PSCAD Cookbook

Series Compensation Study

Written for v4.5
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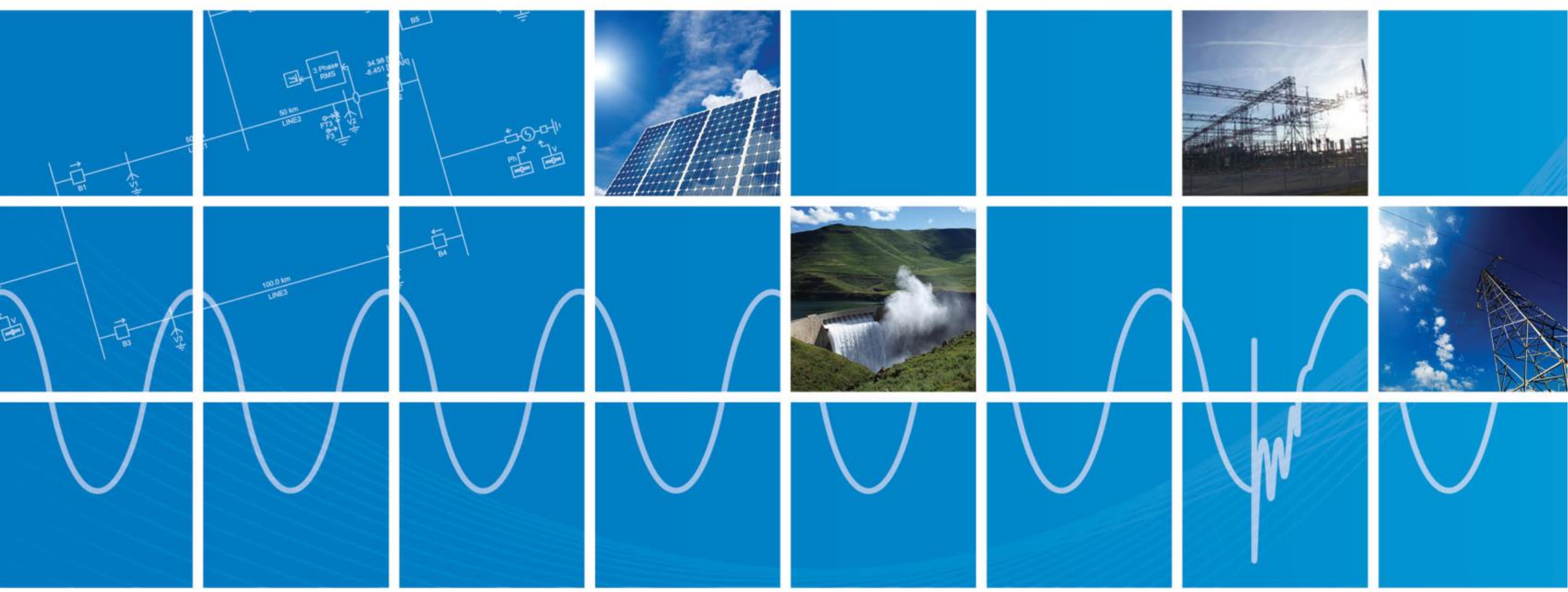

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9.1 Series Compensation and MOV Protection Study

Motivation

For long transmission lines, the inductive reactance becomes prominent and can considerably reduce the amount of power that can be transferred from the generator to the load end. Therefore, for maximum power transfer, series capacitors are applied to reduce the overall inductive reactance of the transmission line (see Equation [1]). The benefits of applying series capacitors on a transmission line include:

(i) improving stability margins,

(ii) better load division on parallel paths,

(iii) ability to adjust line load levels,

(iv) reducing transmission line losses, and

(v) reducing voltage drop on the system during severe disturbances.

Typically, series capacitors are applied to compensate from 25 to 75 percent of the inductive reactance of the transmission line.

$$P = \frac{E_S \cdot E_R \cdot \sin(\delta)}{X_L - X_C} \qquad (1)$$

Where:

- E_S is the source voltage;
- E_R is the receiver voltage;
- P is the power transfer; and
- δ is the angle between the source and receiver voltages.

From Equation [1], it is clear that the capacitive reactance (X_C) reduces the total impedance of the line, thereby allowing increased power flow for the same system angle. In other words, capacitive reactance (X_C) can increase the power transfer level on the transmission line for the same system angle separation. This improves power system stability.

