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Simulation of Series Compensated Transmission Lines Protected with Mov

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Abstract**—**In this paper the behavior of fixed series compensated extra high voltage transmission lines during faults is simulated. Many over-voltage protection schemes for series capacitors are limited in terms of size and performance, and are easily affected by environmental conditions. While the need for more compact and environmentally robust equipment is required. use of series capacitors for compensating part of the inductive reactance of long transmission lines increases the power transmission capacity. Emphasis is given on the impact of modern capacitor protection techniques (MOV protection). The simulation study is performed using MATLAB/SIMULINK®and results are given for a three phase and a single phase to ground fault.

Keywords**—**Series compensation, MOV - protected series capacitors, balanced and unbalanced faults

I. INTRODUCTION

IN recent years, the highly increasing cost of building new transmission lines, compounded by the difficulty to obtain new transmission corridors, has led to a search for increasing the transmission capacity of existing lines[1-2]. use of series capacitors for compensating part of the inductive reactance of long transmission lines increases the power transmission capacity[3-4]. It also increases transient stability margins, optimizes load-sharing between parallel transmission lines and reduces system losses [5-6-7]. Transmission line compensation implies a modification in the electric characteristic of the transmission line with the objective of increase power transfer capability[8]. In the case of series compensation, the objective is to cancel part of the reactance of the line by means of series capacitors[9]. This result is an enhanced system stability, which is evidenced with an increased power transfer capability of the line, a reduction in the transmission angle at a given level of power transfer and an increased virtual natural load [10-11-12].

Series compensation has been in use since the early part of the 20th century. The first series capacitor for EHV power transmission application was installed in a 245 kV line back in 195 1 in Sweden [13]. It was followed by a similar project in the USA in 1951[14]. The first 400 kV series compensation project was energized in 1954 in Sweden[15]. In 1960s the first 500 kV series compensation project was introduced in the USA[16]. As a result of the success of these projects, series compensation has become a common practice to enhance the power transfer over long AC transmission lines[17]. One of the main considerations in the design and application of series capacitors is their protection against overvoltage. In modern installations, the traditional gap type scheme which bypasses the series capacitor to avoid overvoltage is replaced with Metal Oxide Varistor (M0V). The main advantage of this Protection scheme is that the capacitor is not entirely bypassed during a fault, so reinsertion is instantaneous and without transients[18-19].

The presence of the capacitor in the circuit immediately after a fault is very important, because it helps the transient stability of the system. Also in case of unbalanced faults, only the protection devices of the faulted phases operate leaving the capacitor of the other phases on line.

To determine the various design parameters for planning and implementing, MOV protected capacitors in a network; it is indispensable to be able to model such devices in a fault Analysis program and predict the level of short circuit currents as well as the energy absorbed by the conducting MOV.

II. MOV PROTECTION

The typical circuit for MOV-protected series capacitors is shown in Fig.1.

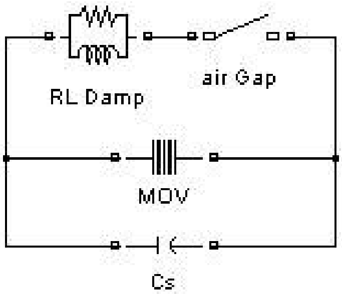

Fig. 1 MOV protection scheme for series capacitors

Under normal operation, as long as the voltage across the capacitor is below a protective level, the varistor presents high resistance. When the varistor conducts, its resistance becomes very low and it diverts part of the fault current away from the capacitor. Since there is an upper limit for energy dissipation in the MOV, for its protection there is special circuitry with an energy monitor, which calculates the energy dissipated by the varistor and triggers the air gap to divert the current from the MOV. The bypass switch closes when the gap energy limit is reached.

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III. POWER SYSTEM SIMULATION

The system of Fig. 2 is studied using MATLAB/simulink. The transmission line is one 400 kV double circuit, heavy type, with 2 conductors per phase .

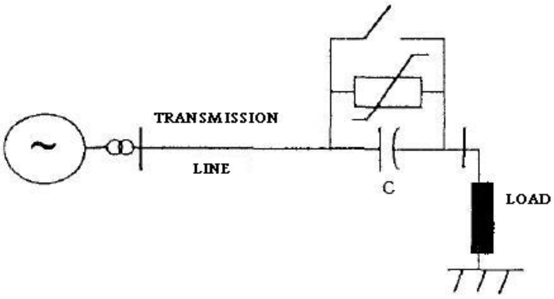

Fig. 2 Power system

Total line reactance in positive-sequence is105.6 ohms and Capacitance required for 40% compensation is Xc=42.24 ohms or Cs= 62.8 μf. MOV protection level required to protect the capacitors at 2.5 times the nominal capacitor voltage.

