AN ACCURATE FAULT LOCATION ALGORITHM IN DISTANCE PROTECTION FOR THYRISTOR CONTROL SERIES COMPENSATED TRANSMISSION LINE

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Abstract: In this paper, an accurate fault location algorithm for series compensated power transmission lines is presented. A distributed time domain model is used for modeling of the transmission lines. The algorithm makes use of two subroutines for estimation of the fault distance-one for faults behind the series capacitors and another one for faults in front of the series capacitors. Then a special procedure to select the correct solution is utilized. Samples of voltages and currents at both ends of the line are taken synchronously and used to calculate the location of the fault. Simulation of MHO relay has been implemented in MATLAB environment for LG and LLLG fault at different locations and impedance observed with and without series compensations has completed and analyzed with different fault. MATLAB program for distance algorithm is implemented for simulation system has completed and algorithm is attached in report. Malfunction of relay in distance algorithm for series compensated transmission line has been minimized up to 0.2% error. Results are verified at different fault at different distance, different firing angle and results are as per desired values.

Keywords— Mho Relay, Fault Identification, Distance Relay, Matlab

I. INTRODUCTION

A power system is a complex network consists of generators, transformers, transmission and distribution lines and their protection system [1-3]. Different types of problem such as short circuit, noise effect and others are occurring in power system networks and due to this short circuit heavy current flow through the equipment working in the system causing damage of equipments [4-5]. Most of the equipments are very expensive in power system, so the whole power system can be considered as a very large capital investment. In power system terminology short circuits are commonly known as 'Fault'. To protect those equipments from such problems we need some protective arrangements. These arrangements consist of protective relays and circuit breakers. If a fault occurs in the system, automatic protective device is required to isolate the faulty section and keep the healthy section in operation. Relays are the protective devices are used in the power system protection. In the faulty condition relay operate and send the trip wave to breaker. In electrical fault condition the disturbance occurs in generated power and required power or may not full fill. So, to maintain the power system balance and reduce the damaged due to the faults we need to find the fault, isolate the faulty part is required. Maintaining continue electric power supply to customers is a main work for the power generation stations. In the power system, protective relays are responsible for discriminating between normal and fault conditions. The relays should detect the faults in 20 to 40 milliseconds.

Measurement of distance from the current and voltage waveform during the fault condition may have some errors and it is affect the stability of the relays. We must have to be careful when consideration of the output requirement of the current and voltage transformer. Cascade operation of the protective devices can raise the disturbance in the electricity supply system.

Protective relays act as the brain of any protective system that help to sense the problems in power system network and provide a command to the circuit breaker weather to trip or not. In this way the work of relay is to detect and locate a fault and provide a trip signal to the circuit breaker. Distance protection provides an excellent way of obtaining discrimination, selectivity, and speed of operation by allowing trip operation up to a certain range of distance. For protection of transmission line the distance type relay is used and this protection is managed in overlapping area. There is whole area is covered by the distance protection. A relay decides which zone contains the faults from the comparison of voltage and current signals. So, a distance measured from the relay location to the fault location. The main objective of this work is to analyze line-to-ground and line-to-line fault detection, impedance calculation and protection in different zone considering wide variations in system and fault parameters. Finally, feasibility of the proposed scheme has been tested using MATLAB/SIMULINK software.

II. RESEARCH METHODOLOGY

PSCAD also called a power system computer aided design program is a time based Simulink software or past working analysis of electronic system. PSCAD is a set of programs, which provide a graphical interface to the electromagnetic transients program. Also known as EMTDC. In 1976 the analysis of DC electromagnetic transient (EMTDC) were evolve and also rapidly developed with capability as well as possibility. To set up the whole simulation software there are some library in power system models already given in this. So this library gives a proper and rapid solution in the provided time for calculate and making program of power system and the network. In this Simulink model the more intelligent methods used for customize the quality of the supply for improve accuracy and efficiency and manual analysis takes time and its required special kind of knowledge.

