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PERFORMANCE OF MOV- PROTECTED THREE PHASE SERIES COMPENSATED TRANSMISSION LINE

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Abstract— In this paper simulation of three phase transmission line with series compensation in fault condition is represented. Compensation to transmission line is compensated by series capacitor means fixed series compensation is used. Series capacitor is used with its protective equipment. Metal Oxide Varistor and Air Gap with RL damping circuit are used to protect series capacitor from overvoltage. The purpose of series compensation of long transmission line is to reduce inductive reactance of transmission line and to enhance power transfer ability. This paper represents simulation study in MATLAB/SIMULINK and shows results for single line to ground fault and three phases to ground fault.

Keywords— Fixed series compensation, series capacitor with MOV-protected, Circuit Breaker, and Faults in transmission line.

I. INTRODUCTION

In recent years power demand is ever raising drastically. But there are economic and environmental limitations to enhance fossil fuels based generating systems. Increase in cost of constructing new transmission line including with problems to achieve modern paths of transmission lines has directed to a look for enhancing power transfer capability of available lines[1-2]. In transmission line series capacitor acts as a compensation unit of inductive reactance which leads to rise the power transfer [3-4]. It helps to enhance margin of transient stability as well as optimum sharing of load between parallel transmission lines [5-6-7]. Compensation to transmission line provides improvement in electric characteristics of transmission line with goal of enhancing power transmission capacity [8]. To minimize transfer reactance of transmission line at power frequency with the help of series capacitors is objective of series compensation [9]. It helps to raise capability of power transfer, stability of power system, to enhance load capacity, voltage control as well as voltage regulation by minimizing losses in transmission line. [10-11-12].

Series compensation in transmission line has been in practice since the beginning of the 20th century. The former series capacitor compensation in 245 kV line for application of EHV power transfer was established in 1951 in Sweden [13]. Similar project was implemented in the USA in 1952[14]. The first 400kV series compensated transmission line was installed on Sweden in 1954. The first 500kV line was energized with series compensation unit in USA in 1960[15]. From the successful results of these implementation, series compensation has come to be regular repetition in AC transmission line to improve power transfer capacity [16].

This paper represents simulation of three phase series compensated transmission line. Transmission line voltage is 500kV. The line is compensated by unit consist of series capacitor and its protective device Metal Oxide Varistor (MOV). Section-II represents working of series capacitor in transmission line. Section-III explains series capacitor model. Section-IV contains simulation of MOV-protected three phase series compensated transmission line. Section-V consist of analysis the simulation results. Finally, Section-VI contains conclusion of this paper.

II. WORKING OF SERIES CAPACITOR IN TRANSMISSION LINE

The power transmitted through transmission line from sending end to receiving end is explained by using following fig-1 it is uncompensated transmission line.

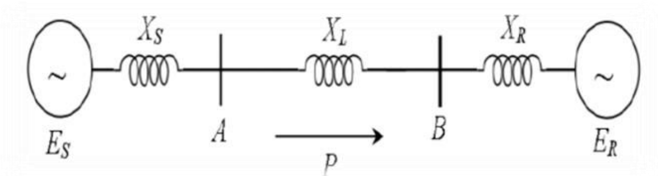

Fig 1. Uncompensated Transmission line

The active power transferred in uncompensated transmission lines is given by

$$P = (E_S * E_R / X_t) * \sin\delta$$

Where,

E_S = Voltage at Sending end

E_R = Voltage at Receiving end

X_t = Transmission line transfer reactance

δ = Load angle

To compensate the inductive reactance of transmission line series capacitors are set up in transmission line. Because the electrical distance of transmission line will be minimized

