CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, MATLAB Simulink software is used for simulating two algorithms: Siemens and General Electric. These simulations try to verify that the algorithms are secure in different conditions. The case study for both algorithms is the same. These simulations are flexible for any system network.

4.2 Simulation

MATLAB software is contained from two parts, MATLAB programming which is a writing program for computing and the other part is MATLAB Simulink which visualizes the boxes containing any computations. It is a graphical program that models a system by several block diagrams. “Simulink can work with linear, nonlinear, continuous time, discrete time, multirate, and hybrid systems” [30] [31].

Figure 4.1 shows the system case study. This system contains of Yny transformer and a resistive load which is grounded. It shows the connection of residual CTs and star point CT.

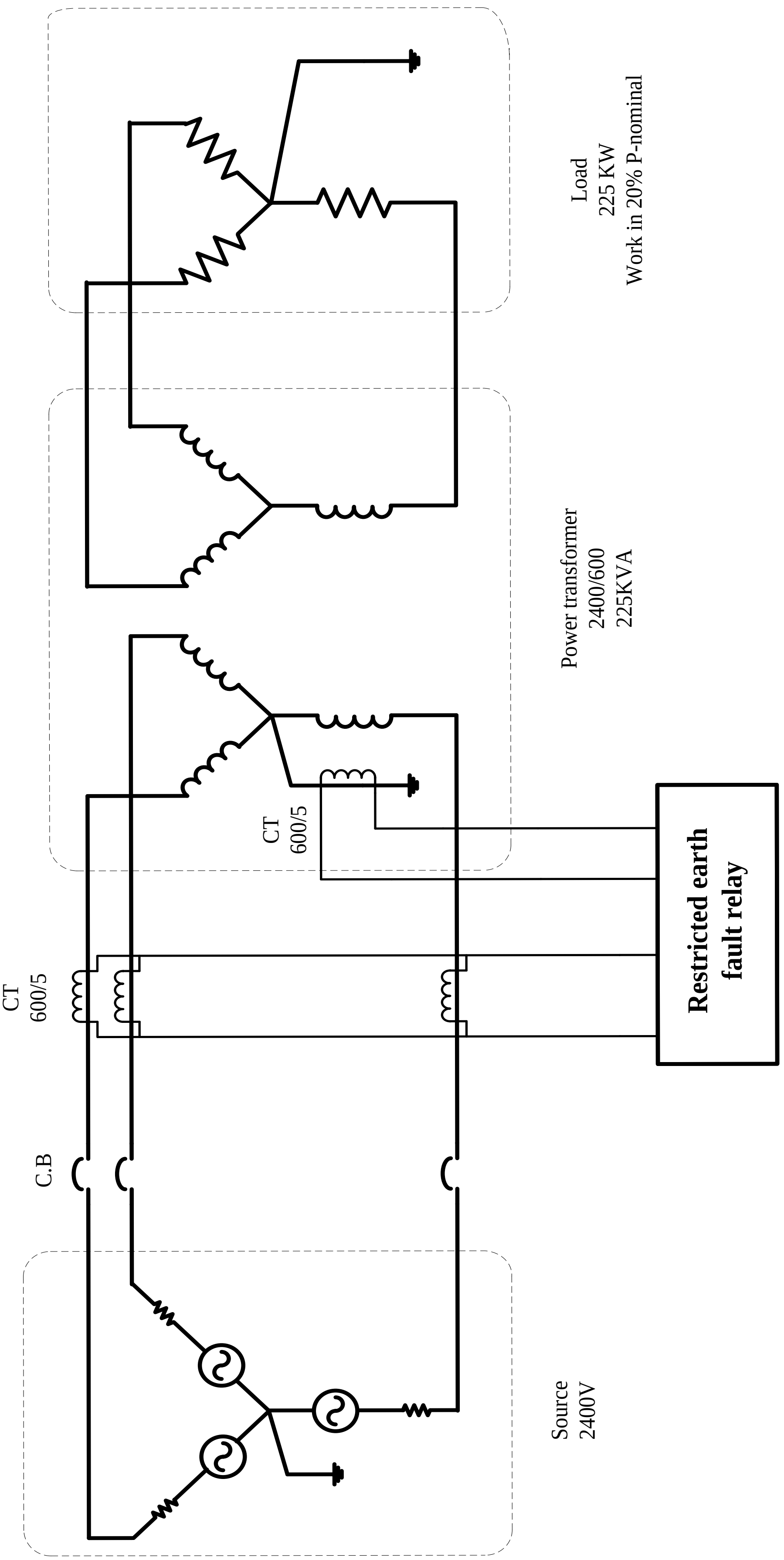


Figure 4.1: Case study [31].

In the following figures, the parameters of each equipment that is used in the case study is defined. Source has only resistant and inductance of source is neglected. The source, circuit breaker (C.B), transformer, load parameters are shown in figures 4.2, 4.3, 4.4 and 4.5.

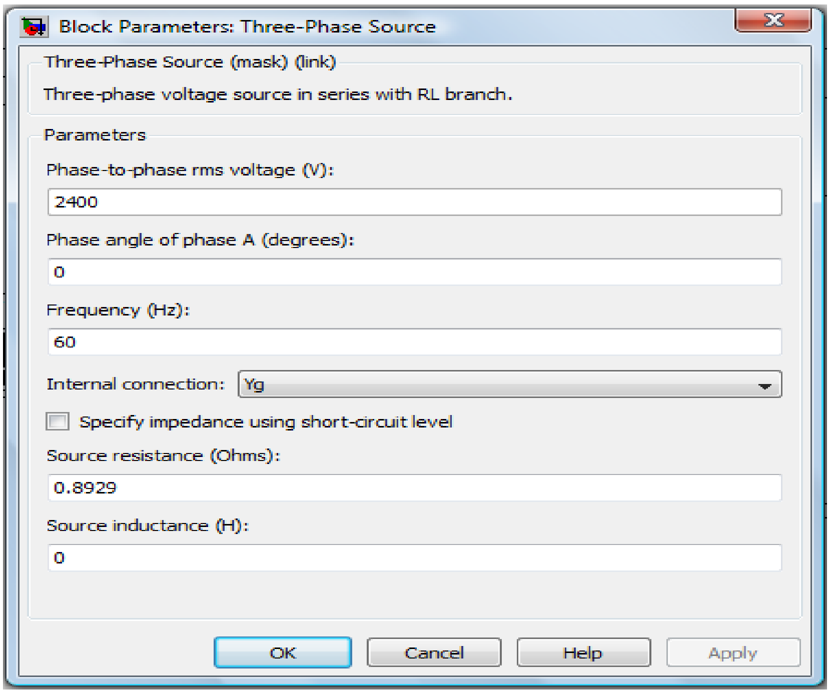


Figure 4.2: Source parameters.

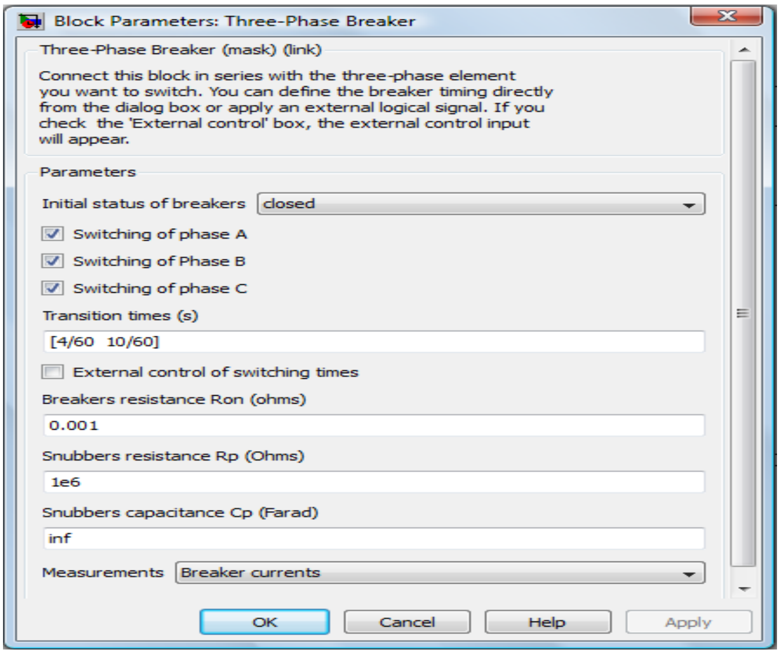


Figure 4.3: Circuit breaker parameters.