The series capacitors are exposed to a wide range of currents, which can result in large voltages across the capacitors. Thus additional equipment is usually applied to protect the capacitors. This study describes the use of MOV to protect the capacitors from overvoltage that arises due to a fault.

System Overview

To demonstrate series compensation and overvoltage protection of the capacitor, a simple transmission system has been developed as shown in Figure 1.

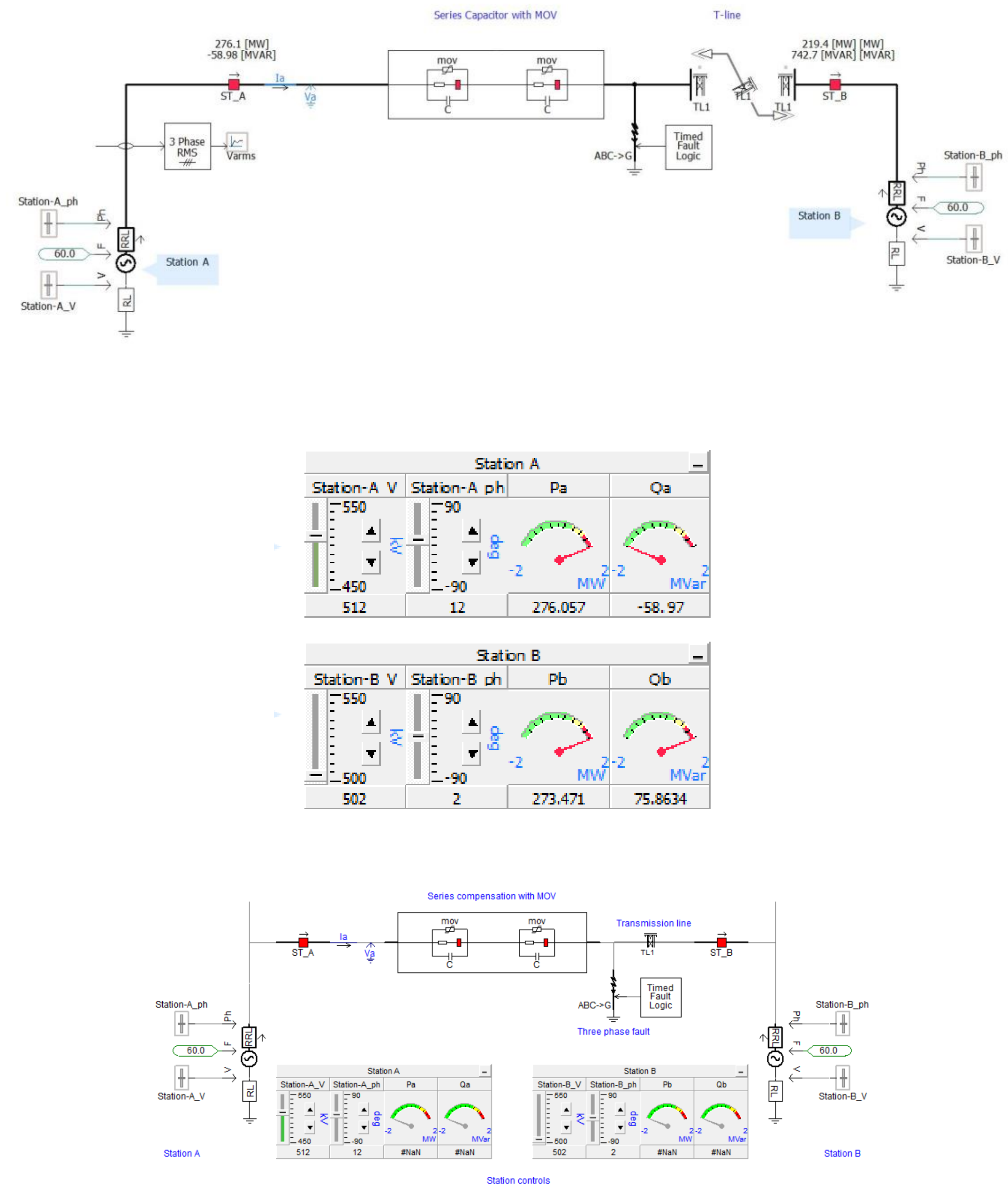

Figure 1: PSCAD Model

The system in Figure 1 consists of two stations (A and B) connected by a 120 km transmission line. The systems on either side of the transmission line are simplified using Thevenin's equivalent voltage sources. The system is designed such that the voltage of Station A leads Station B by 10°. The magnitude and phase angle of the stations can be controlled externally to establish the required active and reactive power flow as shown in Figure 1.