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when series capacitor (jXc) is introduced in transmission line. It helps to reduce net reactance of transmission line as shown in fig-3. So that power transfer capacity of transmission line increases. Since active power transmitted over series compensated transmission line is given by,

$$P=((E_S*E_R)/X_t-X_C)*\sin\delta$$

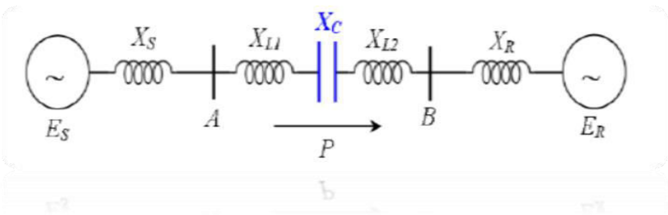

Fig 2. Series compensated transmission line

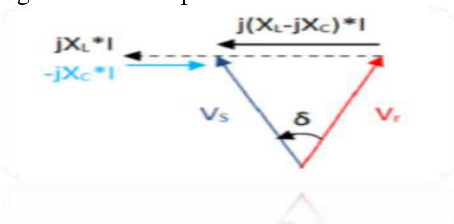

Fig 3. Net impedance of transmission line

The power transfer over the series compensated transmission line is generally interpreted by the system shown in fig 2. Series compensation has been frequently used in long transmission line and other place where lines are long and wide transfer of power is required over these long distances.

Series compensated transmission lines are utilized in modern HV and EHV transmission system to enhance performance of the power system, to improve capability of power transfer, to improve flow of power, voltage control as well as to reduce capital investment [17-18-19].

III. SERIES CAPACITOR MODEL

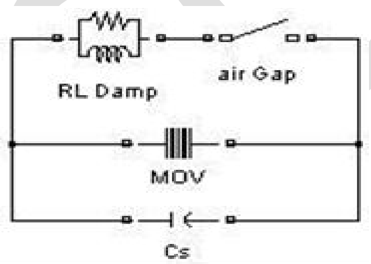

Fig 4. Series capacitor model

In series compensation for proper functioning of series capacitor, it is utilised along with its protective facilities. It is necessary to control, to protect and to enable capacitor bank to operate as a combined segment of power system.

Series capacitor unit is presented in fig 4. It is necessary to bypass series capacitor (SC) during fault condition. The type of diversion protection for protection of series capacitor depends on approach followed by utilities. They are as follows

1. Metal Oxide Varistors (MOV)
2. Air Gap with R-L damping

Series capacitor bank and its protective facilities are connected in parallel as represented in fig 4. It is necessary to protect Series capacitor from over voltages and overheating during internal and external faults due to flow of large fault current. When instantaneous voltage across SC increases beyond certain voltage level then immediately MOV starts conducting. It absorbs energy as well as protects SC from overheating. It is essential to protect series capacitor with MOV when fault current level is very high as well as if it overreaches maximum capacity level energy dissipated across MOV. So air gap is secondary bypass protection system to SC [17-18-19].

IV. SIMULATION OF MOV-PROTECTED THREE PHASE SERIES COMPENSATED TRANSMISSION LINE

To study performance of series compensated transmission line under various fault conditions the transmission network shown in fig 5 is used. The MATLAB/Simulink simulation for this system is presented in fig 6. Fig 7 represents the series compensating capacitor model protected with MOV. Required data for simulation of system is represented in Table 1. The XY segment of transmission line is compensated with series capacitor and degree of compensation is 40%.