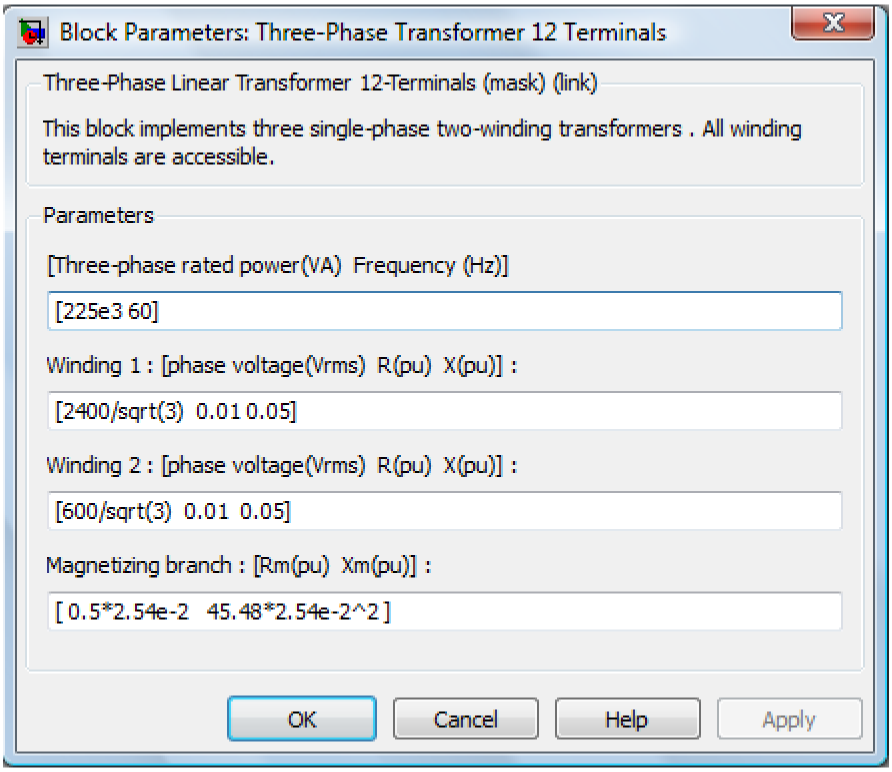


Figure 4.4: Transformer parameters.

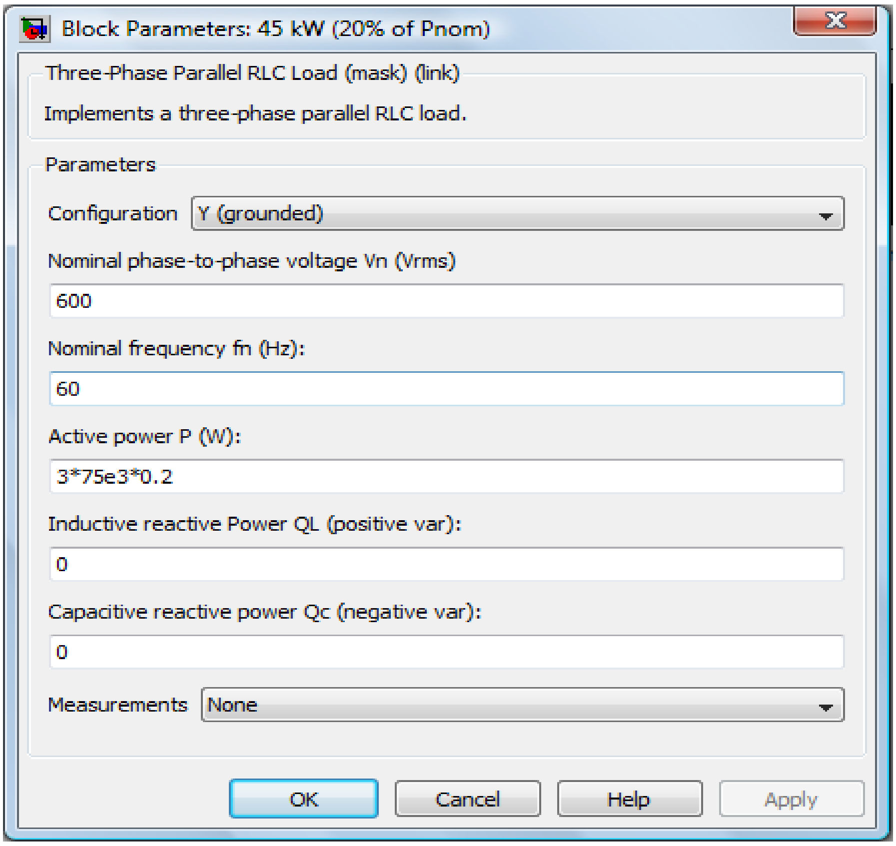


Figure 4.5: Load parameters.

4.3 Siemens algorithm

Siemens simulation is shown in figures 4.6 and 4.7. Figure 4.6 shows the connection for the simulation of this relay in the network. Figure 4.7 shows the simulation of Siemens algorithm. The restraint current, tripping effective current, short circuit currents are shown.

In the simulation three conditions which contain single line to ground fault occurs inside of the protection zone, single line to ground fault outside the protection zone and normal condition without fault are investigated. The behavior of the relay operation, restraint current and star point current which is the tripping effect are assessed. The relay operates digitally which contains two levels. One means the relay operates and zero means the relay does not operate. In this simulation for showing better, usage of tripping relays, auxiliary relays, lock out relays and connection to the tripping coil of circuit breakers are neglected.

4.3.1 Normal condition

Figure 4.6 shows the relay in normal condition with no faults happening. As it is mentioned, figure 4.7 shows the Siemens restricted earth fault algorithm. This simulation is based on the equation 2.27. It is assumed that the slope is 1 and k=1. Figure 4.8 shows the three phase current at normal condition. Also, figure 4.9 shows the star point current. As it illustrates, the star point current is equal to zero and it means that there is no current in the star point branch because there is not any fault with ground connection. Figure 4.10 shows the restraint current instead of effective tripping current or I_{REF} (equation 2.26). The above figure shows the restraint current as it mentioned in chapter 2, if this current is more than effective tripping current, relay should not operate. In this figure because there is not fault current in star point, thus the effective and restraint current are almost zero. Figure 4.11 shows the relay operation.

This figure shows the relay operation is always zero and it means relay does not operate at normal condition.

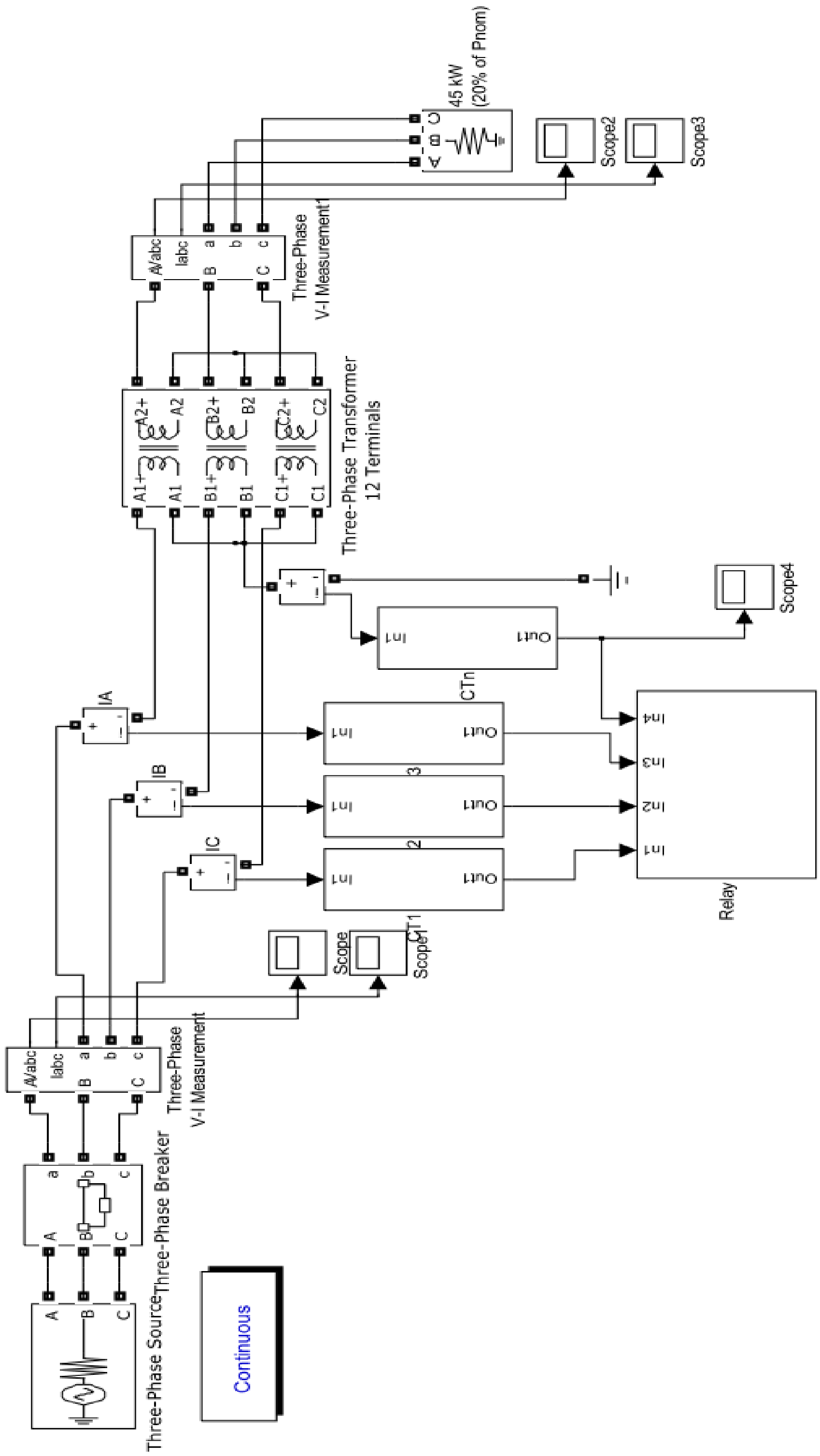


Figure 4.6: Siemens relay connected to the network.

