International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-4, Issue-03, March 2018
ISSN: 2395-3470
www.ijseas.com

MODELLING AND SIMULATION OF A SINGLE PHASE SERIES COMPENSATION NETWORK

Abdullahi Musa Askira[1], J. D. Jiya[2] M. Abdulkadir[1]
[1]Faculty of Engineering, Department of Electrical and Electronics Engineering, University of Maiduguri, Nigeria
[2]Electrical Engineering Programme, Abubakar Tafawa Balewa University Bauchi, Bauchi state, Nigeria

Abstract

In alternating current (AC) power transmission system, compensation is the management of reactive power to improve the reliability of power system. Many over-voltage protection schemes for series capacitors are limited in terms of size and performance, and are easily affected by environmental conditions; thus, 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 which increases the power transmission capacity is a solution to this problem. The main aim of this paper is to model and simulate a single phase series compensation network using computer simulation package MATLAB/Simulink to improve the system reliability, stability, efficiency, cost effectiveness by means of compensation. There are mainly two methods, Shunt compensation where the shunt compensator is functionally a controlled reactive current source which is connected in parallel with the transmission line to control its voltage and then series compensation where the series compensator is functionally a controlled voltage source which is connected in series with the transmission line to control its current. The results for the transient performance of the system when a fault is occurred at any node are presented.

1. Introduction

According to Rolf Gruenbaum, and G. Thomas Bellamhe, in a transmission system, due to the transmission line reactance, there are limitations on power transmission ability of a line which leads towards building of a new transmission line which is costly. Series capacitive compensation is used to increase power transmission capability by canceling the line reactance (Rolf Gruenbaum et al, 2012 and Thomas Bellamhe, 1997). Ullasn Eminoglu reported that, voltage regulation becomes an important and sometimes critical issue in the presence of load, which varies the demands for reactive power (Ullasn Eminoglu). As according to Rolf Gruenbaum and Belur, location of the compensator is also an important aspect (Rolf Gruenbaum, 2012 and Belur, 1970). Adebayo reported that series capacitor compensation provides additional options for load flow control and voltage stability of power system (Adebayo, 2013). Compensation means the modification of electrical characteristics of a transmission line in order to increase its power transmission capacity, to satisfy the fundamental requirements for transmission. Compensation system ideally performs following functions: It helps to improve voltage profile at all levels of power transmission. It improves stability by increasing the maximum transmittable power. It provides an economical means for meeting the reactive power requirements of the transmission system.

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 (Glove et al, 2010 and Kundur, 1994). Use of series capacitors for compensating part of the inductive reactance of long transmission lines increases the power transmission capacity (Henschel et al, 2005 and McNabb et al, 2001). It also increases transient stability margins, optimizes load-sharing between parallel transmission lines and reduces system losses Trad et al, 2001; Bui-Van et al, 2003 and IEEE). Transmission line compensation implies a modification in the electric characteristic of the transmission line with the objective of increase power transfer capability (Puetro, 1992). In the case of series compensation, the objective is to cancel part of the reactance of the line by means of series capacitors (Zimmerman et al, 1997). 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 (Xuan et al, 1992).

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 1951 in Sweden (Courwl et al, 1997). It was followed by a similar project in the USA in 1951(Godsworthy 1987). The first 400 kV series compensation project was energized in 1954 in Sweden (Lord, 1989). In 1960s the first 500 kV series compensation project was introduced in the USA (de Oliveira, 1991). 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 (Courts et al, 1980). 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 (Gruenbaum et al, 1989).

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.

2. MOV Protection

The typical circuit for Metal Oxide Varistors (MOV)-protected series capacitors is shown in Figure 1.