Transmission Line

Refer to Section 12.2 for a description of transmission line modeling in PSCAD.

The impedance of the transmission line can be obtained from the line constant program output file. Using the impedance, the reactive power consumed by the line can then be calculated ($Q_L = I^2 X_L$). In this study, the value of X_C has been adjusted such that the reactive power supplied by the capacitor ($Q_C = E_S^2 / X_C$) is equal to half the reactive power consumed by the line.

MOV Capacitor Block

Series capacitors are normally subjected to a voltage which is only a few percent of the rated line voltage. If a line is shorted due to a fault beyond the capacitor, then a much larger voltage will appear across the capacitor terminals. It is not economical to design a capacitor that can withstand this high voltage, due to both size and cost increase. Therefore, provisions are made to bypass the capacitor during faults and for reinsertion after the faults are cleared.

As mentioned earlier, protective equipment is applied to the series capacitor to protect it from excessive voltages which can occur during faults. This particular case makes use of an MOV (nonlinear resistors) to limit the increased voltage in the system due to the three-phase to ground fault. The main advantage of using an MOV is that the reinsertion time is almost instantaneous and it minimizes transient instability.

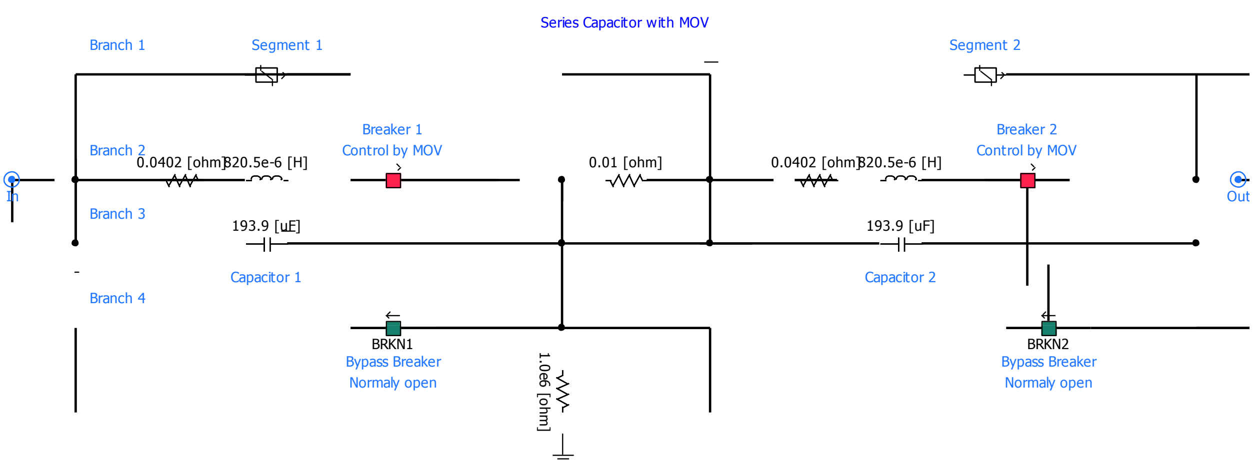

Figure 2: Series Capacitor with MOV Protection

In Figure 2, a capacitor bank is connected in series with the transmission line. Each of these capacitors is protected by an MOV, which is represented by the surge arrestor component in PSCAD. The arrestor characteristics are obtained from the MOV data. There is also an RL branch (Branch 2) that is used to limit high frequency "inrush currents". The breaker in Branch 2 is triggered by the MOV protection controller when the current or the energy through the MOV exceeds the specified threshold. The breaker (BRKN1) in Branch 4 is manually controlled to bypass or insert the series capacitor.