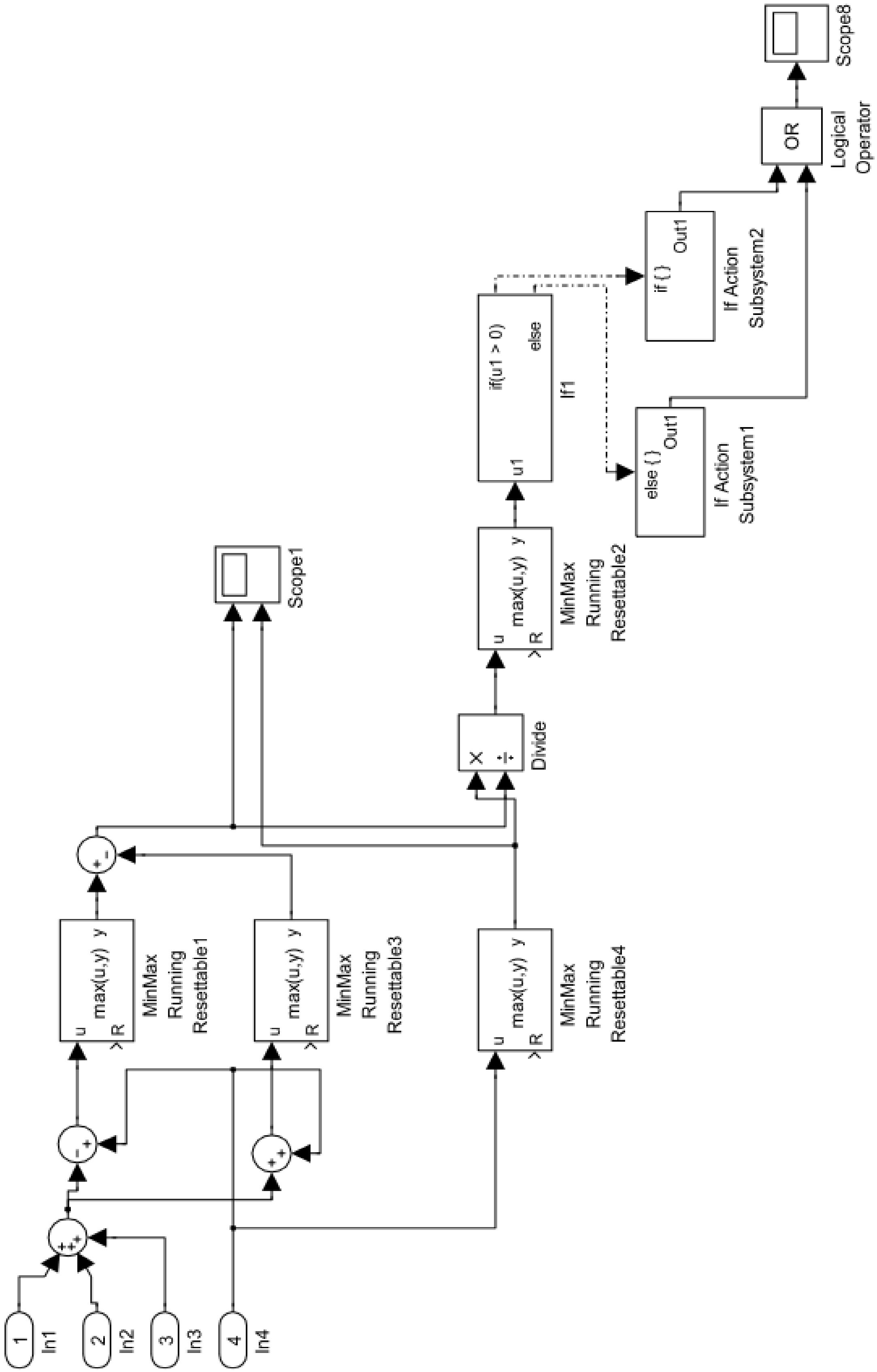


Figure 4.7: Siemens REF algorithm simulation.

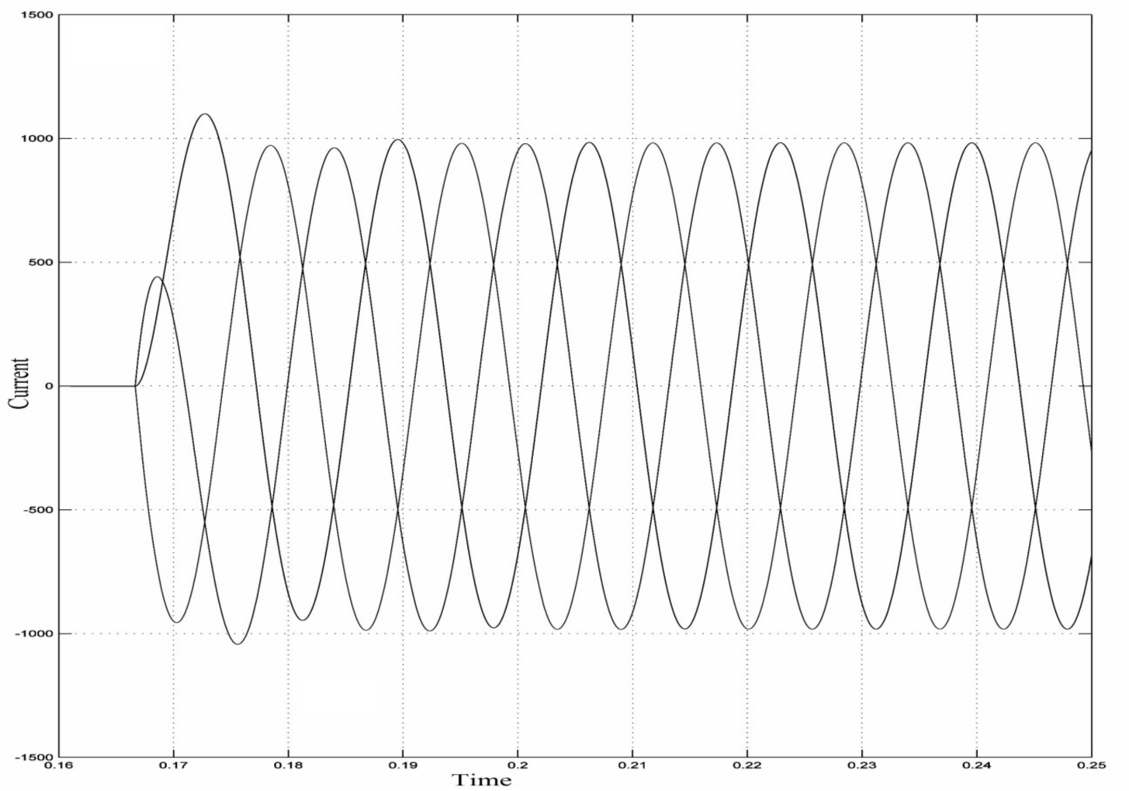


Figure 4.8: Three phase current at normal condition in Siemens algorithm.

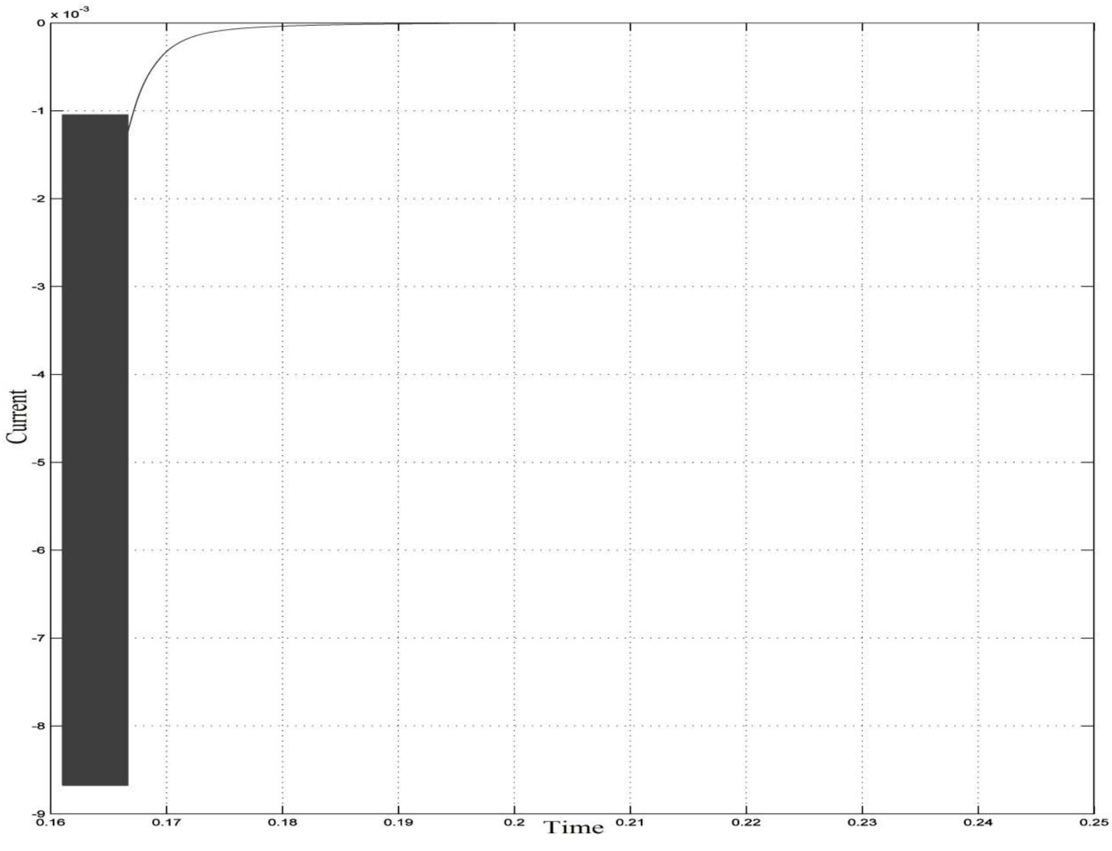


Figure 4.9: Star point current at normal condition in Siemens algorithm.