Fast Fourier Transform

Due to the presence of harmonics resultant voltage and current graph in simulation are fluctuated, when error happened in power system. The current as well as voltage must consider at fundamental frequency to compute the apparent impedance. To overcome the harmonics from the resultant signal of current and voltage there are different types of phasor algorithms are evolve and stable the quality of power. FFT is used to remove DC component and harmonics and estimate the complex phasor element at fundamental frequency. As consider function of time, the FFT block in PSCAD is used to measure the fundamental component like magnitude and phase of the given input signal. Before the signal send to harmonic constituents block the signals are sampled. This given unit is developed with the aliasing type filter. These types of filters are used to reduce the extra noise and harmonics. Some information contain in the sinusoidal steady state component with 50Hz frequency by using impedance measurement in distance protection. Therefore, filtering is necessary to maintain part of the stable condition and to remove other items.

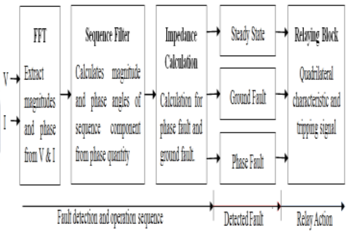


Figure-1: Block diagram distance relay model

Calculation of impedance

The two bus system like bus A and bus B in one line graph with part of network was showed below. Error with the resistance Rf happened with X% at the point F of line from A bus.

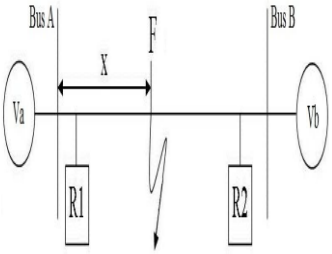


Fig.2- Test System Model

Fault like phase to ground (line A to earth), connected relay find the impedance of transmission given below equation till the point X. (Fault resistance = 0)

$$X * Z1 = \frac{Var}{IAR + Ko * IOR}$$

In equation, Var and IAR are equal to voltage and current respectively. It is measured at the point of relay.

I_{OR} = current of zero sequence

K_0 given in equation,

$K_0 = \frac{Z0-Z1}{Z1}$

Z0 and Z1 is the sequence component.

With the consideration of RF, the measure value of impedance written in equation,

$Zr = x*Z1+\frac{If}{Ir}$ Rf

For AB fault assumption,

$x*Z1 = \frac{VAR-VBR}{IAR-IBR} = \frac{VABR}{IABR}$

For SLG fault:-

Va = Va1+Va2+Va0

= IA1*Z1+IA2*Z2+IA0*Z0

= IA1*Z1+IA2*Z1+IA0*Z1-IA0*Z1+IA0*Z0

= Ia*Z_1+Ia0*(Z0-Z_1)

Than the relay seen the impedance is given

Zseen= Va/Ia= Va / Ia+k*Ia0

Where Z1, Z2, Z0 are sequence impedances Z1=Z2 for transmission lines and k=(Z0-Z1)/Z1.

For LL fault:-

Va1-Va2=(Ia1-Ia2)*Z1

Zseen= (Va1-Va2)/ (Ia1-Ia2).

Mho Relay Algorithm

Every protective area is set to cover the appropriate length of the power network. The standard selections of location in the network protection cover 80 to 90% of the line area 1. 12 - 150% in area 2 and 200-250% in third area. The performance time associated with every location is different form first area, the transfer applies there. Still, allocation 2 is delayed to allow area 1 transfer to run first. Area 3 delays time for allows the appropriate relays closer for the fault to work first otherwise occurs at the Zone-1, Zone-2. Time setting is processed to the individual zone to allow the relay closest to the fault operates first and other is use to backup. If the nearest relay is not working properly than connected relay locate at the back up terminal. This relay saw the error in the area after the fault will still disconnected the failed component. And somehow the zone-2 relays is not work than the located relay aside from the fault line will work in zone 3.