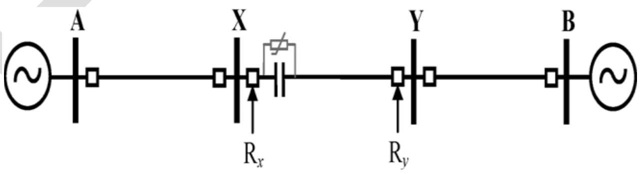

Fig 5. Transmission Network

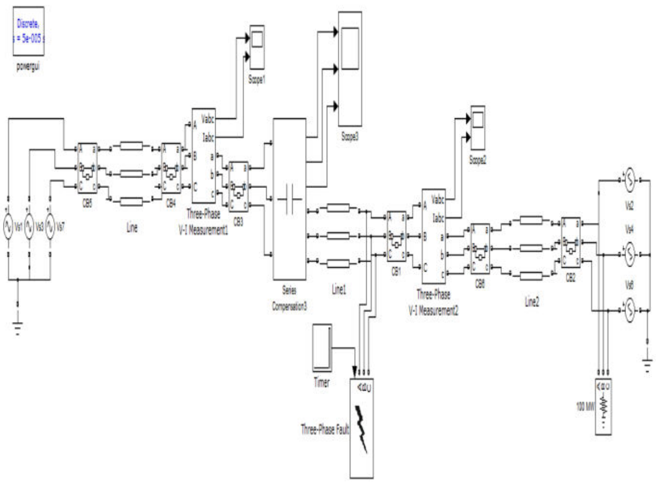

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Fig 6. Simulated system in MATLAB

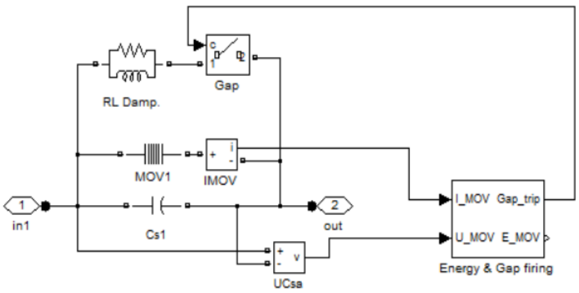

Fig 7. Series capacitor compensation model in MATLAB

Table 1.
Simulated System Data

Parameter	Value	Unit
System Voltage	500	kV
System Frequency	60	Hz
Lines Length (AX, XY, YB)	100	km
Lines Positive Seq. Series Impedance	$0.0185 + j0.3766$	Ω/km
Lines Positive Seq. Capacitive Reactance	0.22789	MΩ×km
Lines Zero Seq. Series Impedance	$0.3618 + j1.2277$	Ω/km
Lines Zero Seq. Capacitive Reactance	0.34513	MΩ×km
Sources Positive Seq. impedance	$1.43 + j16.21$	Ω
Sources Zero Seq. impedance	$3.068 + j28.746$	Ω
MOV Reference Current	10	kA
MOV Reference Voltage	338	kV
MOV Exponent	24	-

A. Single Phase to Ground fault:

In Simulink single line to ground fault is applied to phase A at t=1 sec. Initially all circuit breakers are closed. After occurrence of fault relay opens circuit breaker at t=1.0667sec (after four cycles). And fault is cleared at t=1.1 sec. During fault current reaches to 7 kA and MOV conduction takes place at every half cycle. Energy across MOV reaches to 3.14 MJ. At t=1.0667 sec relays opens circuit breaker at both ends of line section XY. So energy remains constant 3.14 MJ. Air gap is not fired because energy dissipation across MOV does not exceed threshold value of MOV. After opening of circuit breaker fault current reaches to zero. Transmission line and series capacitor initiate to discharge through fault path and shunt reactance.

At first zero crossing after opening order given to circuit breaker, the fault extinguishes and then capacitor stops discharging and voltage across it oscillates around 300kV. In fig 8 and fig. 14. ‘Bus X’ represents ‘three phase VI measurement1’ block which is present in fig 6. Similarly in fig. 9 and fig. 15 ‘bus Y’ represents ‘three phase VI measurement2’ block which is present in fig. 6

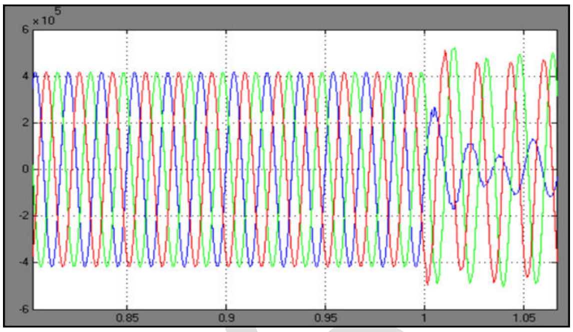

Fig 8. Voltage at Bus X (V)