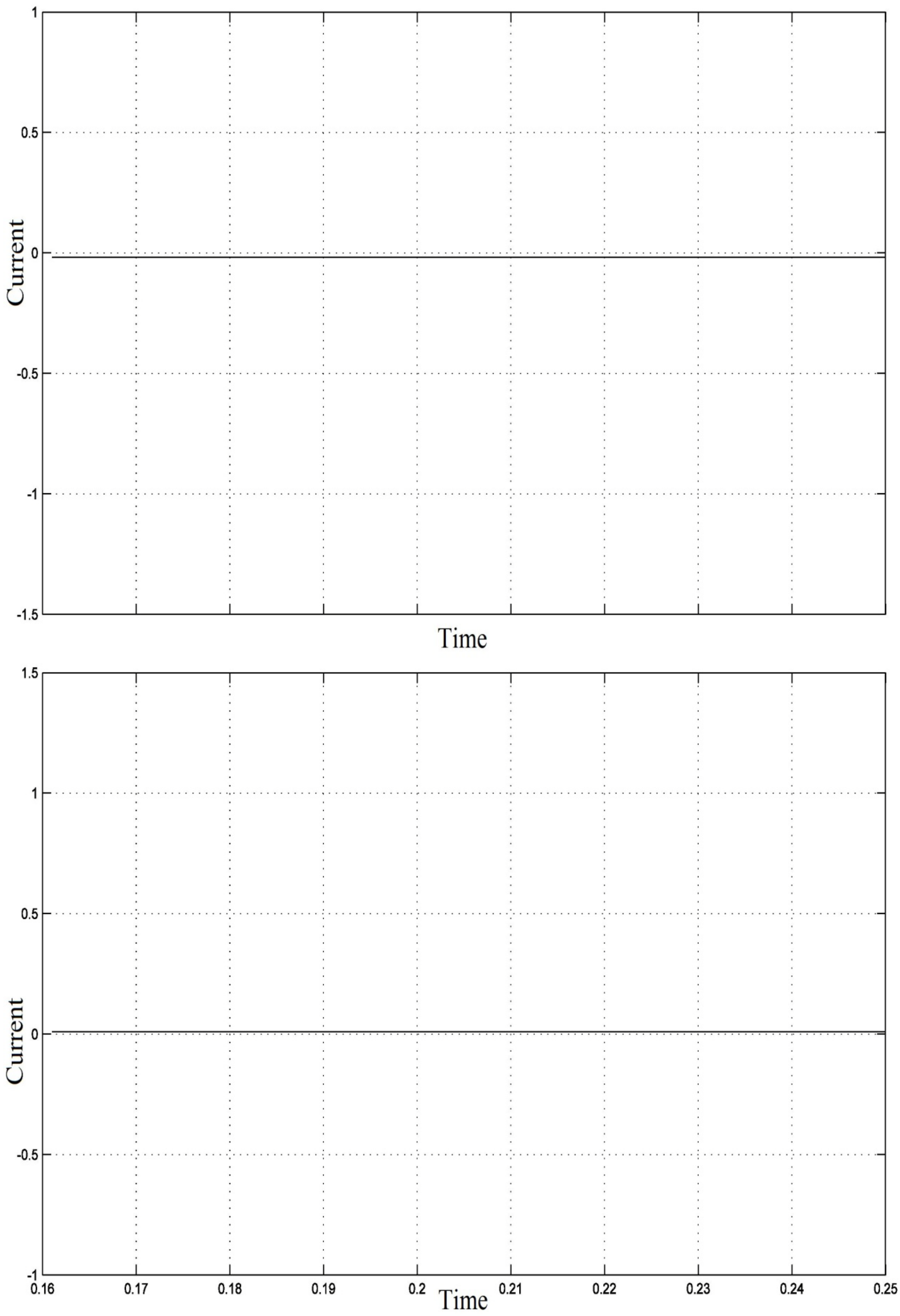


Figure 4.10: Restraint (above) and tripping (below) current at normal condition in Siemens algorithm.

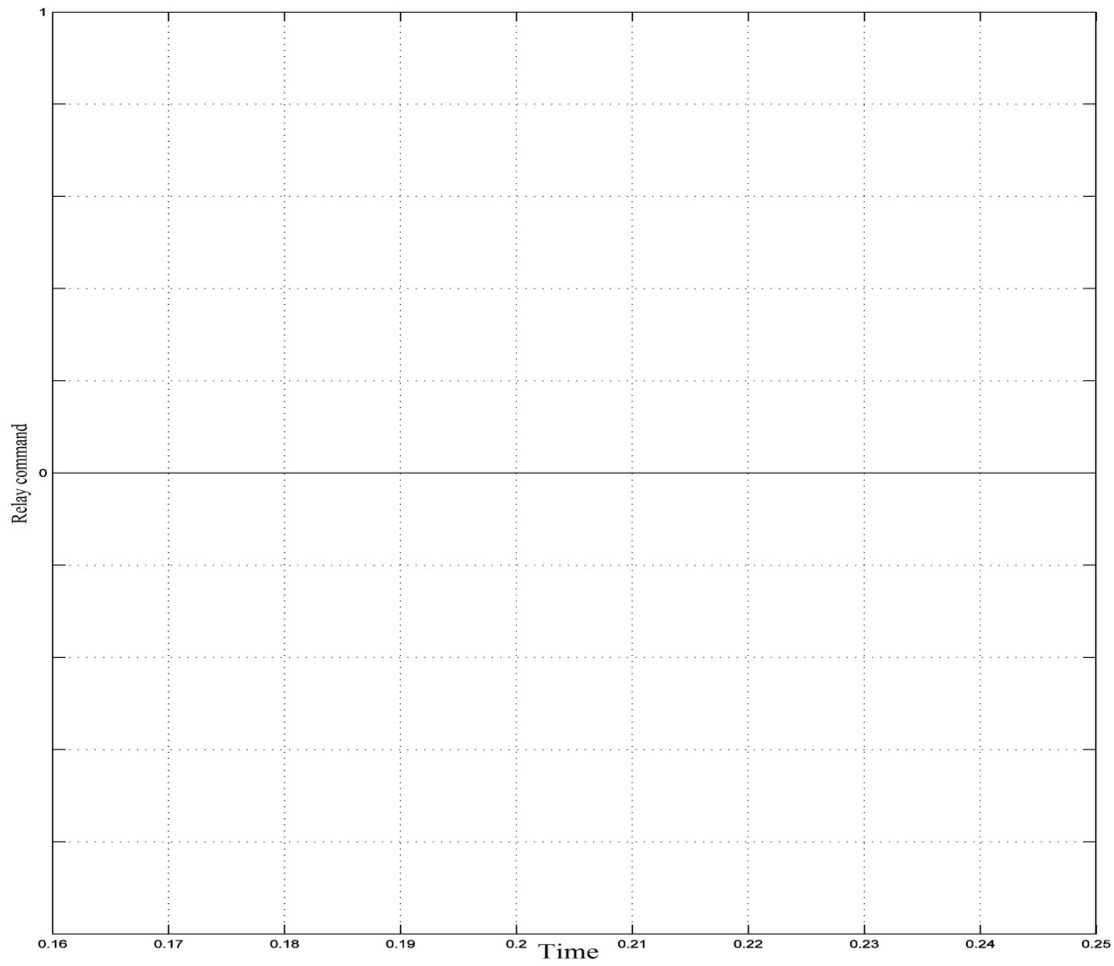


Figure 4.11: Relay operation command at normal condition in Siemens algorithm.

4.3.2 Out of zone fault

In this section, ground fault outside protection zone is investigated. Figure 4.12 shows the network connection for outside single line to ground fault. Figure 4.13 shows the three phases current. Figure 4.14 shows the star point current outside single line to ground fault. Figure 4.15 shows the fault current outside single line to ground fault. Figure 4.16 shows the relay operation. It illustrates that the external earth fault relay does not operate. Figure 4.17 shows the absolute value of restraint current instead of tripping effective current. In this section also the restraint current at above part of figure 4.17 is more than effective tripping current at below part of this figure. Thus, the relay does not operate.