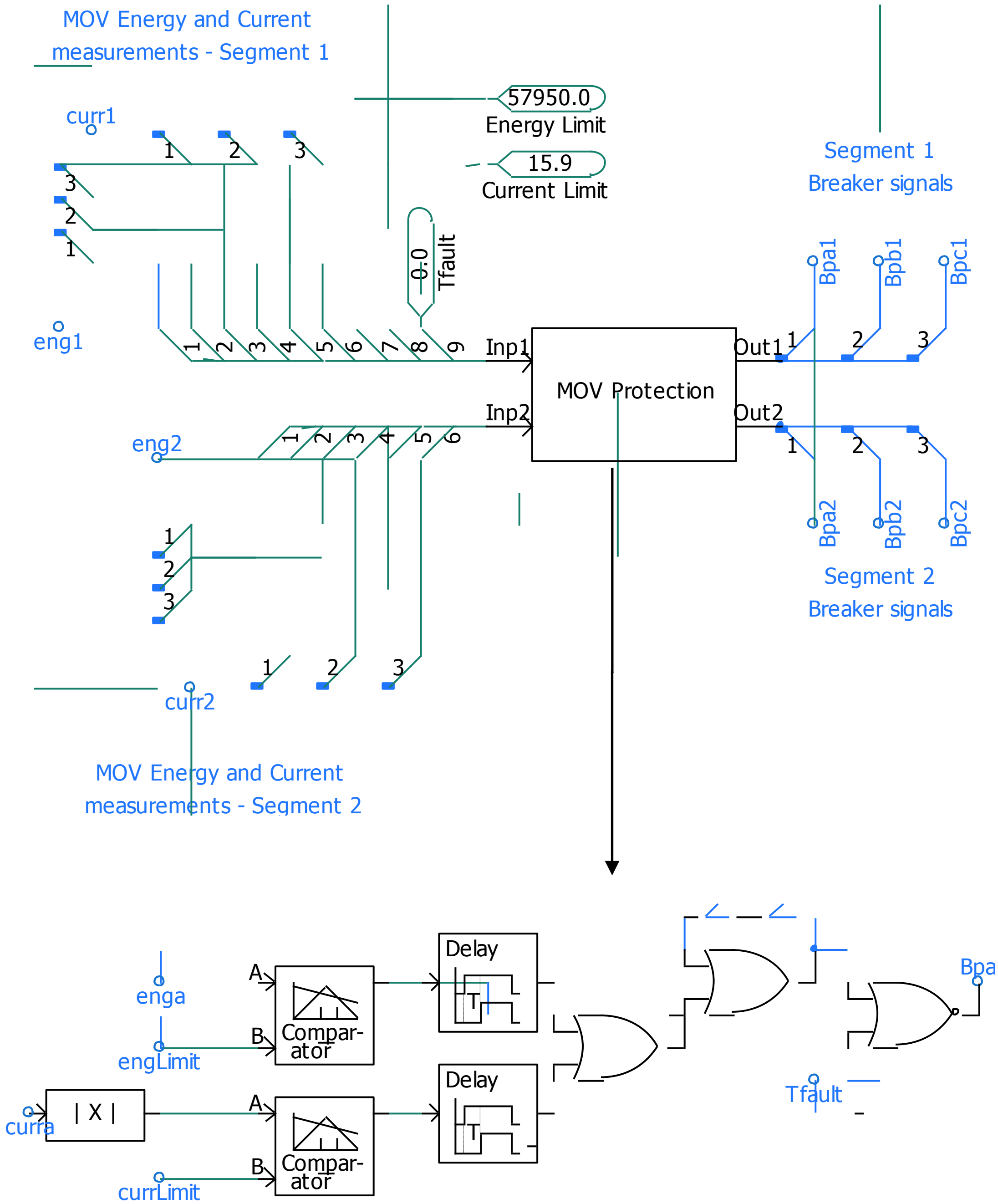

Figure 3: MOV Protection Controls with 57950kJ energy limit and 15.9kA Current limit

In this application, the MOV is protected by electronic controls. The page module 'MOV protect' monitors the energy accumulated and current through the MOV at all times. The control system for the MOV protection is illustrated in Figure 3. The system essentially compares the energy dissipated in the MOV (enga) and the current through the MOV (curra) with the MOV ratings (engLimit & currLimit). If either one of the signals exceed the specified limit, then the bypass branch (Branch 2) is triggered, which then redirects the fault current away from the MOV. Closing the bypass switch creates a closed loop with the series capacitor and the bypass branch elements (inductor and resistor). The inductor will limit high frequency outrush currents (created due to capacitor discharge) to the ratings of the series capacitor and the resistor will provide additional damping.

Simulation Results

An external fault (ABC→G) is simulated at t=2.0 sec, which causes the current flowing through the capacitor (Icap1) hence increasing the capacitor voltage. The surge arrestor (MOV) becomes active and current flows through it (Curr1) when the capacitor voltage increases beyond the MOV's protective level. In response, the MOV will clamp the capacitor voltage (Vcap1) at the protective level and will not allow it to increase. The simulation results in Figure 4 show that the capacitor voltage (Vcap1) has been clamped by the MOV.