III. TCSC OPERATION

Thyristor controlled series capacitor is an important member of FACTS family. It is also called advanced series compensation (ASC) with thyristor controlled impedance. It has high potential in application because it may improve power system, including power flow control, power swing damping, transient stability enhancing and SSR mitigation.

BASIC CONCEPTS:

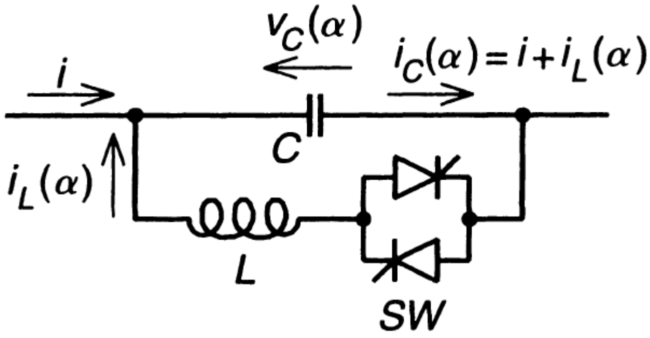


Fig-3 Basic module of TCSC

TCSC consist of series compensating capacitor shunted by Thyristor- Controlled Reactor (TCR). However, a practical TCSC module also includes protective equipment normally installed with series capacitors as shown below.

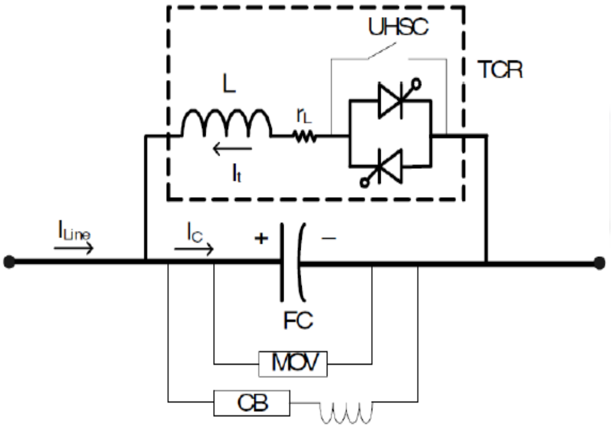


Fig-4 Practical module of TCSC

A metal-oxide varistor (MOV), essentially a nonlinear resistor, is connected across the series capacitor to prevent the occurrence of high-capacitor over-voltages. Not only does the MOV limit the voltage across the capacitor, but it allows the capacitor to remain in circuit even during fault conditions and helps improve the transient stability. Also installed across the capacitor is a circuit breaker, CB, for controlling its insertion in the line. In addition, the CB bypasses the capacitor if severe fault or equipment-malfunction events occur. If the TCSC valves are required to operate in the fully "on" mode for prolonged durations, the conduction losses are minimized by installing an ultra–high-speed contact (UHSC) across the valve. This metallic contact offers a virtually lossless feature similar to that of circuit breakers and is capable of handling many switching operations. The metallic contact is closed shortly after the thyristor valve is turned on, and it is opened shortly before the valve is turned off. In a practical TCSC implementation, several such basic compensators may be connected in series to obtain the desired voltage rating and operating characteristics.

DIFFERENT OPERATING MODES OF TCSC:

There are four modes of operation of TCSC as follows:

BLOCKING MODE:

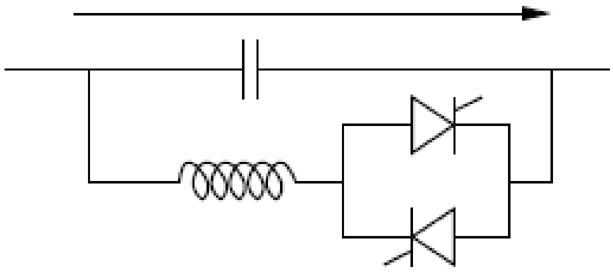


Figure-5 Thyristor Blocking mode

In this mode, also known as the waiting mode, the firing pulses to the thyristor valves are blocked. If the thyristors are conducting and a blocking command is given, the thyristors turn off as soon as the current through them reaches a zero crossing. The TCSC module is thus reduced to a fixed-series capacitor, and the net TCSC reactance is capacitive. In this mode, the dc-offset voltages of the capacitors are monitored and quickly discharged using a dc-offset control without causing any harm to the transmission-system transformers.