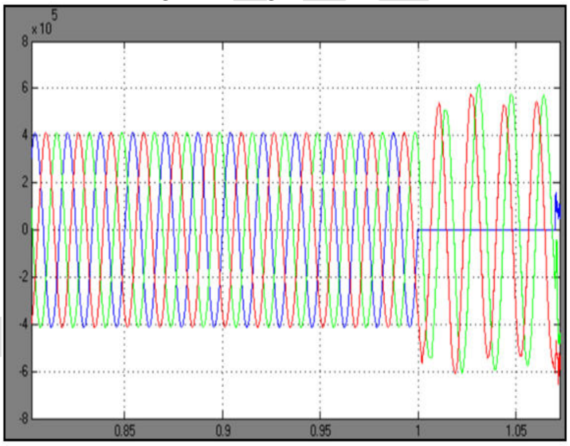

Fig 9. Voltage at Bus Y (V)

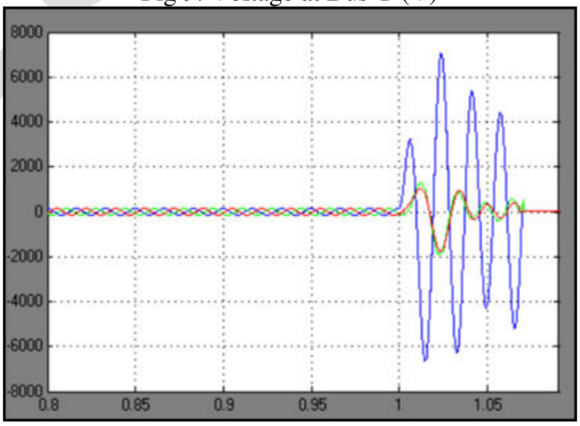

Fig 10. Fault current (A)

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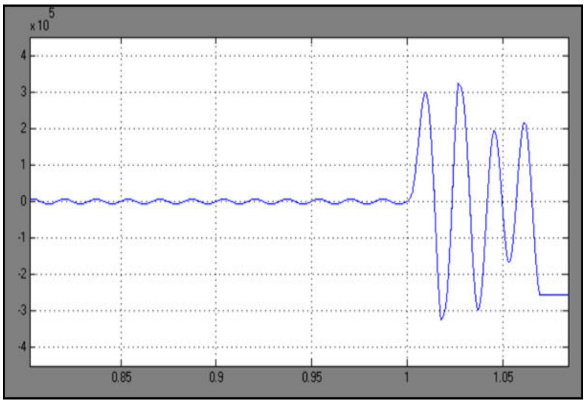

Fig 11. Voltage of series capacitor (V)

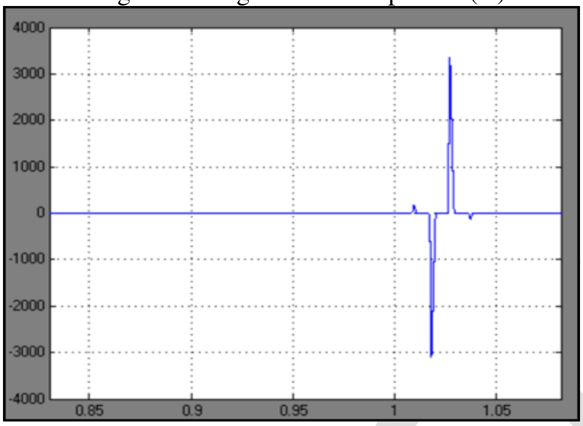

Fig 12. MOV current (A)

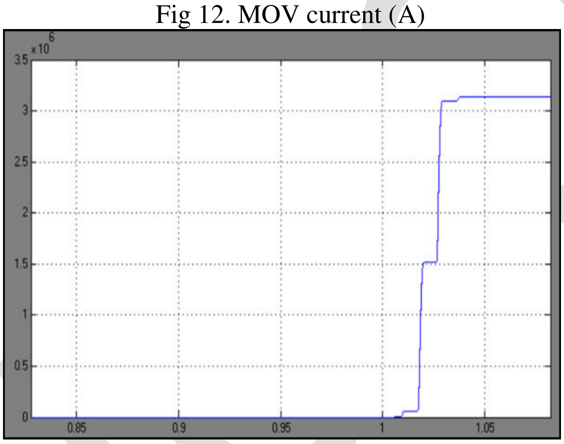

Fig 13. Energy dissipation in the MOV (J)

