Selection Of Settings For Two IDMT Relays And Confirming The Behavior Of The Two IDMT Relays Using A Real-Time Digital Simulator (RTDS)

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Abstract— **This document showcases the report on the experiment performed to determine the operation of two IDMT relays connected to a 132kV/11kV 20MVA transformer with the impedance of 6% radial feeder. With the load of 15MVA the fault level was set at 6000 MVA. The current ratio was calculated to 200:1 for the high voltage side Current Transformer and 1000:1 for the low voltage side Current Transformer. The current multipliers were calculated to be 0.52 and 0.94 for the upstream and downstream relays respectively. The time multiplier was inferred to be 0.18 for the upstream relay and 0.075 for the downstream relay. It was observed that the relays operated as expected, with the downstream relay tripping the circuit breaker at 0.2 seconds and the upstream relay tripping the circuit breaker at 0.5 seconds.**

I. INTRODUCTION

Analysis of power systems faults is essential to assure safety and protection on power systems [1]. In power systems overcurrent protection therefore becomes significant, it reduces the disturbances caused by failures and increases the reliability-quality of continuous power delivery [2]. This intend is usually achieved through the application of the Inverse Definite Minimum Time (IDMT) relays. It is crucial for IDMT relays to give high reliability and accuracy in the detection of fault current and calculation of operation time [2]. High voltage power systems usually have multiple relays such that a failure of a certain relay to trip is encountered by the back-up relay to ensure that the entire system is not compromised [3], [4] and [5]. The system that allows the study of the faults and the response time of relays towards the mitigation, which is also available in the school to carry out the experiment is the Real Time Digital Simulator (RTDS), which will be used to simulate power system in the real-time [6].

II. BACKGROUND

A. Experimental Set-up

B. Experimental Parameters For The Network

TABLE I: Systematic Parameters

Parameter	Value
Primary voltage of the Transformer	132 kV
Secondary voltage of the Transformer	11 kV
Fault level	6000 MVA
Load	15MW
Transformer Impedance	6%

III. EXPERIMENT APPROACH

In this section, the CT ratios will be determined using the current that is rated and applying the current multiplier a time multiplier to the relay settings. The experiment aims to monitor the functioning of the IDMT relays for different occurring faults, therefore the time taken to clear the fault will be the primary objective. This observation requires the study of current, due to relays not being familiar with the higher current available in transformer and the line the CT is therefore necessary to give usable current in the relays.

A. CT Ratios

It is necessary to calculate the rated current for the transformer, for both high ($V = 132kV$) and low ($V = 11kV$) voltage side first to allow determination of CT ratios. The rated current is obtained using equation 1 below.

$$I_{rated} = \frac{S}{\sqrt{3} \cdot V} \tag{1}$$

Where S denotes load rated at 15 MW and V symbolizes the nominal voltage. The rated current is therefore calculated as shown below for both respective sides.

1) For High Voltage Side (132kV):

$$I_{rated} = \frac{20MVA}{\sqrt{3} \cdot 132kV} = 87.48A \tag{2}$$

2) For Low Voltage Side (11kV):

$$I_{rated} = \frac{15MW}{\sqrt{3} \cdot 11kV} = 787.30A \tag{3}$$

The load rating was applied in the calculation of the rated current since the load is constant. It is covert the actual current using to ratios as aforementioned since the IDMT relays cannot maintain high current. Therefore the ratio of 200:1 is selected for the high voltage side and the ratio of 1000:1 for the low voltage side. The ratios where selected based on fact that the Current Multiplier equation contains a factor of 1.2 of which when the obtained High voltage current product with this constant gives a current equal to 104.976A which makes the selected ratio suitable, also for the Low voltage current product with the constant will give the current of 944.74A which also shows that the selected ratio is also suitable for safety factors.

IV. DETERMINING PARAMETERS OF THE IDMT RELAY SETTINGS

A. Current Multiplier

The IDMT relays require knowledge of the Current Multiplier (CM). Equation 4 below is used to perform the calculations.

$$CM = \frac{1.2 \cdot I}{CT} \tag{4}$$

Where I characterizes the rated current, CT symbolizes the current transformer ratio and the constant is used to permit the short-run equipment overloading. The current multipliers for the two available relays are therefore calculated as shown below.