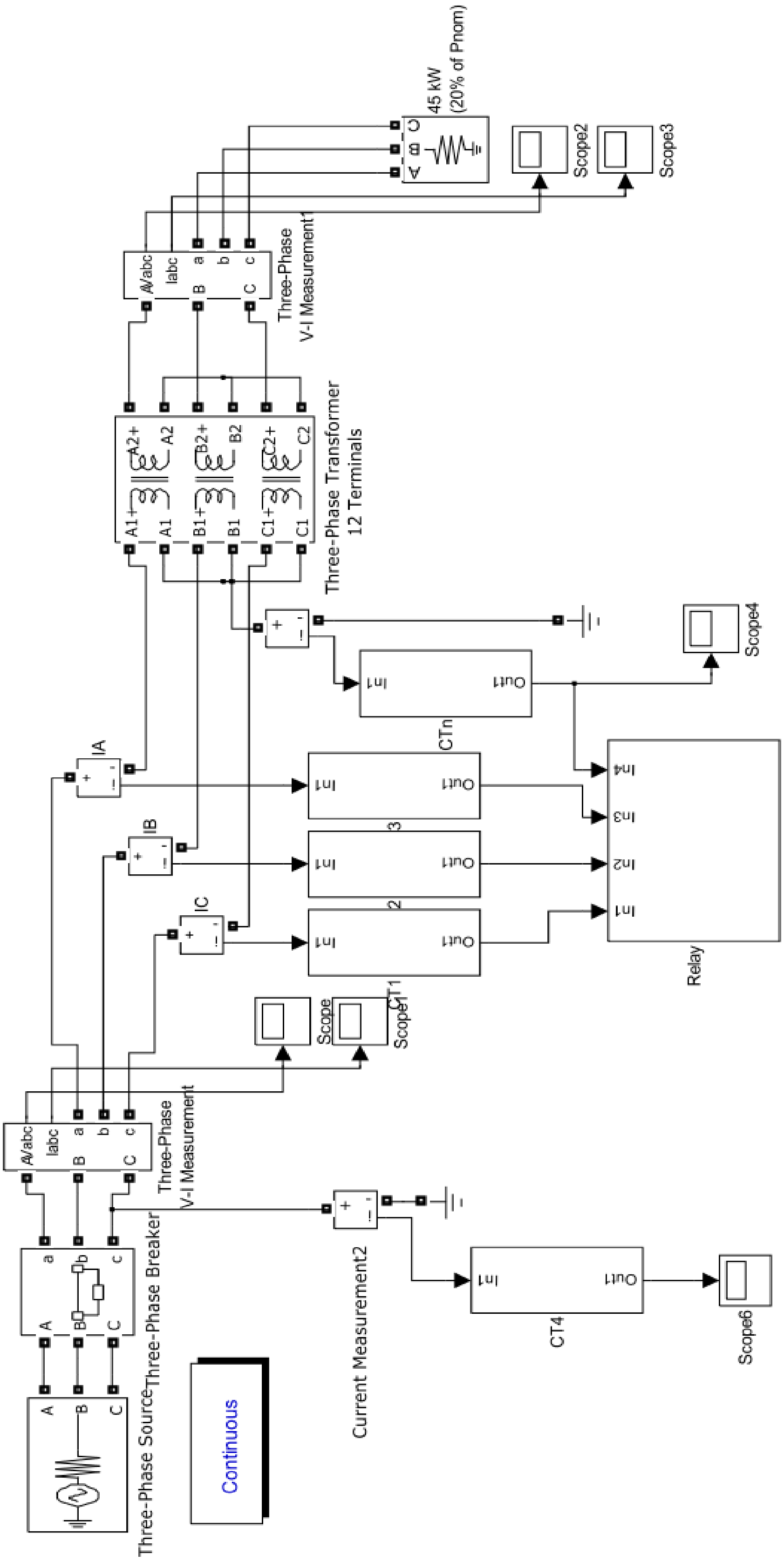


Figure 4.12: Out of zone fault in Siemens relay.

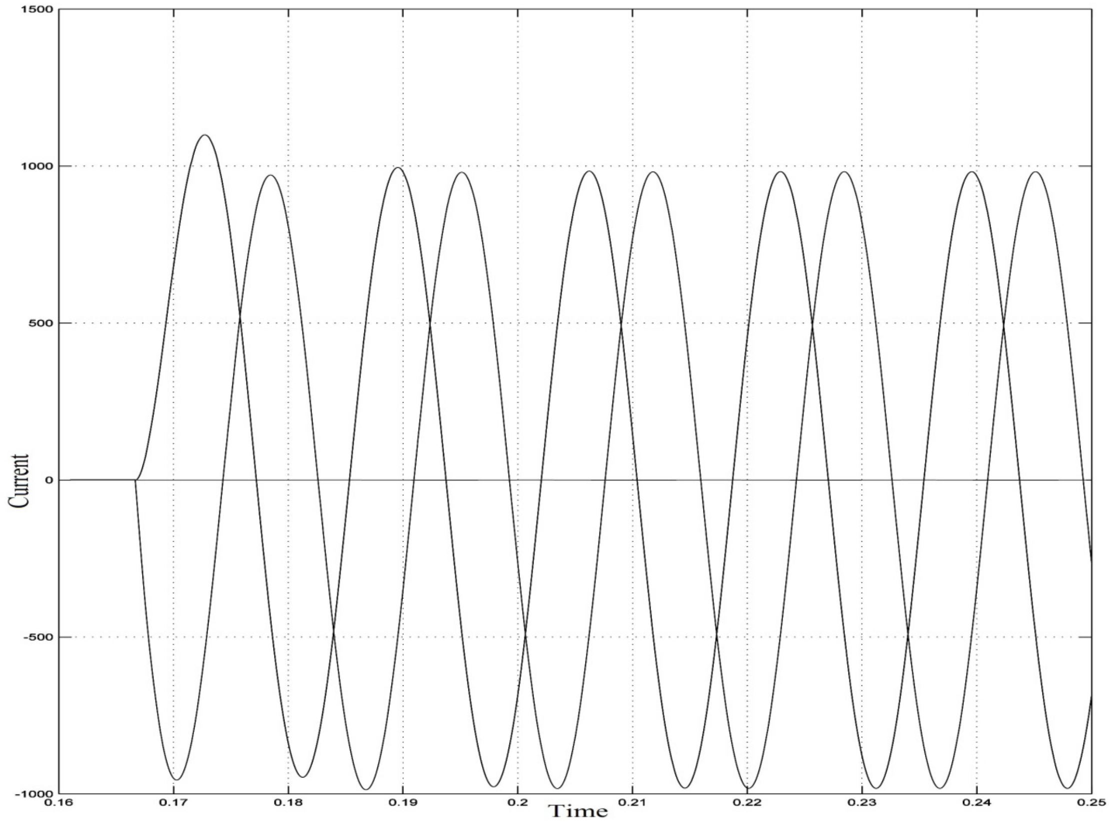


Figure 4.13: Three phase current at out of zone fault in Siemens algorithm.

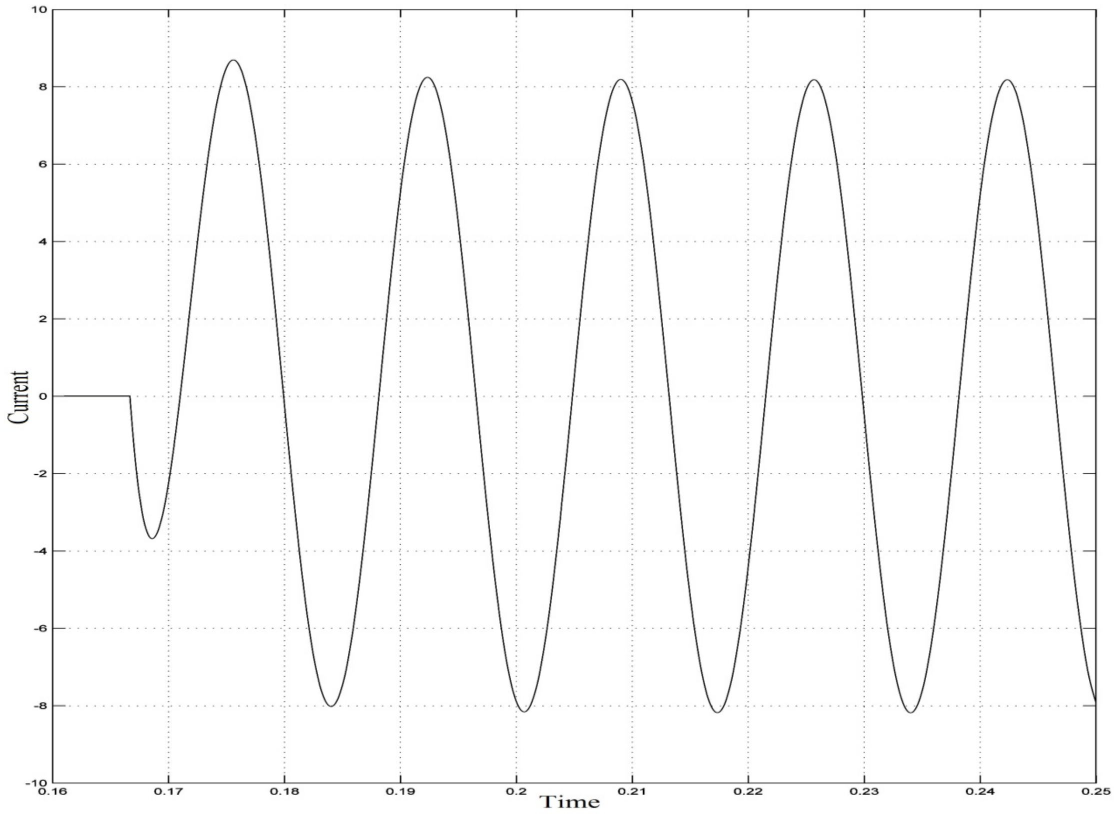


Figure 4.14: Star point current at out of zone fault in Siemens algorithm.