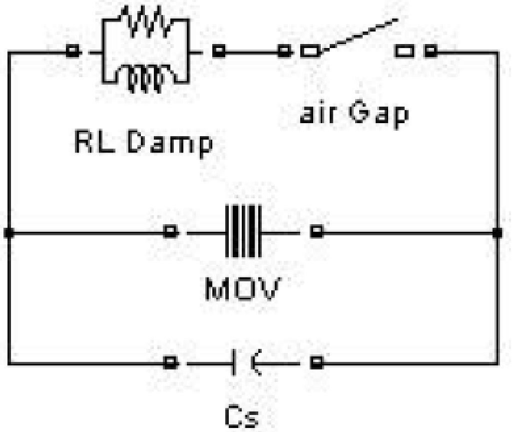

Fig. 1 MOV protection scheme for series capacitors

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.

During load conditions or low current faults, the voltage drop across the series capacitor is below the protection level and thereby there is no conduction of MOV’s. The series capacitor bank is equivalent to a pure reactance equal to the reactance of the actual capacitor. However, with faults involving high currents the voltage drop will be much above the protection level of MOV's causing them to conduct, practically bypassing the series capacitor.

The series compensation circuit under this condition represents a small resistance. Between the two extremes there will be operating conditions under which comparable amount of current flows through the series capacitor and the MOV's. The impedance will then be a combination of resistance and capacitance.

Series Capacitor located at line ends are more likely to create voltage and current reversals because of the absence of the line impedance between the relay location and the series capacitor (Martilla, 1992). Voltage reversal at a bus occurs if the reactance of the capacitor is greater than the reactance of the line section up to the fault location. Voltage inversion causes a loss of directionality to distance relays. Current reversals are bound to occur when the capacitive reactance is greater than the sum of the inductive reactance of the source and the faulted line section, in which case the fault current becomes capacitive. The capacitive current leading the voltage results in a false directional decision of the distance relay.

Also, the presence of series capacitor introduces a slow decaying low frequency component in the relaying signals, which may cause the impedance estimate to oscillate thereby causing errors both for zone detection and directional elements of distance relays (NewBould).

From the foregoing discussion, it is evident that the effect of series capacitor with its MOV on line protection during fault condition needs a detailed study before installation of the series capacitors

3. Power System Modelling and Simulation

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

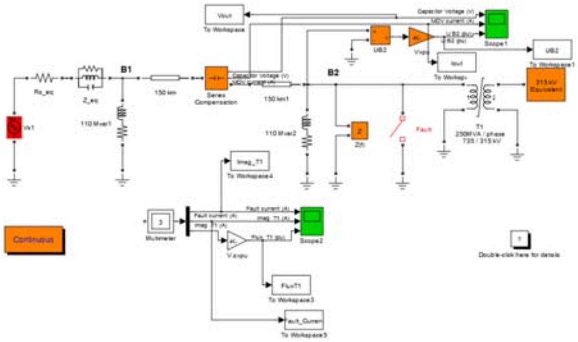

Fig. 2. Overview of the transmission line with series compensation

2.1 Circuit Description

A 735 kV, 300 km line is used to transmit power from bus B1 (735 kV equivalent system) to bus B2 (315 kV equivalent). In order to simplify, only one phase of the system has been represented. (A detailed simulation of a three-phase series compensated network is presented in demo power_3phseries and explained in the case studies section of the user's manual.)

In order to increase the transmission capacity, the line is series compensated at its center by a capacitor representing 40% of the line reactance. The line is also shunt compensated at both ends by a 330 Mvar shunt reactance (110 Mvar /phase). Open the Series Compensation subsystem. Notice that the series capacitor is protected by a metal oxide varistor (MOV) simulated by the Surge Arrester block. The 250 MVA, 735 kV / 315 kV transformer is a Saturable Transformer block simulating one phase of the three-phase 750 MVA transformer. A Multimeter block is used to monitor the fault current as well as the flux and magnetizing current of the transformer.

4. Results and Discussion

The results for the transient performance of the circuit when a 6-cycle fault is applied at node B2 is presented in Figure 3 to 8. Fault is simulated by the Breaker block. Switching times are defined in the Breaker block menu (closing at t = 3 cycles and opening at t = 9 cycles).

4.1 Single Line to Ground Fault

One studies 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.