1) Upstream Relay:

$$CM = \frac{1.2 \times 87.48}{200} = 0.52 \tag{5}$$

2) Downstream Relay:

$$CM = \frac{1.2 \times 787.30}{1000} = 0.94 \tag{6}$$

B. Time Multiplier

Another knowledge required by the IDMT relays is the Time Multiplier. The calculation of the Time Multiplier requires the calculation of the fault first which is determined using the impedances available in the set-up. The solution will proceed by determining the per unit model of the network as shown by equation 7 below.

$$per \quad unit(p.u) = \frac{actual}{base} \tag{7}$$

The fault level is given to 6000 MVA and the base apparent power (S_{base}) is given to be 20 MVA, the per unit is therefore obtained as shown below.

$$Z_{pu} = \frac{20MVA}{6000MVA} = 3.33 \times 10^{-3} \quad pu \tag{8}$$

It is therefore necessary to calculate the base impedances (Z_{base}) of the Low and High voltage sides of the transformer of which their calculation is performed using equation 9 below.

$$Z_{base} = \frac{V^2}{S_{base}} \tag{9}$$

Therefore the base impedances for both High and Low voltage sides are calculated as follows

1) High Voltage side:

$$Z_{base} = \frac{(132kV)^2}{20MVA} = 871.3\Omega \tag{10}$$

2) Low Voltage side:

$$Z_{base} = \frac{(11kV)^2}{20MVA} = 6.05\Omega \tag{11}$$

It is therefore possible to calculate the base current using equation 1 by replacing the rated current with the required base current symbol. The calculations for the base currents are therefore performed as shown below

3) High Voltage side:

$$I_{base} = \frac{20MVA}{\sqrt{3} \cdot 132kV} = 87.48A \tag{12}$$

4) Low Voltage side:

$$I_{base} = \frac{15MW}{\sqrt{3} \cdot 11kV} = 783.30A \tag{13}$$

With the above calculations, it is therefore possible to calculate the actual impedance of the source when the fault level reaches 6000 MVA using equation 7 above.

$$Z_{actual} = 3.33 \times 10^{-3} \times 871.3 = 2.90\Omega \tag{14}$$

It is now possible to calculate the fault current using the base current (I_{base}) and the per-unit current (I_{pu}). The per unit current is therefore calculated using equation 15 below.

$$I_{pu} = \frac{1}{Z_{pu}} \tag{15}$$

Where Z_pu characterizes the sum of the source per unit impedance as well as the transformer per unit impedance. The per unit current is calculated to be 15.79 p.u. The fault currents for the Low and High voltage sides are calculated as shown below.

5) High Voltage side:

$$I_{actual} = 15.79 \times 87.48 = 1381.31A \tag{16}$$

6) Low Voltage side:

$$I_{actual} = 15.79 \times 783.30 = 12368.31A \tag{17}$$

Therefore, the per-unit currents for both the up and down-stream relays can be determined using equation 18 below.

$$I_{pu} = \frac{I_{fault}}{CM \cdot I_n \cdot CT_{ratio}} \tag{18}$$

Where I_{fault} characterizes the actual fault current and I_n is symbolizes the nominal current imposed to the relay. The calculations are carried as shown below.

7) Up-stream:

$$I_{pu} = \frac{1381.31}{0.52 \times 1 \times 200} = 13.28 \quad pu \tag{19}$$

8) Down-stream:

$$I_{pu} = \frac{12368.31}{0.94 \times 1 \times 1000} = 13.16 \quad pu \tag{20}$$

Finally, the per-unit currents for both relays can be applied to normal inverse curves of the IDMT relay to determine the Time Multiplier. Using the graphs, the Time Multiplier were measured as follows:

$$TM_{up-stream} = 0.180 \tag{21}$$

$$TM_{down-stream} = 0.075 \tag{22}$$

C. Operating Time

The operating time is the time taken by the relay to respond to the fault. From the determined and calculated data, it is now possible to calculate the operating times for both the down-stream and up-stream relays. The operating times is calculated using equation 23 below, where TO is the operating time.

$$TO = \frac{0.14}{\left[\frac{I_{Fault}}{CM \times I_n \times CT_{ratio}}\right]^{0.02} - 1} \times TM \tag{23}$$

1) Down-stream:

$$TO = \frac{0.14}{\left[\frac{12368.31}{0.94 \times 1 \times 1000}\right]^{0.02} - 1} \times 0.075 = 0.1985 = 0.2 \tag{24}$$

2) Up-stream:

$$TO = \frac{0.14}{\left[\frac{1381.31}{0.52 \times 1 \times 200}\right]^{0.02} - 1} \times 0.180 = 0.4747 = 0.5 \tag{25}$$

Table 2 below provides a summary of the obtained results for both the Current and Time Multiplier.