BYPASS MODE:

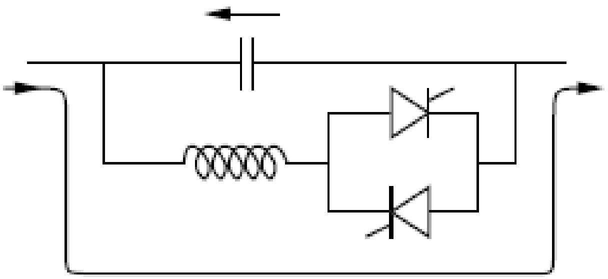


Figure-6 Thyristor bypass mode

In this bypassed mode, the thyristors are made to fully conduct with a conduction angle of 180°. Gate pulses are applied as soon as the voltage across the thyristors reaches zero and becomes positive, resulting in a continuous sinusoidal of flow current through the thyristor valves. The TCSC module behaves like a parallel capacitor–inductor combination. In this mode, the resulting voltage in the steady state across the TCSC is inductive and the valve current is somewhat bigger than the line current due to the current generation in the capacitor bank. For practical TCSCs with X_L/X_C ratio between 0.1 to 0.3 ranges, the capacitor voltage at a given line current is much lower in bypass than in blocking mode. Therefore, the bypass mode is utilized as a means to reduce the capacitor stress during faults.

CAPACITIVE VERNIER MODE:

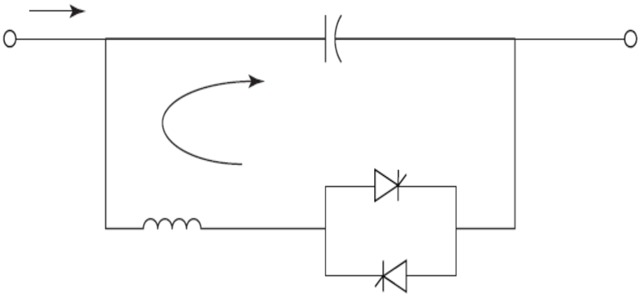


Figure-7 Capacitive Vernier mode

In capacitive Vernier mode a trigger pulse is supplied to the thyristor having forward voltage just before the capacitor voltage crosses the zero line, so a capacitor discharge current pulse will circulate through the parallel inductive branch. Th discharge current pulse adds to the line current through the capacitor and causes a capacitor voltage that adds to the voltage caused by the line current. The capacitor peak voltage thus will be increased in proportion to the charge that passes through the thyristor branch. The fundamental voltage also increases almost proportionally to the charge. From the system point of view, this mode inserts capacitors to the line up to nearly three times the fixed capacitor. This is the normal operating mode of TCSC.

INDUCTIVE VERNIER MODE:

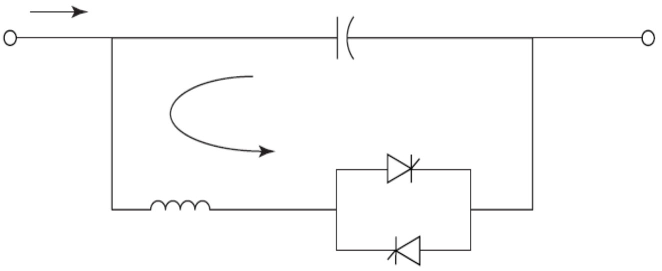


Figure-8 Inductive Vernier Mode

In inductive Vernier mode the circulating current in the TCSC thyristor branch is bigger than the line current. In this mode, large thyristor currents result and further the capacitor voltage waveform is very much distorted from its sinusoidal shape. The peak voltage appears close to the turn on. The poor waveform and the high valve stress make the inductive boost mode less attractive for steady state operation.