A. Single line to ground fault

We study the transient performance of this system when phase-to-ground faults are applied on phase A. The fault and the two line circuit breakers CB1 and CB2 are simulated with blocks from the three-phase library. A line-to-ground fault is applied on phase A at t = 1s. The two circuit breakers which are initially closed are then open at t = 1.08 s(four cycle later). The fault is eliminated at t =1.1s, one cycle after line opening. When a line-to-ground fault is applied the fault current reaches 0.8 KA.

During the fault, the MOV conducts at every half cycle and the energy dissipated in the MOV builds up to 5.8 MJ.

At t = 1.08s the line protection relays open breakers CB1 and CB2 and the energy stays constant at 5.8 MJ. As the maximum energy does not exceed the 12 MJ threshold level, the gap is not fired. After breaker opening the fault current drops to a small value and the line and series capacitance start to discharge through the fault and the shunt reactance.

The fault current extinguishes at the first zero crossing after the opening order given to the fault breaker (t = 1.1 s). Then, the series capacitor stops discharging and its voltage oscillate around 220 kv.

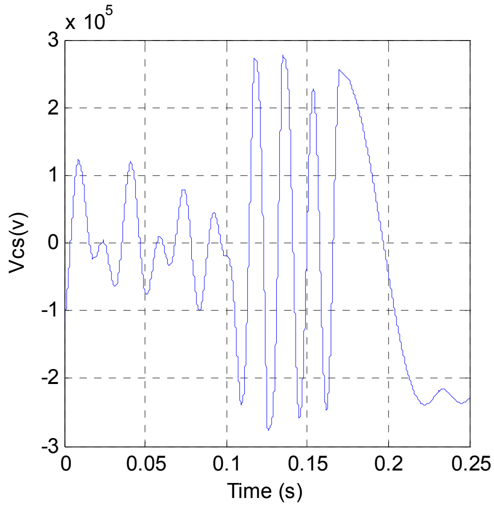

Fig 3 Voltage of the series capacitor

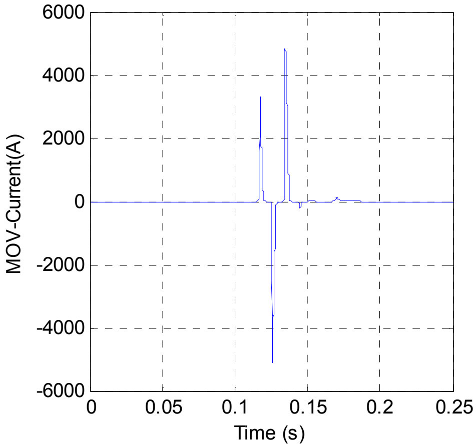

Fig 4 MOV-current

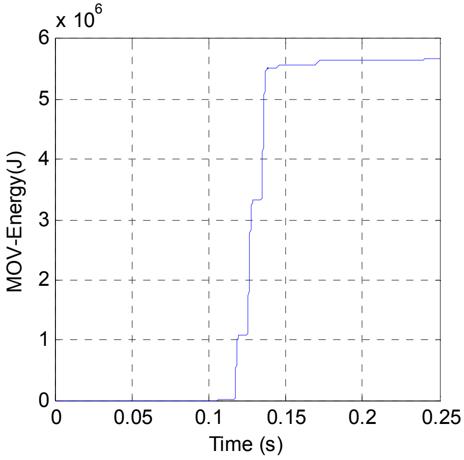

Fig. 5 Energy dissipated in the MOV

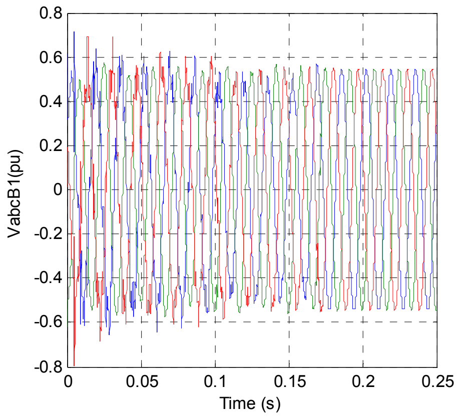

Fig. 6 Voltage at BUS1(pu)