Figure 4 also demonstrates that when the current though the MOV (curr1) tries to exceed the specified limits (at t=2.0145 sec), the breaker is closed by MOV protection after a small delay, and Branch 2 conducts the excess current.

Finally, the results reveal that due to the nonlinear nature of the MOV, conduction alternates between the capacitor (Icap1) and the MOV (Curr1) each half cycle.

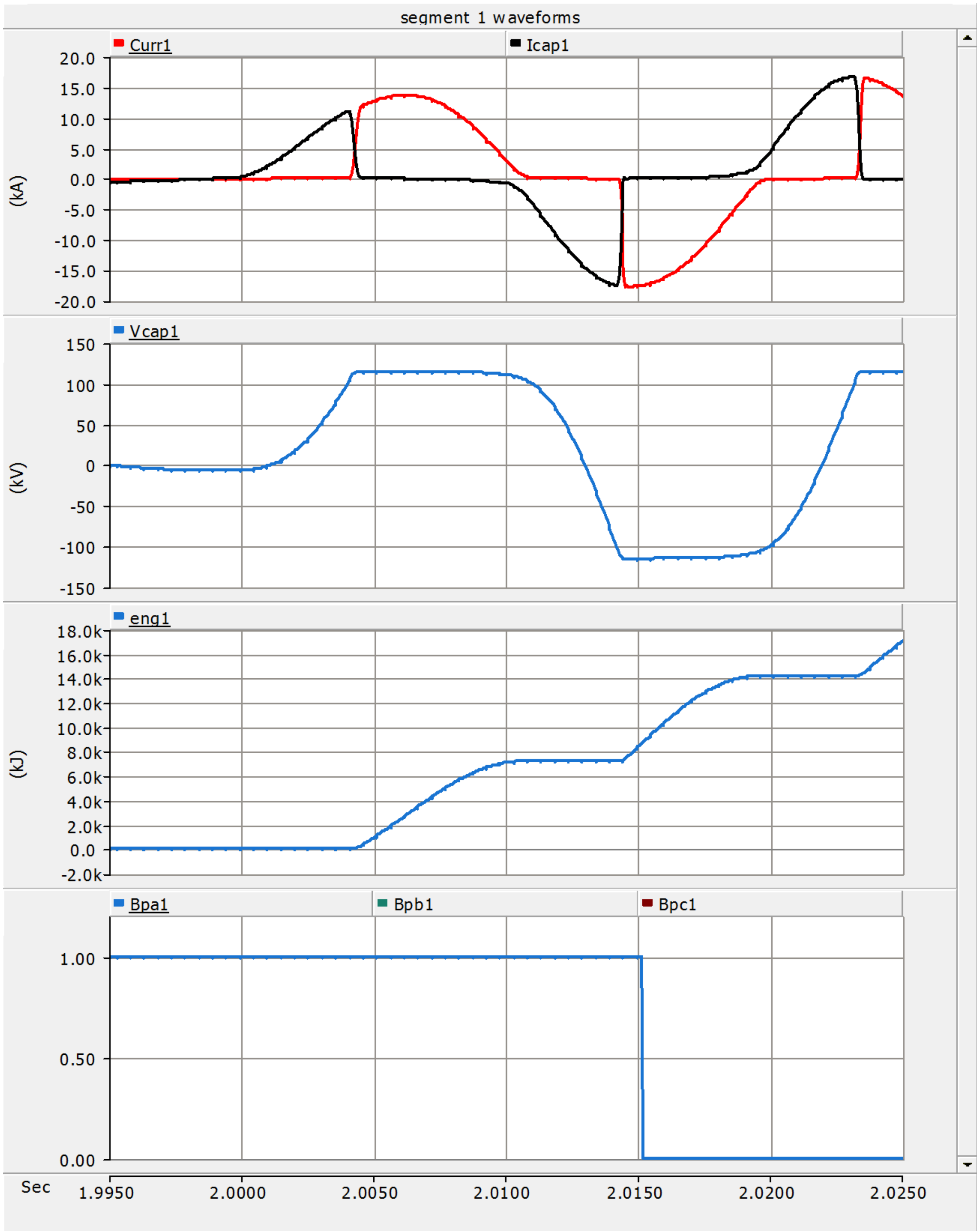

Figure 4: Current and Voltage through the MOV, Capacitor during the fault for phase A Segment 1.

