	**1.0833**	**0.5951**	**0.8167**	**0.5914**	**1.4333**
60	**0.5935**	**1.0833**	**0.5951**	**0.8167**	**0.5914**	**1.4333**
90	0.5924	1.2667	0.5941	0.9833	0.5908	1.5333
120	0.5913	1.4500	0.5905	1.5833	0.5912	1.4667
135	**0.5911**	**1.4833**	**0.5901**	**1.6500**	**0.5913**	**1.4500**
150	**0.5911**	**1.4833**	**0.5901**	**1.6500**	**0.5911**	**1.4833**

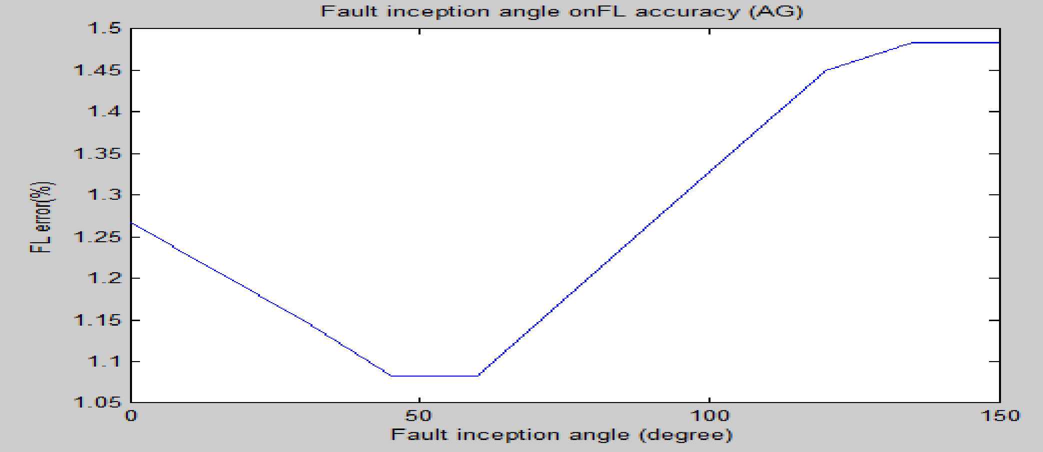


Fig 9: Effect of fault inception angle on FL accuracy (AG)

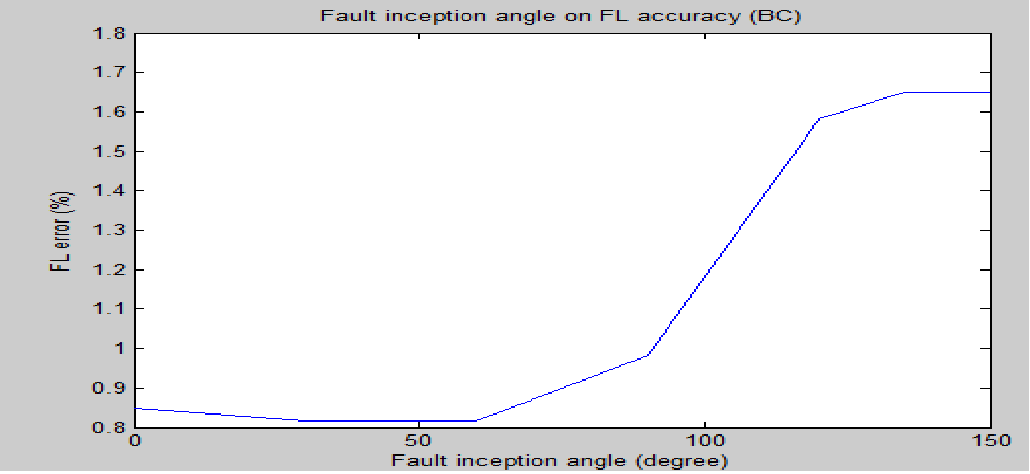


Fig 10: Effect of fault inception angle on FL accuracy (BC)

Fig.9 and fig.10, shows the effect of fault inception angle on the algorithms accuracy.

VII. CONCLUSION

This paper presents fault detection and classification for Series Compensated Line (SCL) using phasor measurement unit. The algorithm uses the positive sequence voltage and current angle measurements at each line end. The partial adaptive algorithms are not sensitive to fault resistance and inception angle and it does not need the knowledge of equivalent system impendence such that they depend on the line parameters provided by the utility. But the proposed algorithm does not need the data provided by the utility. Algorithms is tested in MATLAB and the results shows that the algorithms accuracy is independent of fault location , fault type , fault resistance and fault inception angle.

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