TABLE II: Time and Current Multiplier Results For Low and High Voltage sides

Parameter	Up-stream	Down-stream
Rate current (I_{rated})	87.48 A	787.30
CT Ratio	200:1	1000:1
Current Multiplier	0.52	0.94
Time Multiplier	0.180	0.075

V. RESULTS AND ANALYSIS

The results below showcases the response of the down-stream and up-stream relays for different fault conditions.

A. Three-Phase Fault Down-stream Counteraction

Figure 2 in Appendix showcases the current vs time waveform for the three-phase fault. It is observed that the system operates normally for 0.1 seconds with peak current close to 0.1kA. The fault is therefore introduced to the system afterwards whereby it is observed that the fault is being cleared by the downstream relay at 0.31 seconds which gives the response time of 0.21 seconds from the time the fault was introduced at 0.1 seconds. The response time is equivalent to expected response time from the calculations. A conclusion can therefore be drawn from the obtained results that the parameters were well calculated as the relays operated as required. It should further be observed that both relays recognized the fault but the up-stream relay was not responsible for clearing that fault as it was already counteracted by the downstream relay.

B. Three-Phase Fault Up-stream Counteraction

The down-stream relay was disconnected to observe what happens when the up-stream relay is not responding (in case it fails). The results obtained shows that the upstream relay clears the fault at 0.6 seconds as shown in Figure 3 in the Appendix. Since it also observed that the fault was introduced at 0.1 seconds, this gives the response time 0.5 seconds which is equivalent to the calculated to the expected operating time.

C. Two-Phase Fault Down-stream Counteraction

Figure 4 in the Appendix showcases the obtained simulated results with fault also induced at 0.1 seconds. The relays at this stage also operate as expected as it is observed that the faults are counteracted by the down-stream relay within 0.2 seconds as expected.

D. Phase-Ground Fault

Figure 5 in the Appendix showcases the results for the phase to ground fault. It is observed that the fault is not cleared. This is due to setting the relays to encounter two and three phase faults while the ground to phase faults are not included.

VI. CONCLUSIONS

The IDMT relay's functionality experiment for both the upstream and downstream have been introduced. The experimental setup was highlighted and the current transformer was employed to step down the high current of the line on both the high and low voltage side to meet the requirements of the IDMT relays. The ratios for the current transformer were calculated to be 200:1 and 1000:1 for both the high voltage and low voltage side respectively. Parameters to be set on the relays were successfully calculated and applied. Using the RSCAD and RTDS it was observed that the faults were cleared as expected for both down-stream and up-stream as found to be 0.5 and 0.2 respectively. It was further observed that the relay failed to recognize the phase-ground fault since it was not catered.