B. Three Phase to ground fault:

In Simulink three phase line to ground is applied to transmission line at t= 1sec. Initially circuit breakers are closed and relays open them at t=1.0667sec (after four cycles). Fault is cleared at t= 1.1 sec. during fault , current reaches to 10.7 kA and conduction of MOV takes place at every half cycle and energy reaches to value 30MJ threshold value. So air gap is fired and voltage across series capacitor immediately falls to zero through RL damping circuit.

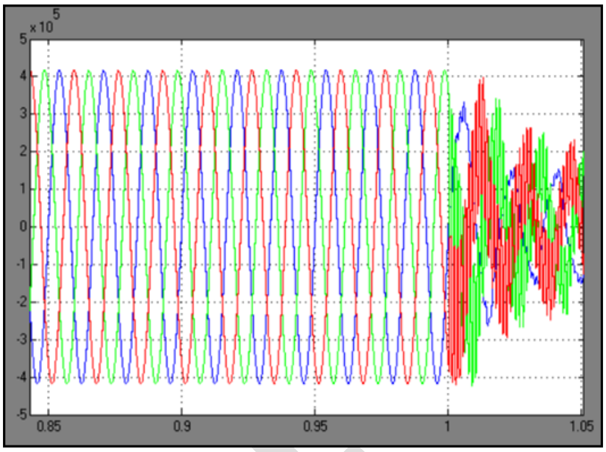

Fig 14. Voltage at Bus X (V)

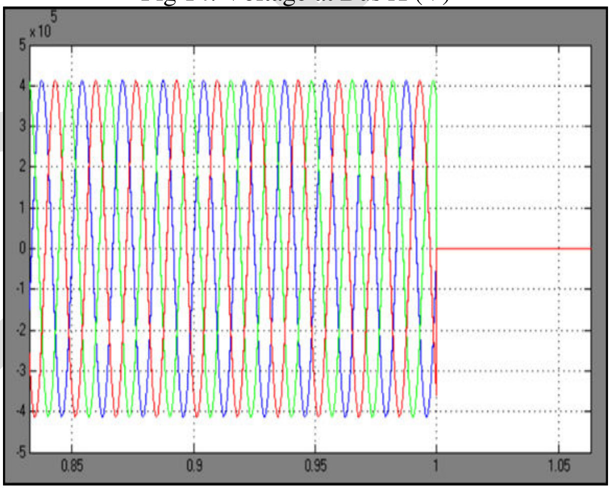

Fig 15. Voltage at Bus Y (V)

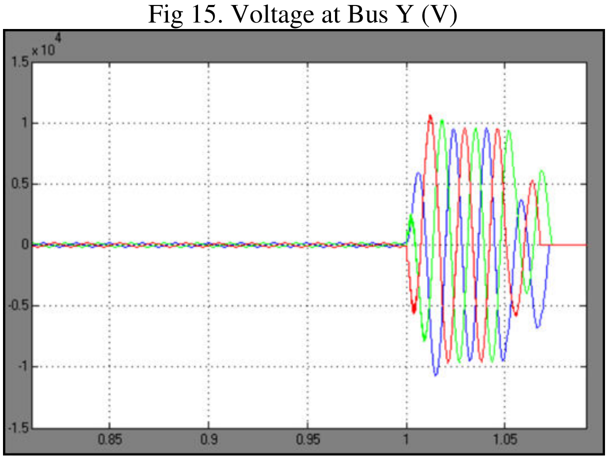

Fig 16. Fault current (A)