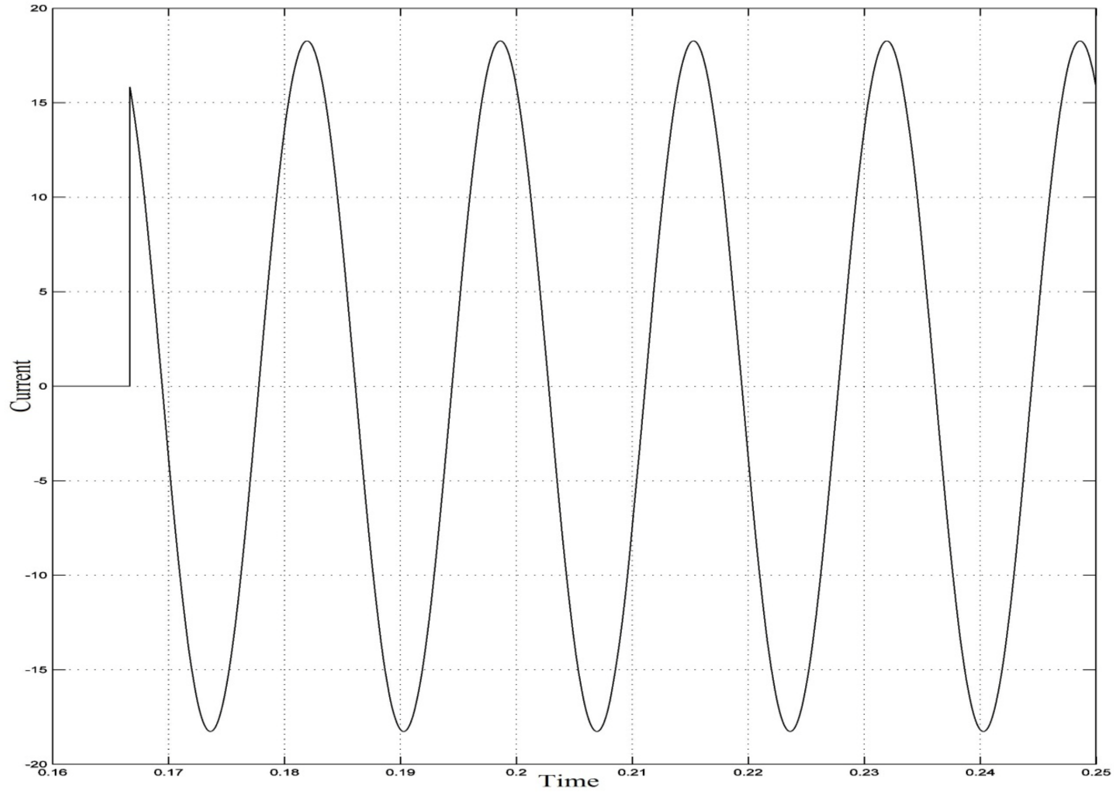


Figure 4.15: Fault current at out of zone fault in Siemens algorithm.

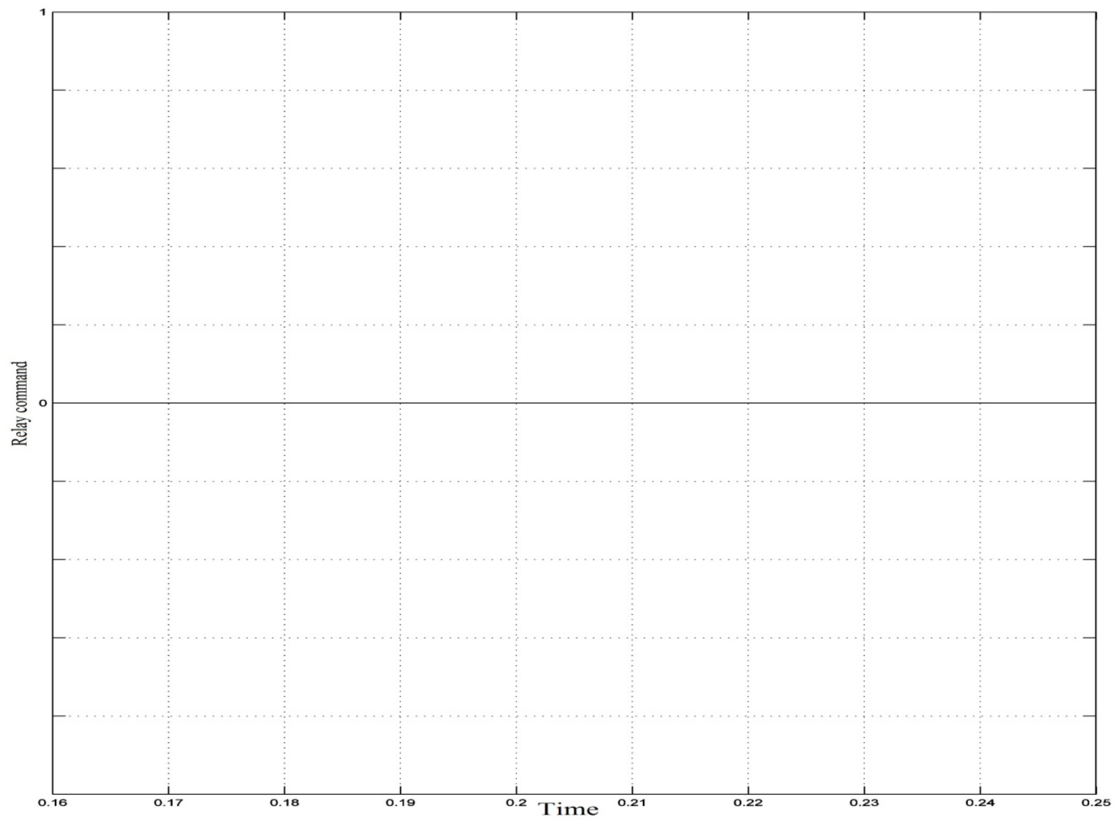


Figure 4.16: Relay operation command at out of zone fault in Siemens algorithm.

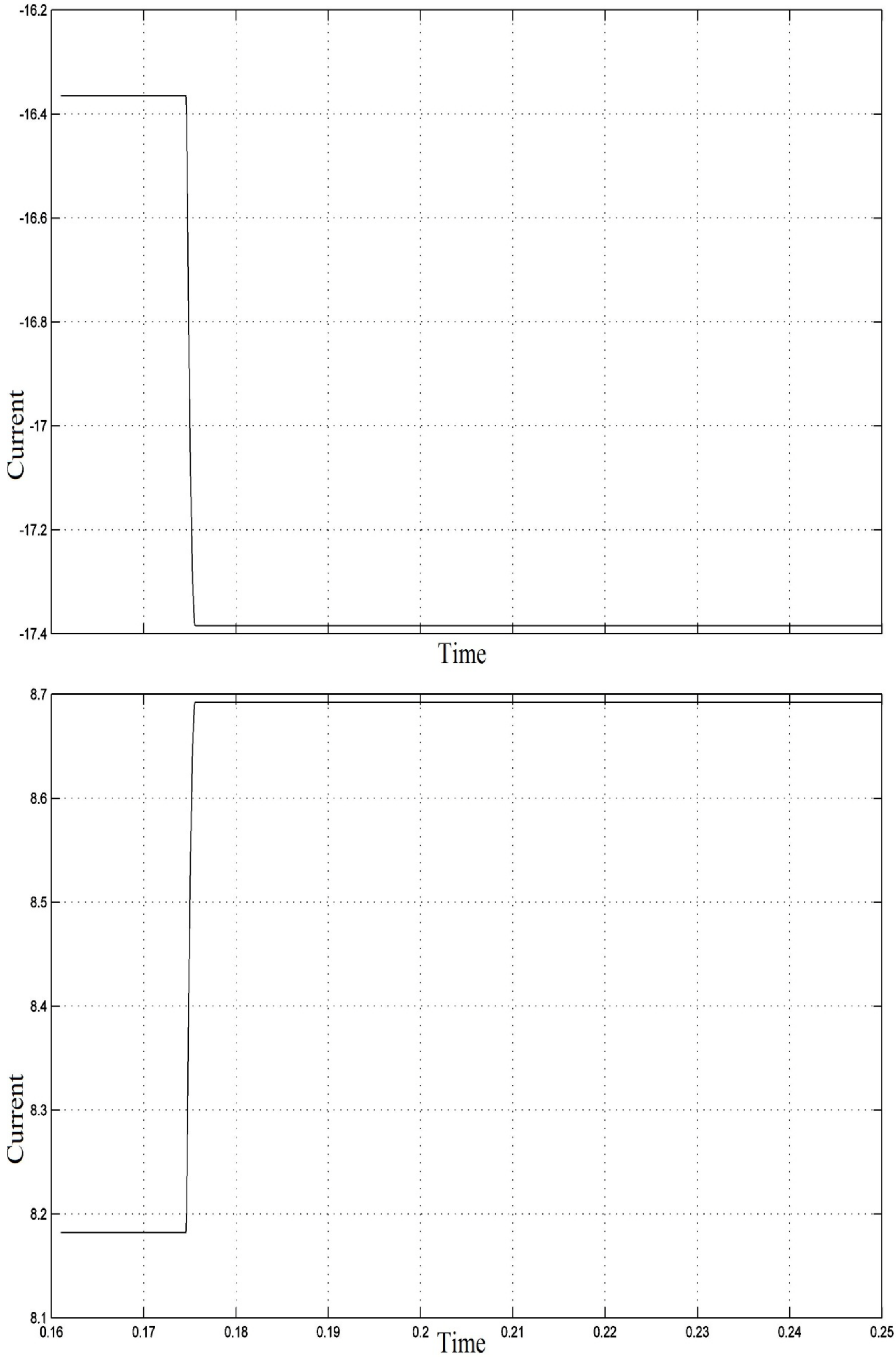


Figure 4.17: Restraint (above) and tripping (below) current at out of zone fault in Siemens algorithm.