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APPENDIX

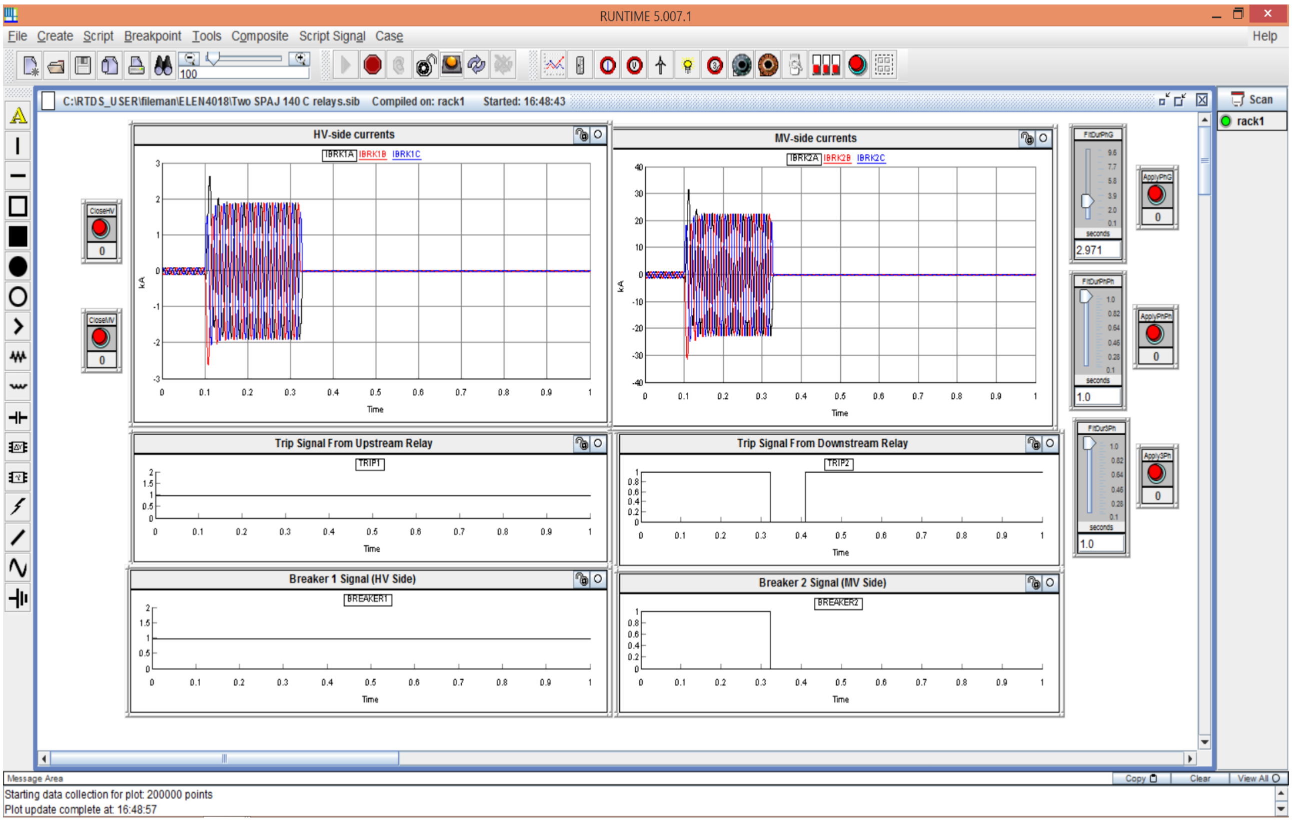

Figure 1: Three-Phase Fault Down-stream Counteraction