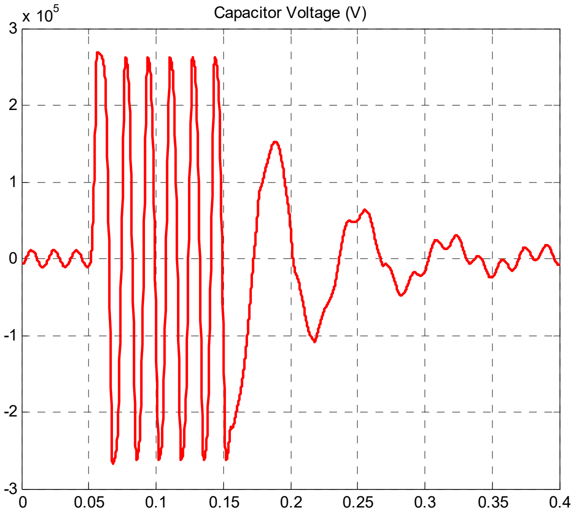

Fig. 3. Capacitor Voltage (V)

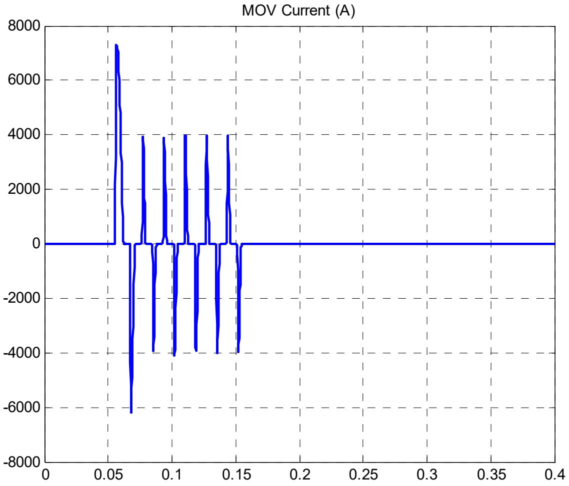

Fig. 4. MOV Current (A)

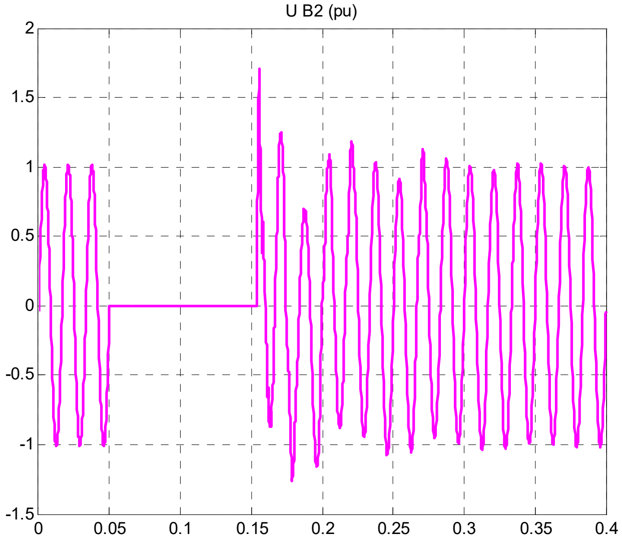

Fig. 5. U B2 (pu)

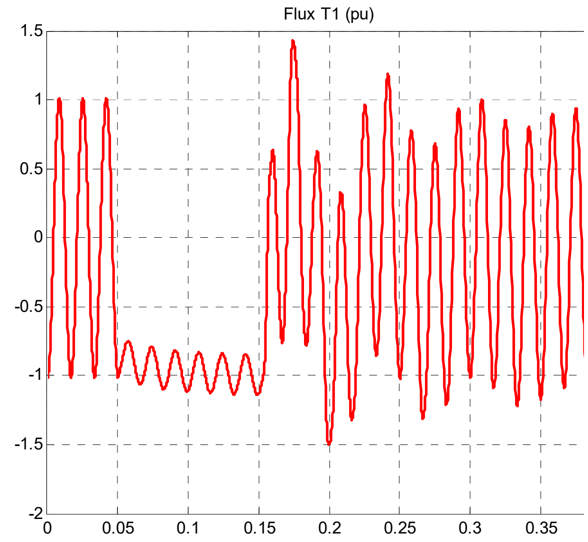

Fig. 6. Flux T1 (pu)