IMPACT OF TCR ON TCSC:

It is possible to continuously control current flowing through the reactor from maximum to zero by firing angle of thyristor. By use of formula $I_{L1} = V\,B_{TCR}$; $B_L = 1/(\omega L)$ and from Eq (1) it is possible to calculate inductive susceptance of TCR (while considering fundamental component of current) as a function of firing angle α as follows:

$$B_{TCR}(\alpha) = \frac{1}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right) = B_L\left(\frac{\pi - 2\alpha - \sin 2}{\pi}\right.$$

Inductive susceptance of TCR, $B_{TCR}(\alpha)$ is changed by firing angle α in the same manner as the magnitude of fundamental component of current $I_{L1}(\alpha)$, it means that it is possible to control it by in from maximum value ($\alpha=0$, $B_{TCR}=B_L$) upto zero ($\alpha=\pi/2$, $B_{TCR}=0$),

From eq (2) for inductive reactance of TCR we get

$$X_{TCR}(\alpha) = \frac{1}{B_{TCR}(\alpha)} = X_L\left(\frac{\pi}{\pi - 2\alpha - \sin 2\alpha}\right) \qquad X_L(=\omega L) \le X_{TCR}(\alpha) \le \infty$$

Thus, the steady-state impedance of the TCSC is that of a parallel LC circuit, consisting of a fixed capacitive impedance, X_C, and a variable inductive impedance, $X_L(\alpha)$, that is,

$$X_{TCSC}(\alpha) = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C} \qquad \text{where } X_L \le X_L(\alpha) \le \infty$$

$X_L = \omega L$ and α is the delay angle measured from the crest of the capacitor voltage or equivalent zero crossing of the line current. As the impedance of the controlled reactor, $X_L(\alpha)$, is varied from its maximum (infinity) toward its minimum (ωL), the TCSC increases its minimum capacitive impedance, $X_{TCSC}.\min = X_C = 1/\omega C$, (and thereby the degree of series capacitive compensation) until parallel resonance at $X_C = X_L(\alpha)$ is established and $X_{TCSC}.\max$ theoretically becomes infinite. Decreasing $X_L(\alpha)$ further, the impedance of the TCSC, $X_{TCSC}(\alpha)$ becomes inductive, reaching its minimum value of $X_L X_C/(X_L - X_C)$ at $\alpha = 0$, where the capacitor is in effect bypassed by the TCR. Therefore, with the usual TCSC arrangement in which the impedance of the TCR reactor, X_L, is smaller than that of the capacitor, X_C, the TCSC has two operating ranges around its internal circuit resonance:

- $\alpha_{Clim} < \alpha < \pi/2$ range, where $X_{TCSC}(\alpha)$ is capacitive,
- $0 < \alpha < \alpha_{Lmax}$ range, where $X_{TCSC}(\alpha)$ is inductive.
- This can be seen in the impedance vs firing angle characteristics of TCSC as below:

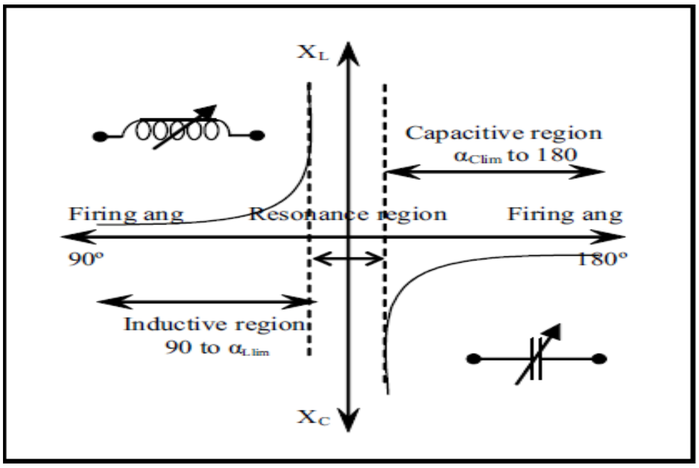


Figure-9 TCSC characteristics.