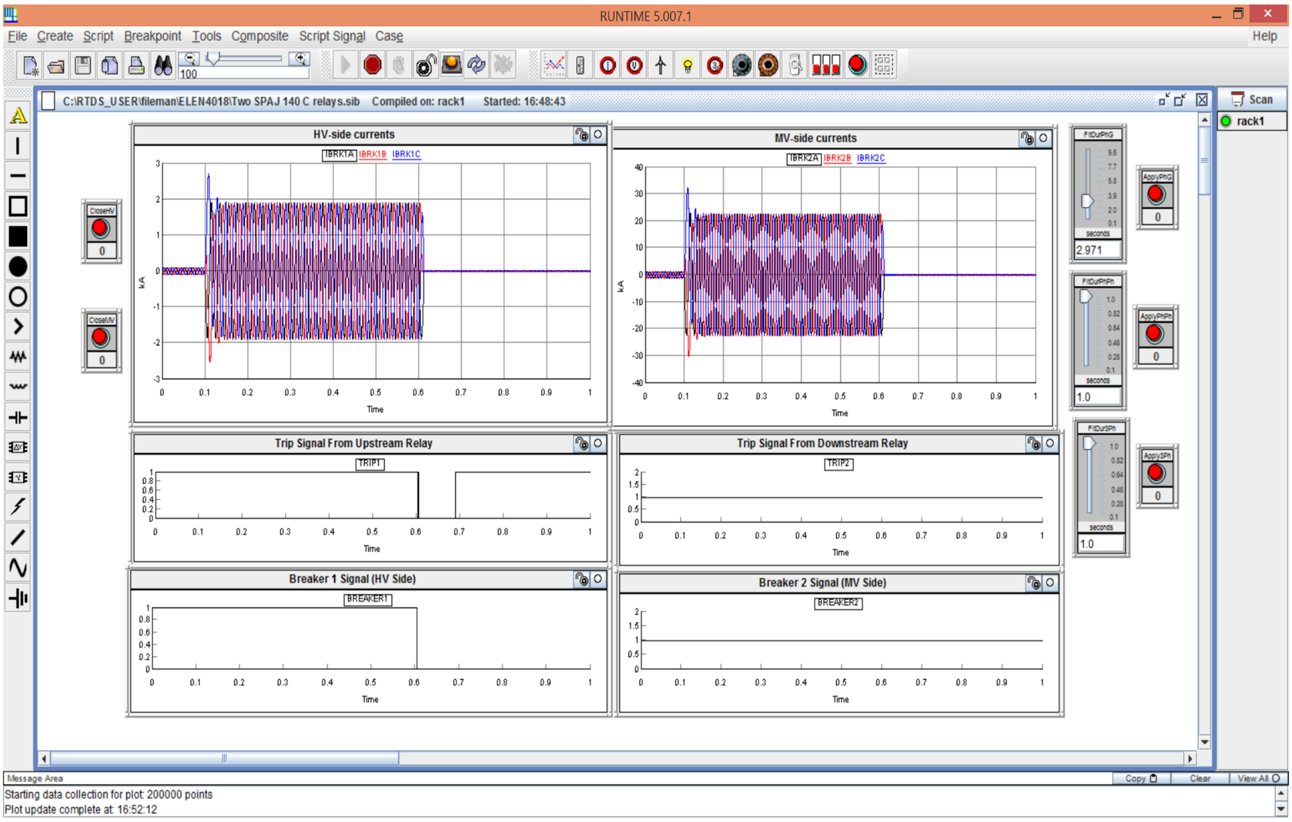

Figure 2: Two-Phase Fault Up-stream Counteraction

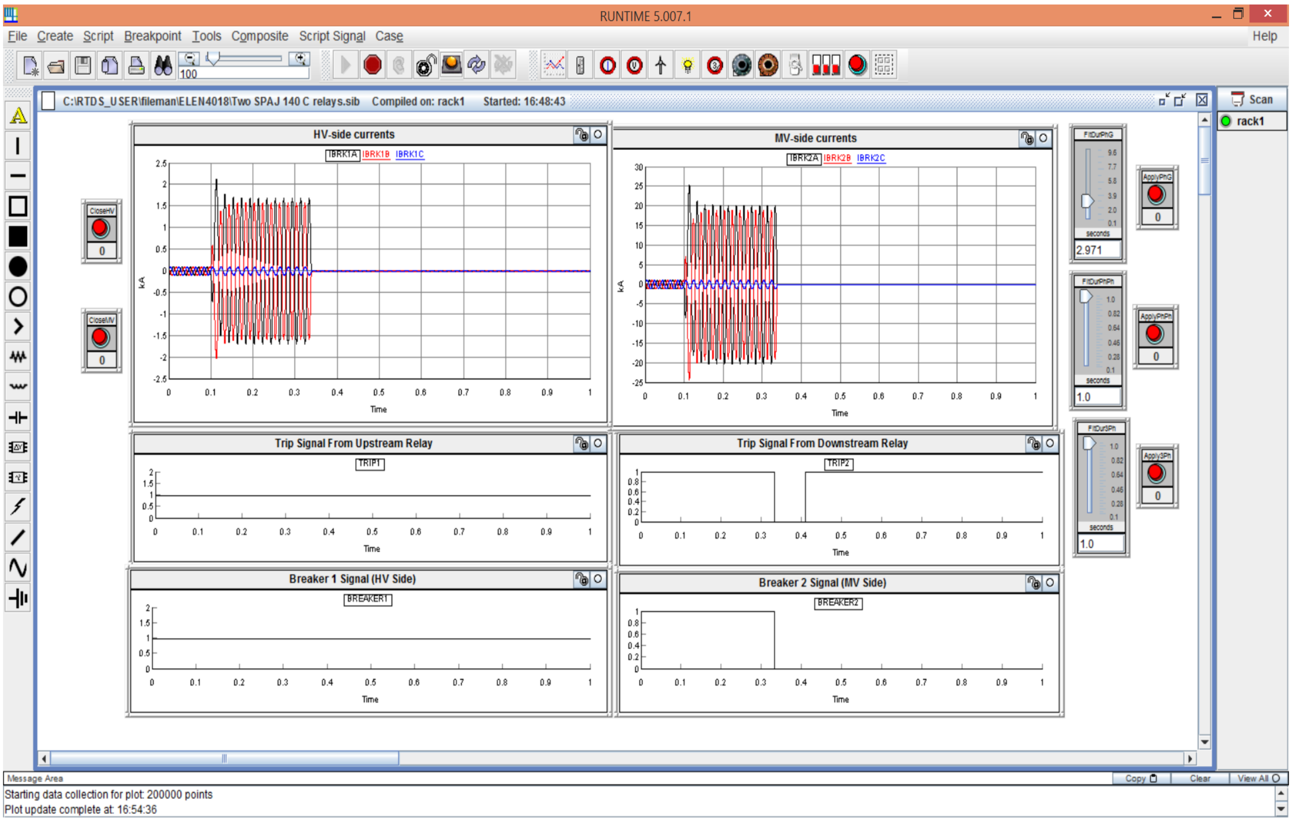