Figure 5 shows the results of simulation once the damping (RL) circuit (in branch 2) comes to circuit as the breaker (in branch 2) is closed by MOV protection. Slowly the voltage across capacitor (Vcap1) reduces and finally the surge arrester (MOV) become inactive as the voltage is below its protection level. As the MOV becomes inactive very high frequency oscillations can be observed in the currents and voltages of Capacitor and Branch 2.

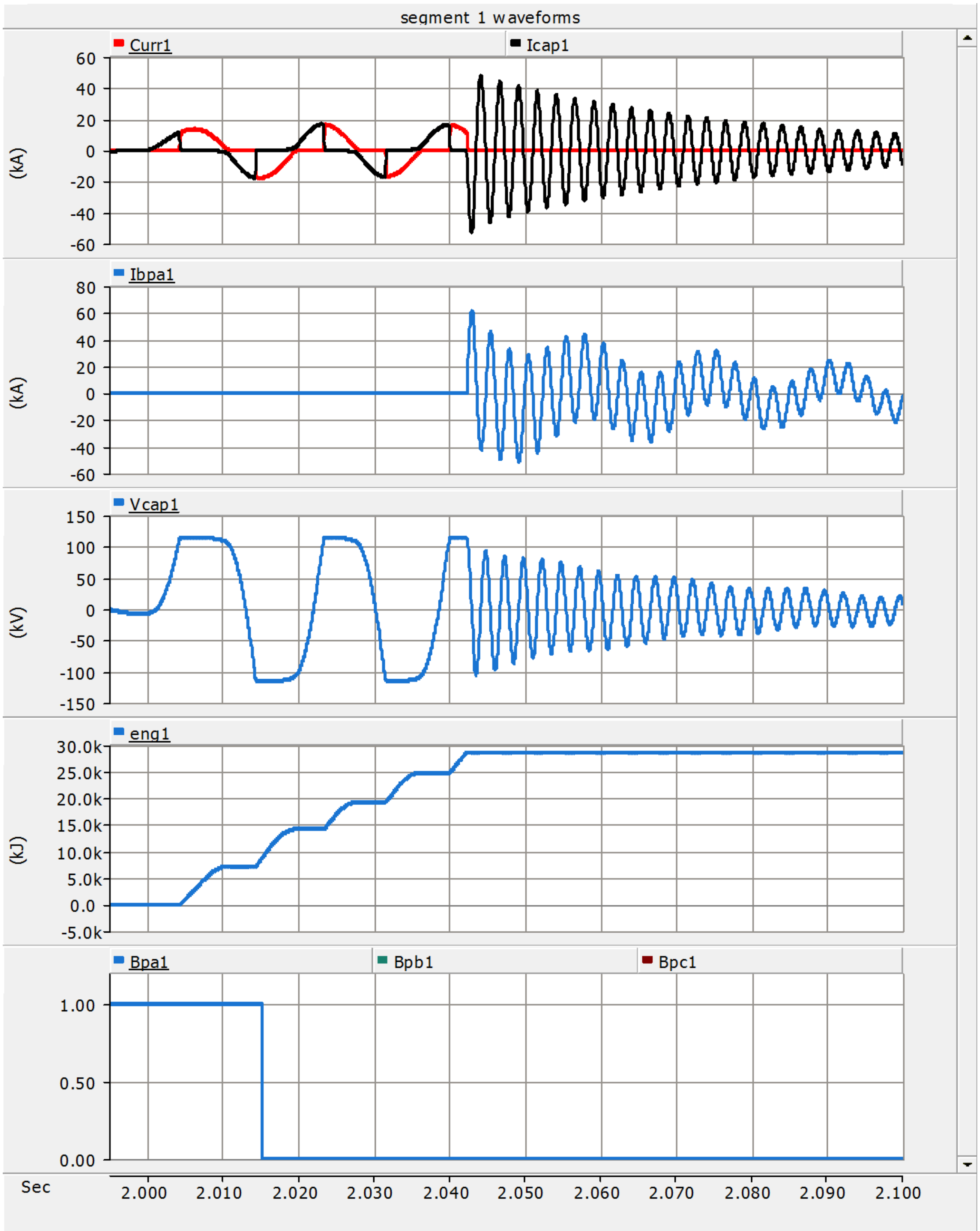

Figure 5: Current and Voltage through the MOV, Capacitor and Damping (RL) circuit.

PSCAD

Refer to PSCAD case: Series_comp_line.pscx

DOCUMENT TRACKING

Rev.	Description	Date
0	Initial	01/Jun/2013
1	Update to new rebranding guidelines	10/Aug/2018