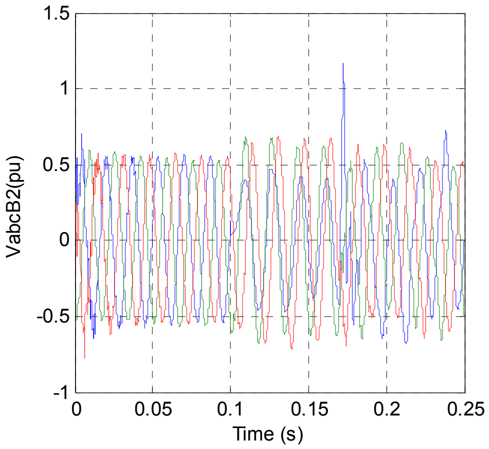

Fig. 7 Voltage at BUS2(pu)

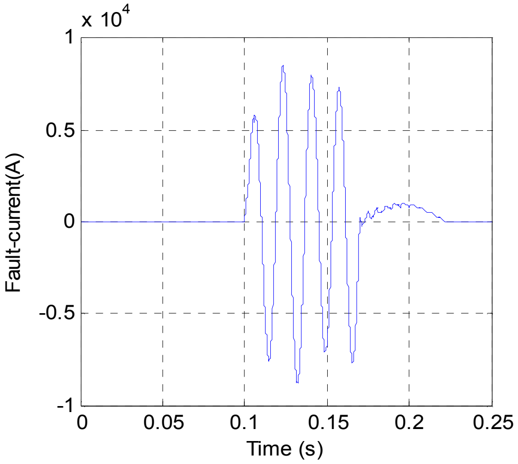

Fig. 8 Fualt current

B. Three line to ground fault

Now we study the transient performance of this system when three phase-to-ground faults are applied. The fault and the two line circuit breakers CB1 and CB2 are simulated with blocks from the three-phase library. A three phase-to-ground fault is applied at t = 1s. The two circuit breakers which are initially closed are then open at t = 1.08 s(four cycle later). The fault is eliminated at t =1.1s, one cycle after line opening.

when a three phase-to-ground fault is applied the fault current reaches 10.2 kA.During the fault, the MOV conducts at every half cycle and the energy reaches the 12MJ threshold level after 2 cycles, two cycles before opening of the line breakers. As result, the gap is fired and the capacitor voltage quickly discharges to zero through the damping circuit.