Figure 3: Two-Phase Fault Down-stream Counteraction

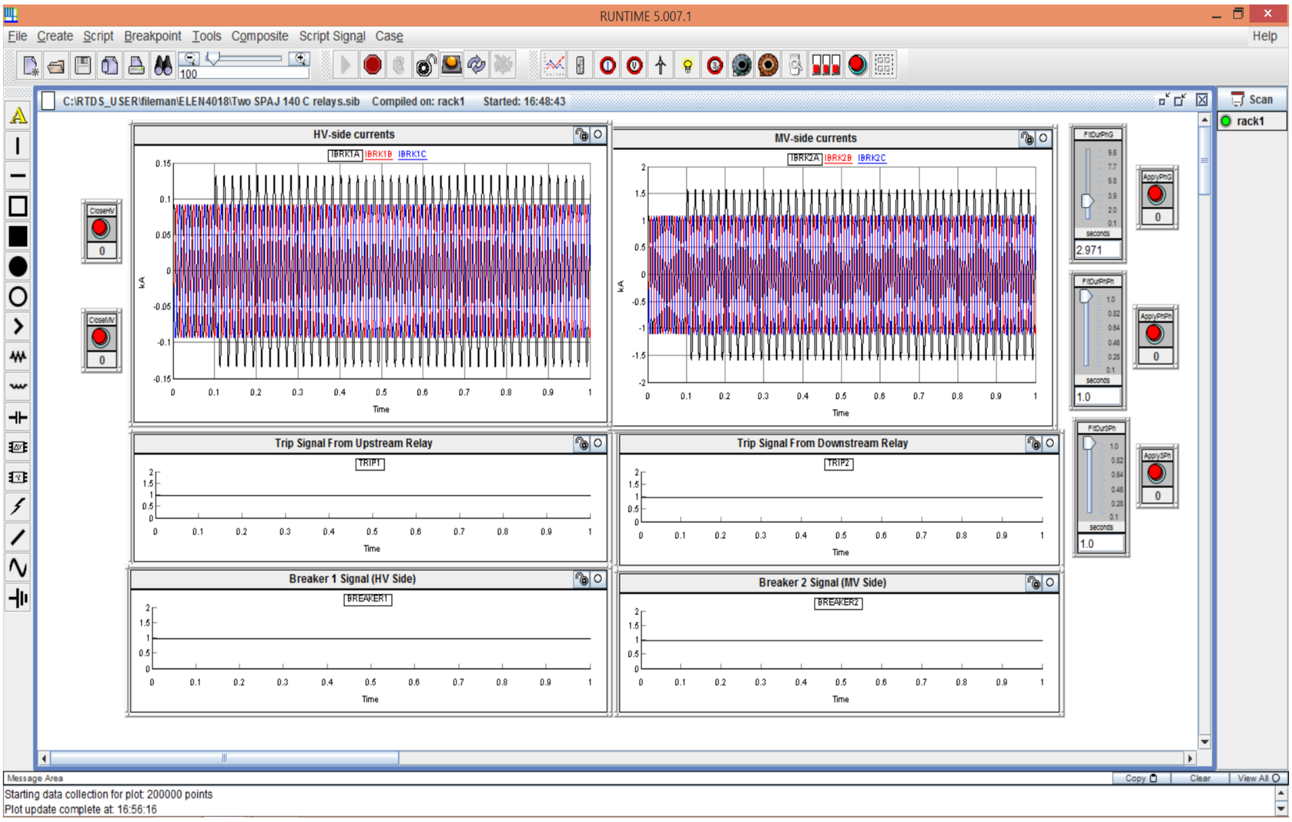

Figure 4: Phase-Ground Fault