4.3.3 In zone fault

Figure 4.19 shows fault occurs inside protection zone. Figure 4.18 shows the three phase currents when single line to ground fault occurs inside of the protection zone. Figure 4.20 shows the star point current. Also figures 4.21, 4.22 and 4.23 show the fault current, restraint and REF current (tripping current) and relay operation command respectively. Figure 4.22 illustrates the relay algorithm sending operation command to operate REF relay.

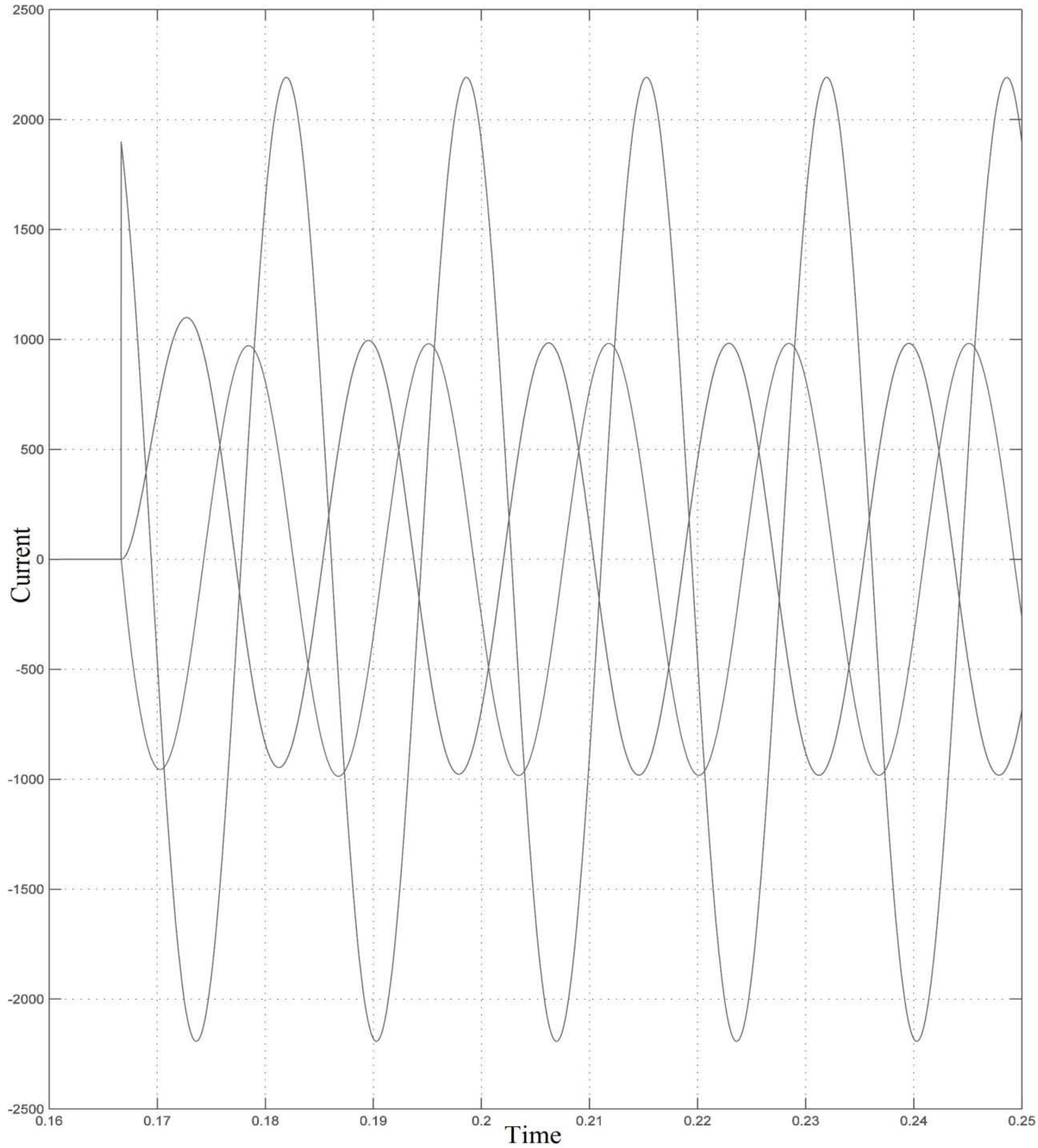


Figure 4.18: Three phase current at in zone fault in Siemens algorithm.

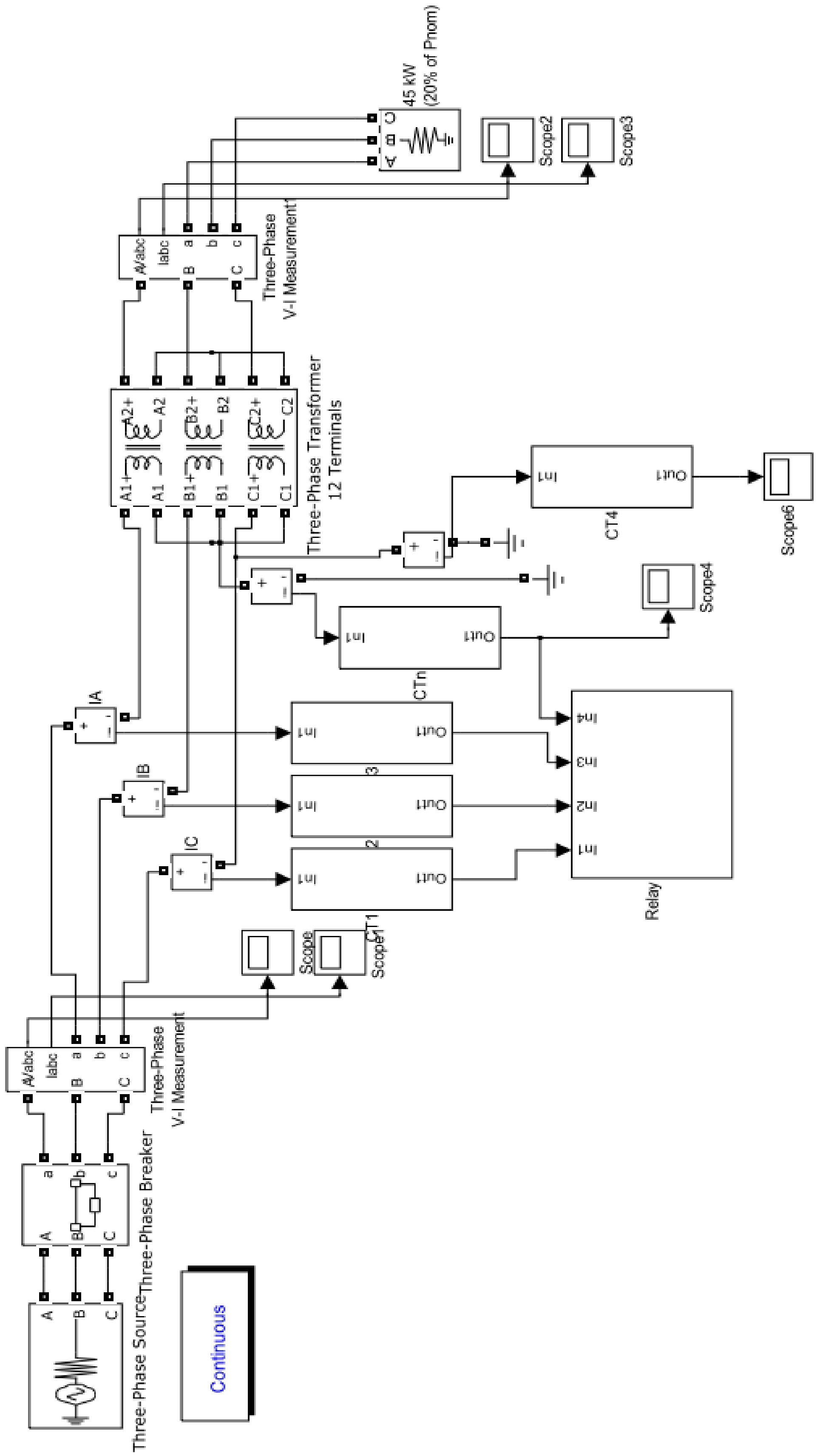


Figure 4.19: In zone fault in Siemens relay.