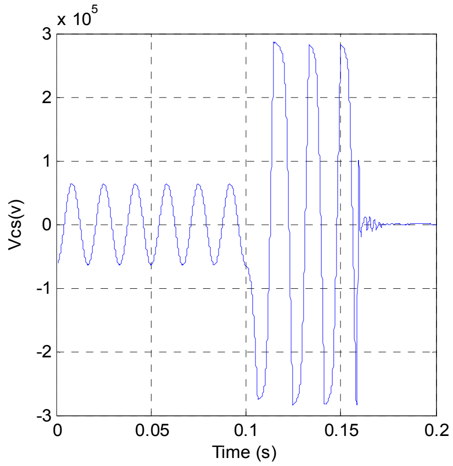

Fig. 9 Voltage of the series capacitor

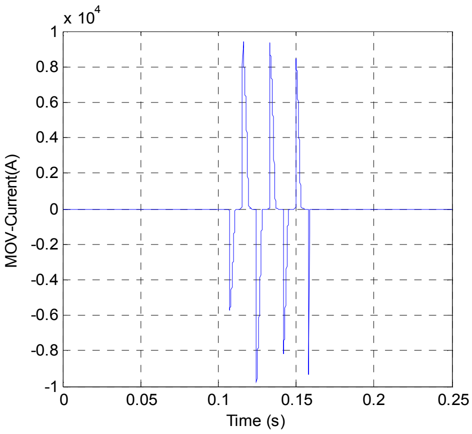

Fig. 10 MOV-current

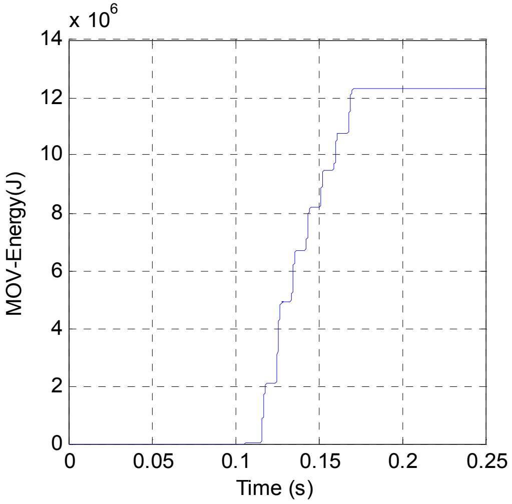

Fig. 11 Energy dissipated in the MOV

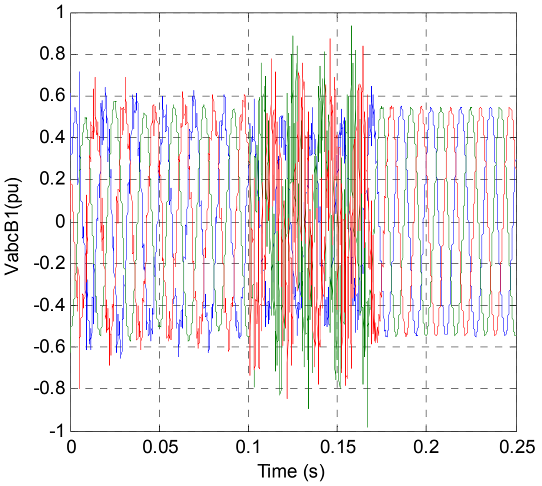

Fig. 12 Voltage at BUS1(pu)

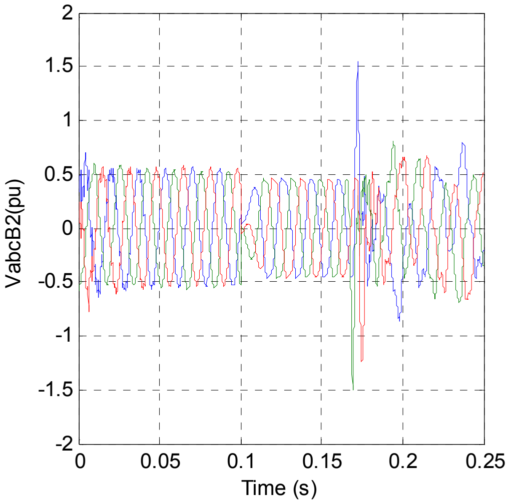

Fig. 13 Voltage at BUS2(pu)

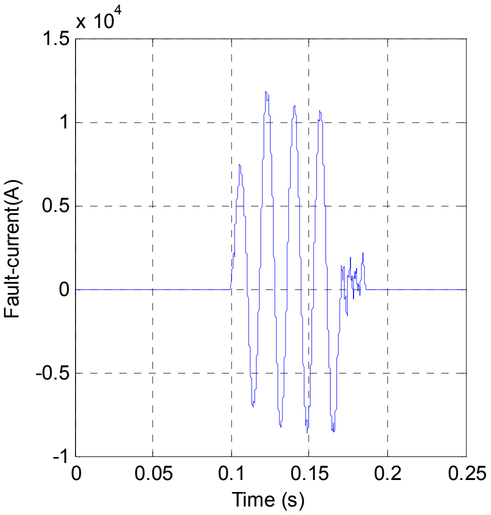

Fig. 14 Fualt current

IV. SIMULATION RESULTS

As long as the voltage across the capacitor is above the protective level, the current is flowing into the MOV and the capacitor current is null when the voltage passes below the protective level, the MOV offers a high resistance and the current, starts flowing into the capacitor again. In any half-cycle of current first the capacitor conducts and then the current is switched to the MOV for the rest of half cycle. The current through the MOV in the unfaulted line is very small compared to that of the faulted phases. It should be noted that the energy of the faulted phases is in MJ, while that of unfaulted line is in mJ. During single line to ground fault, the MOV conducts at every half cycle and the energy dissipated in the MOV builds up to 5.8 MJ.

At t = 1.08s (4 cycle later) the line protection relays open breakers CB1 and CB2 and the energy stays constant at 5.8 MJ. As the maximum energy does not exceed the 12 MJ threshold level, the gap is not fired. During three line to ground fault, the MOV conducts at every half cycle and The energy reaches the 30 MJ threshold level after 2 cycles, two cycle before opening of the line breakers. As a result, the gap is fired and the capacitor voltage quickly discharges to zero through the damping circuit.

V. CONCLUSION

The main results regarding MOV protected series compensation, obtained by the fault simulation are summarized as follows:

During a three phase fault, the MOV protection devices operate immediately, in order to remove the capacitor banks from the system. However, the capacitor is not isolated from the line, so its reinsertion is instantaneous. An important result is that as soon as the bypass switch closes the line current is reduced to a value, as if there were no capacitor banks in the system. During single phase fault, only protection equipment of faulted phase function, while the capacitor banks of the other phases remain in the system to maintain stability. Also, the MOVs' absorbtion of energy is measured in all phases and the energy is exchanged between the capacitor and the MOV.

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