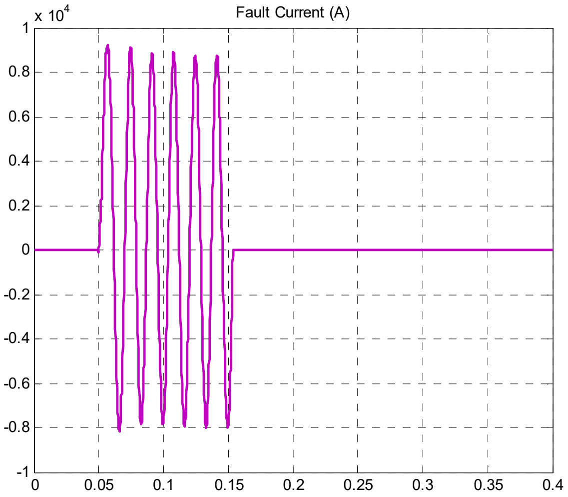

Fig. 7. Fault Current (A)

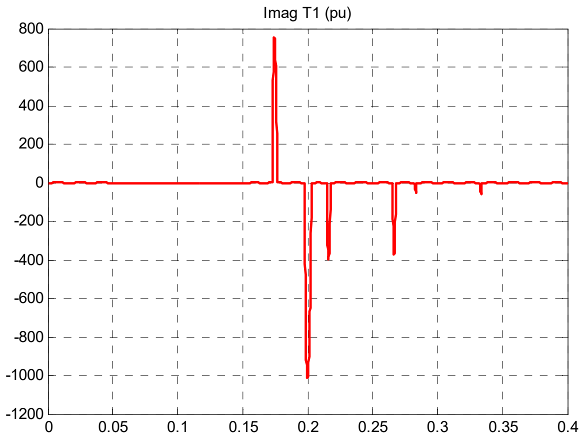

Fig. 8. Imag T1 (pu)

4.3 Frequency Analysis

In order to understand the transient behavior of this series-compensated network, a frequency analysis is first performed by measuring the Impedance at node B2. This measurement is performed by the Impedance Measurement block connected at node B2. Open the Power gui and in the Tools menu select 'Impedance vs Frequency Measurement'. Click on Display to compute and display the impedance for the 0 - 500 Hz range. The impedance curves show two main parallel resonances (impedance maxima and phase inversion), corresponding to 15 Hz and 300 Hz modes. The 15 Hz mode is due to a parallel resonance of the series capacitance and the two shunt reactance. The 300 Hz mode is mainly due to resonance of shunt line capacitance and series reactance of the transmission system. These two modes are likely to be excited at fault clearing.

4.2 Time Domain Simulation - Fault at Bus B2

Start the simulation and observe waveforms on the two Scopes. At t = 3 cycles, a line-to-ground fault is applied and the fault current reaches 10 kA (Figure 7). During the fault, the MOV conducts at every half cycle (Figure 4) and the voltage across the capacitor (Figure 3) is limited to 263 kV. At t = 9 cycles, the fault is cleared. The 15 Hz mode is clearly seen on the capacitor voltage (Figure 3) and bus B2 voltage (Figure 5). During fault the flux in the transformer is trapped to around 1 pu. At fault clearing the flux offset and 15 Hz component cause transformer saturation (flux > 1.2 pu, Figure 4.4), producing magnetizing current pulses (Figure 8).

4. Conclusions

The Simulink model for series compensation network using metal oxide varistor protected series capacitor was developed.

The following three scenarios were evaluated:
a line to ground fault occurred at the secondary bus, an impedance fault occurred on the two transmission lines and the combination of the two faults occurred.

The paper provides details of the efficiency loss with impedance increase. For the third scenario the available load current, load voltage and load power decreased, the moment the two faults were induced

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