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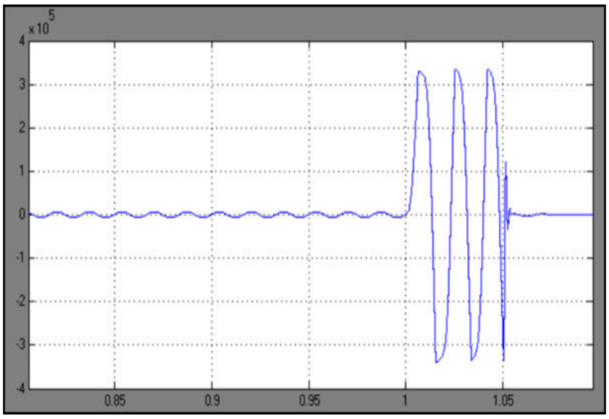

Fig 17. Voltage of series capacitor (V)

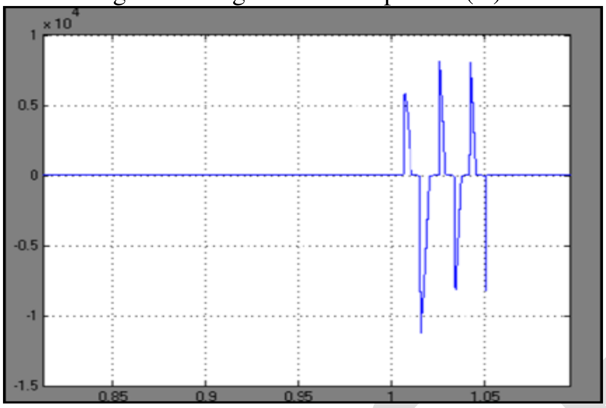

Fig 18. MOV current (A)

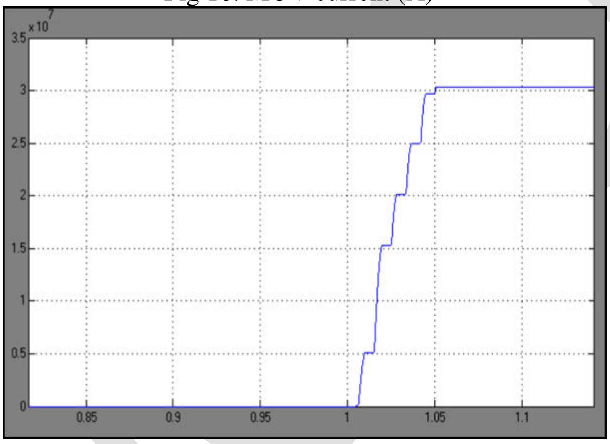

Fig 19. Energy dissipation in the MOV (J)

V. ANALYSIS THE SIMULATION RESULTS

When series capacitor voltage is less than its protective level, current through the MOV is null because it provides high impedance path. In each half cycle of current series capacitor conducts first and then current is diverted to MOV for remaining half cycle. Current flowing through MOV is very small in the unfaulted line as compared to that of the faulted lines. Similarly energy dissipation across mov is in MJ in faulted phase, and that is in mJ in unfaulted phase.

In single phase to ground fault conduction of MOV takes place at every half cycle after the fault occurrence and energy across MOV is 3.14 MJ. Relays at bus X and Y open circuit breaker so energy remains constant 3.14 MJ. Since this value is less than threshold energy value of MOV, air gap is not fired.

During three phase to ground fault, since fault current is large energy dissipation across MOV exceeds its threshold value 30MJ. So air gap is fired and it bypass the series capacitor. So immediately voltage across series capacitor drops to zero through RL damping circuit.

VI. CONCLUSION

The performance of three phase MOV protected transmission line during fault condition is obtained by simulation are discussed as follows:

When three phase to ground fault occurs MOV operates immediately to bypass the capacitor from the system. However capacitor is not completely removed so its reinsertion is immediate. And during single phase to ground fault only function of protection equipment of series capacitor of faulted phase takes place. And series capacitor of remaining un-faulted phase leftovers in the system to maintain stability. As well as energy dissipation across MOV during fault condition is used to decide firing of air gap.

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