IV. SIMULATION & RESULTS

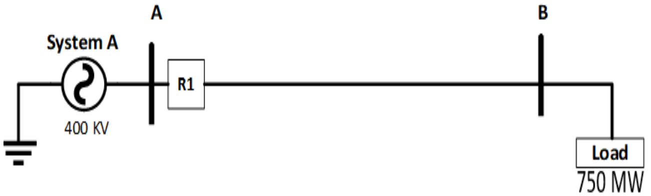


Figure-10 Single line diagram of uncompensated system

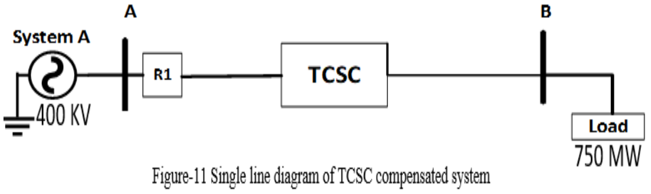


Figure-11 Single line diagram of TCSC compensated system

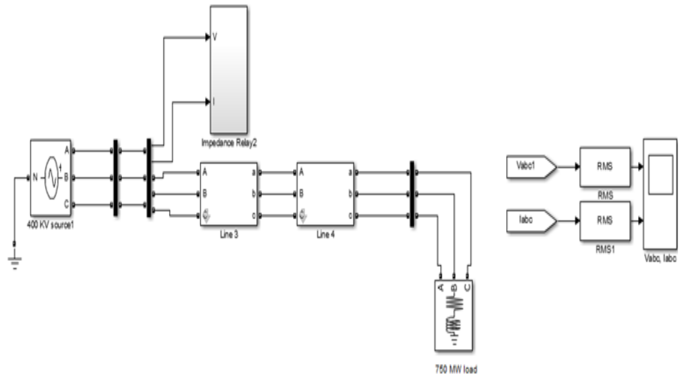


Figure-12 Simulink model of uncompensated transmission line in MATLAB

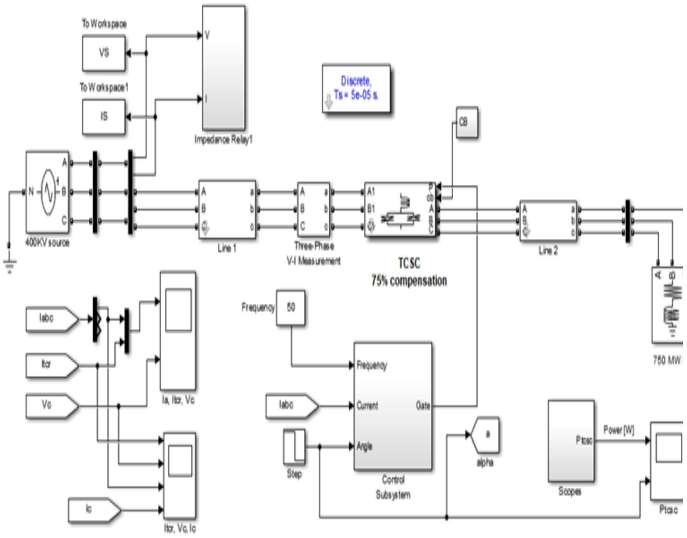


Figure-13 Simulink model of TCSC compensated transmission line in MATLAB

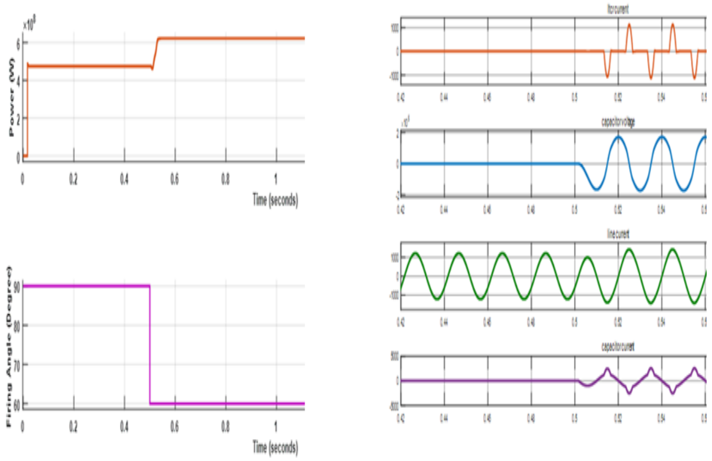


Figure14-Simulation results at α=25° Inductive mode

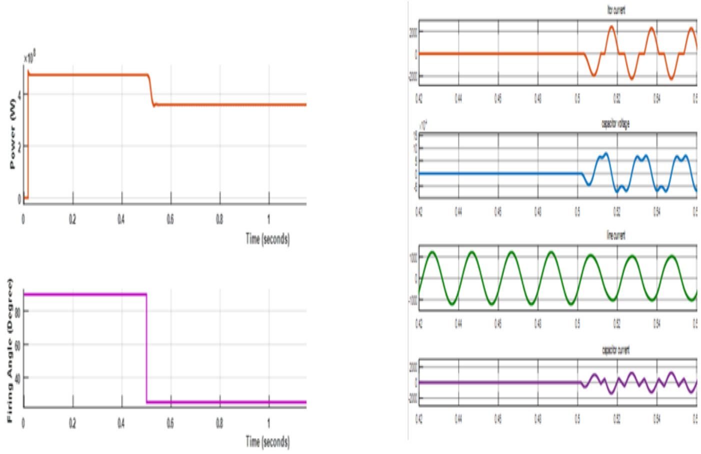
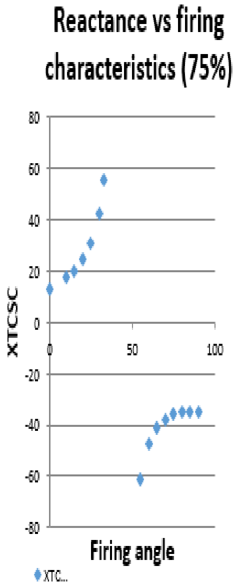


Figure-15 Simulation results at capacitive mode



ALPHA	XTCSC	POWER (W)	ALPHA	XTCSC	POWER (MW)
INDUCTIVE REGION			CAPACITIVE REGION		
0°	-32.7926	399.5	60°	127.9025	597.8
5°	-38.4785	392.8	65°	113.8525	594.5
10°	-46.4021	384.2	70°	105.8549	591.0
15°	-57.9795	374.9	75°	101.4432	588.5
20°	-76.0990	361.5	80°	99.2855	587.3
25°	-106.679	345.1	85°	98.5057	586.9
30°	-174.394	317.4	90°	98.3947	586.87

Figure-16 Reactance Vs firing angle chara. (75%)

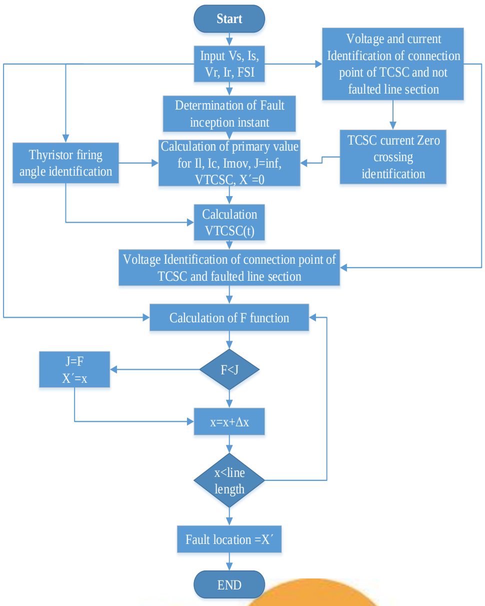
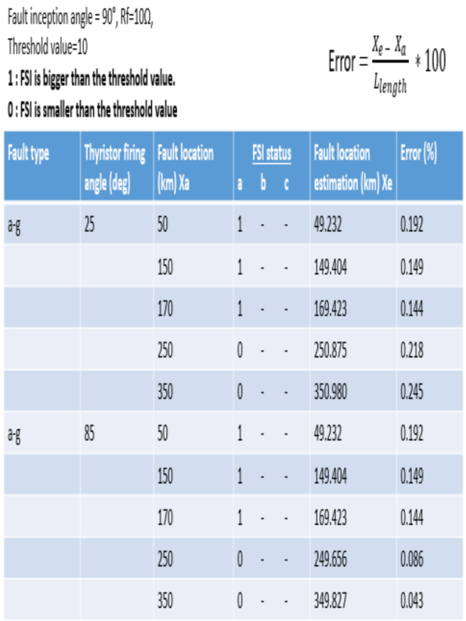


Figure-17 The estimate fault location error minimizing algorithm flowchart

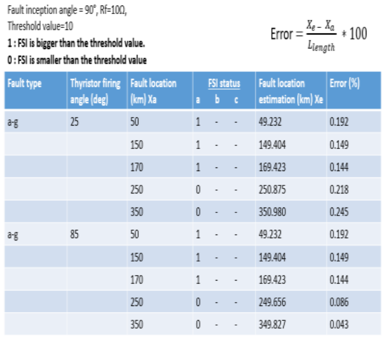


Fault inception angle = 90°, Rf=10Ω,
Threshold value=10
1 : FSI is bigger than the threshold value.
0 : FSI is smaller than the threshold value

$$Error = \frac{X_e - X_a}{L_{length}} * 100$$

Fault type	Thyristor firing angle (deg)	Fault location (km) Xa	FSI status a	b	c	Fault location estimation (km) Xe	Error (%)
a-g	25	50	1	-	-	49.232	0.192
		150	1	-	-	149.404	0.149
		170	1	-	-	169.423	0.144
		250	0	-	-	250.875	0.218
		350	0	-	-	350.980	0.245
a-g	85	50	1	-	-	49.232	0.192
		150	1	-	-	149.404	0.149
		170	1	-	-	169.423	0.144
		250	0	-	-	249.656	0.086
		350	0	-	-	349.827	0.043

Table-1 Calculation for LG fault error minimizing by fault location algorithm



Fault inception angle = 90°, Rf=10Ω,
Threshold value=10
1 : FSI is bigger than the threshold value.
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Fault type	Thyristor firing angle (deg)	Fault location (km) Xa	FSI status a	b	c	Fault location estimation (km) Xe	Error (%)
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		350	0	-	-	349.827	0.043

Table-2 Calculation for LLG fault error minimizing by fault location algorithm

CONCLUSION

In this paper a transmission line with series compensated system is implemented. A MOH relay for fault detection is employed for power system. Simulation of MHO relay has been implemented in MATLAB environment for LG and LLLG fault at different locations and impedance observed with and without series compensations has completed and analyzed with different fault. MATLAB program for distance algorithm is implemented for simulation system has completed and algorithm is attached in report. Malfunction of relay in distance algorithm for series compensated transmission line has been minimized up to 0.2% error. Results are verified at different fault at different distance, different firing angle and results are as per desired values.

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