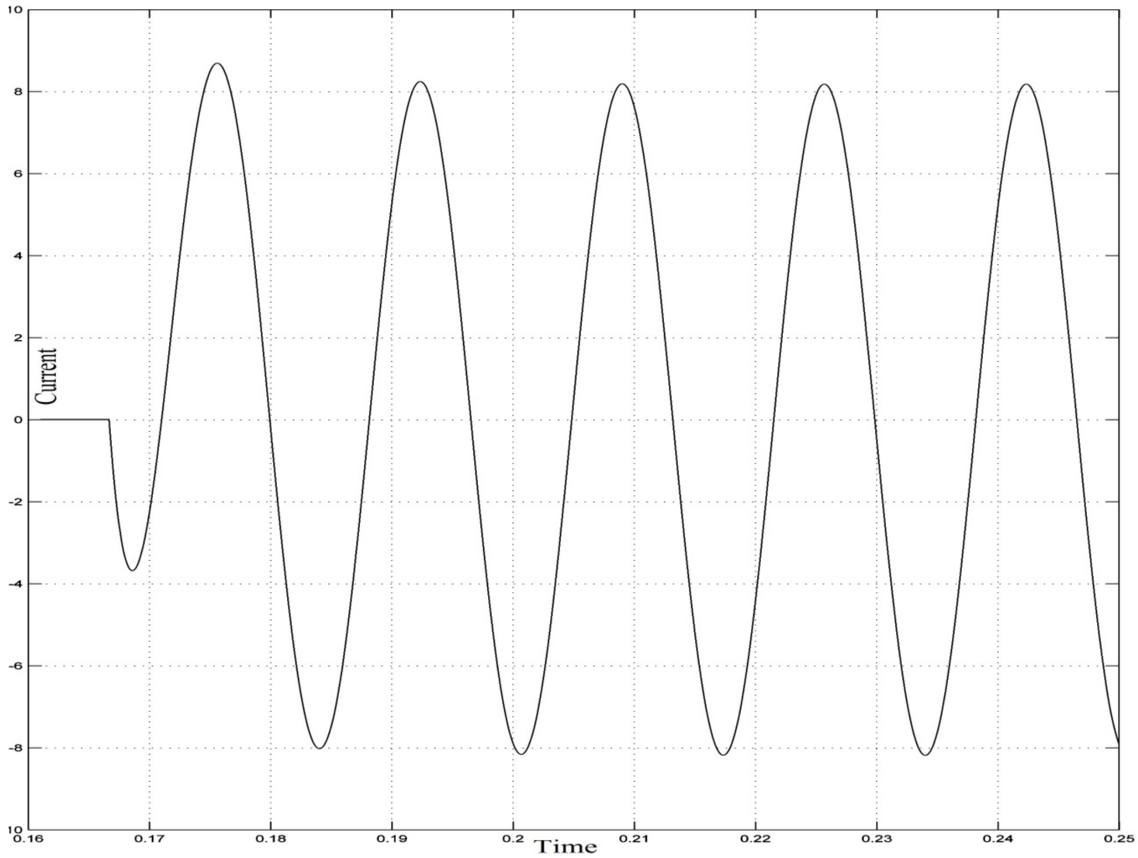


Figure 4.20: Star point current at in zone fault in Siemens algorithm.

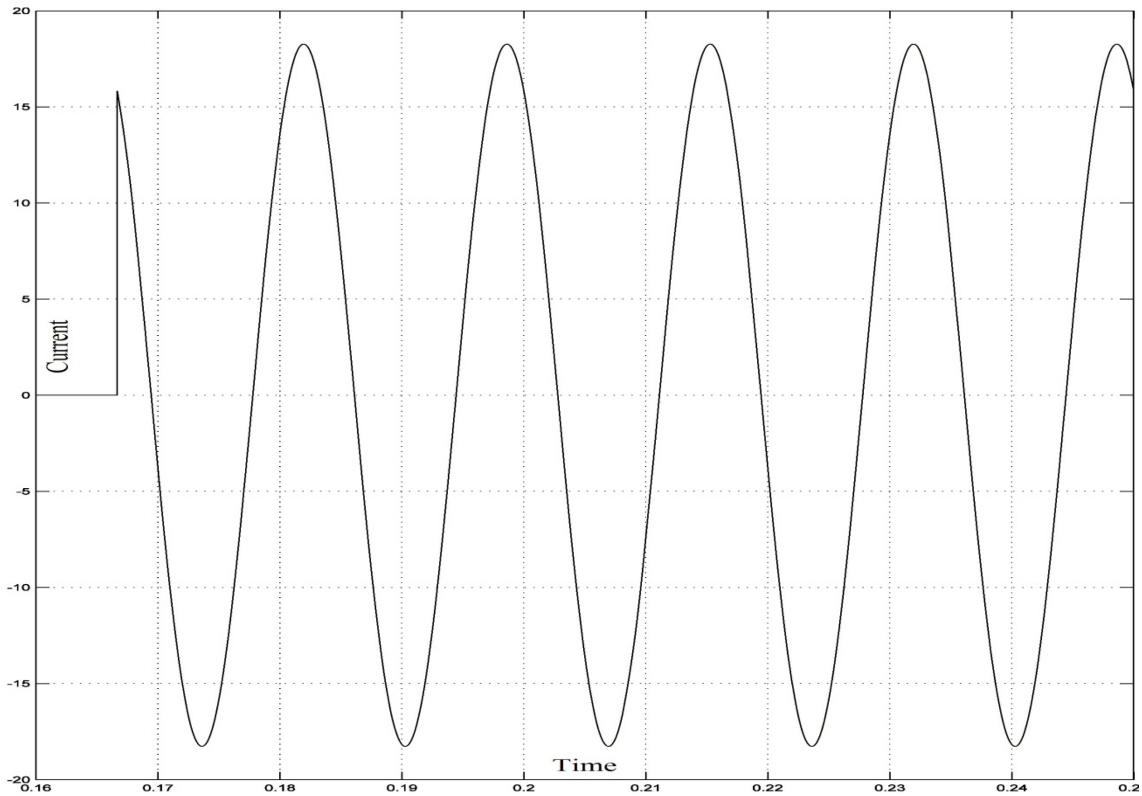


Figure 4.21: Fault current at in zone fault in Siemens algorithm.

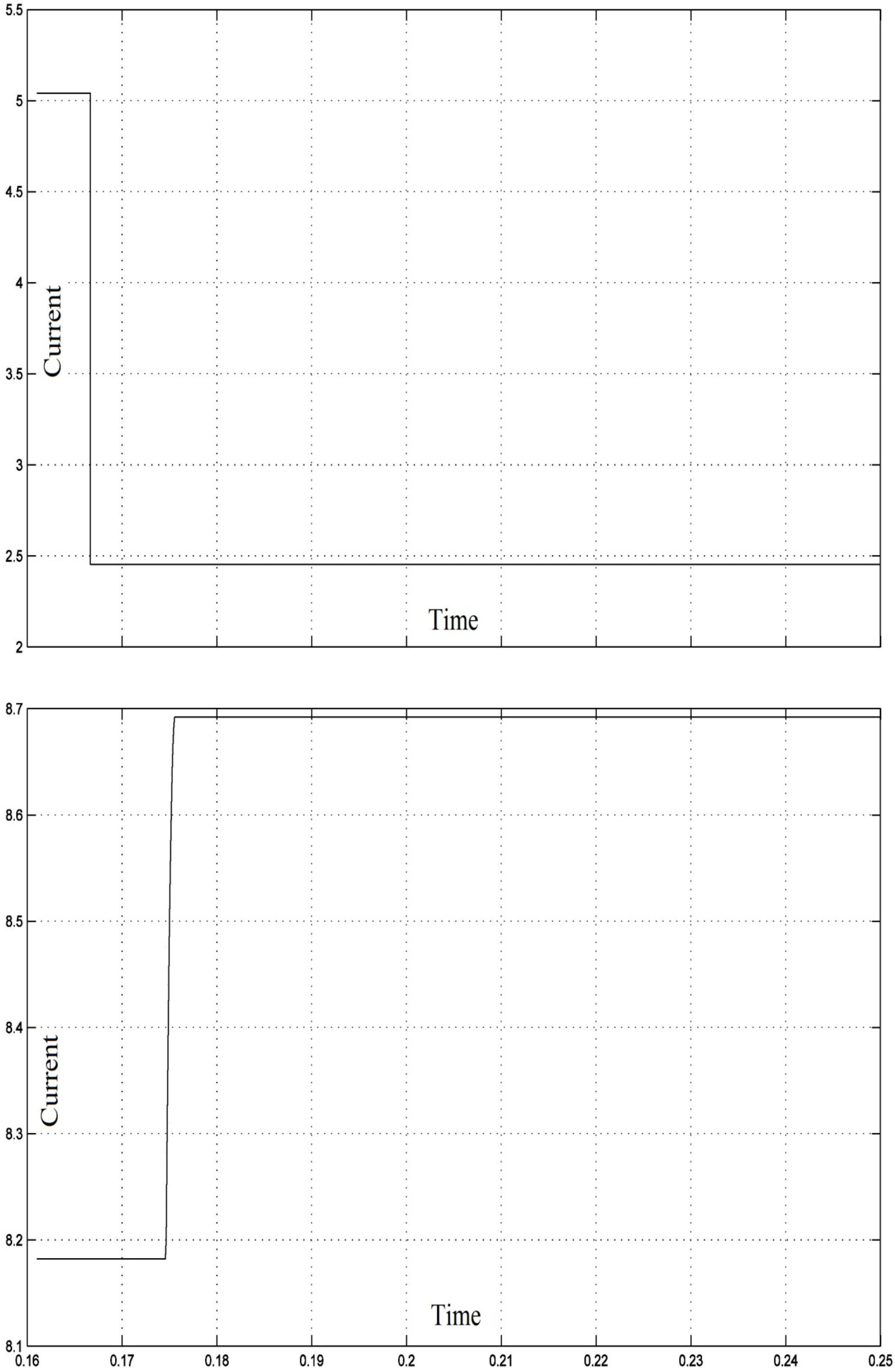


Figure 4.22: Restraint (above) and tripping (below) current at in zone fault in Siemens algorithm.

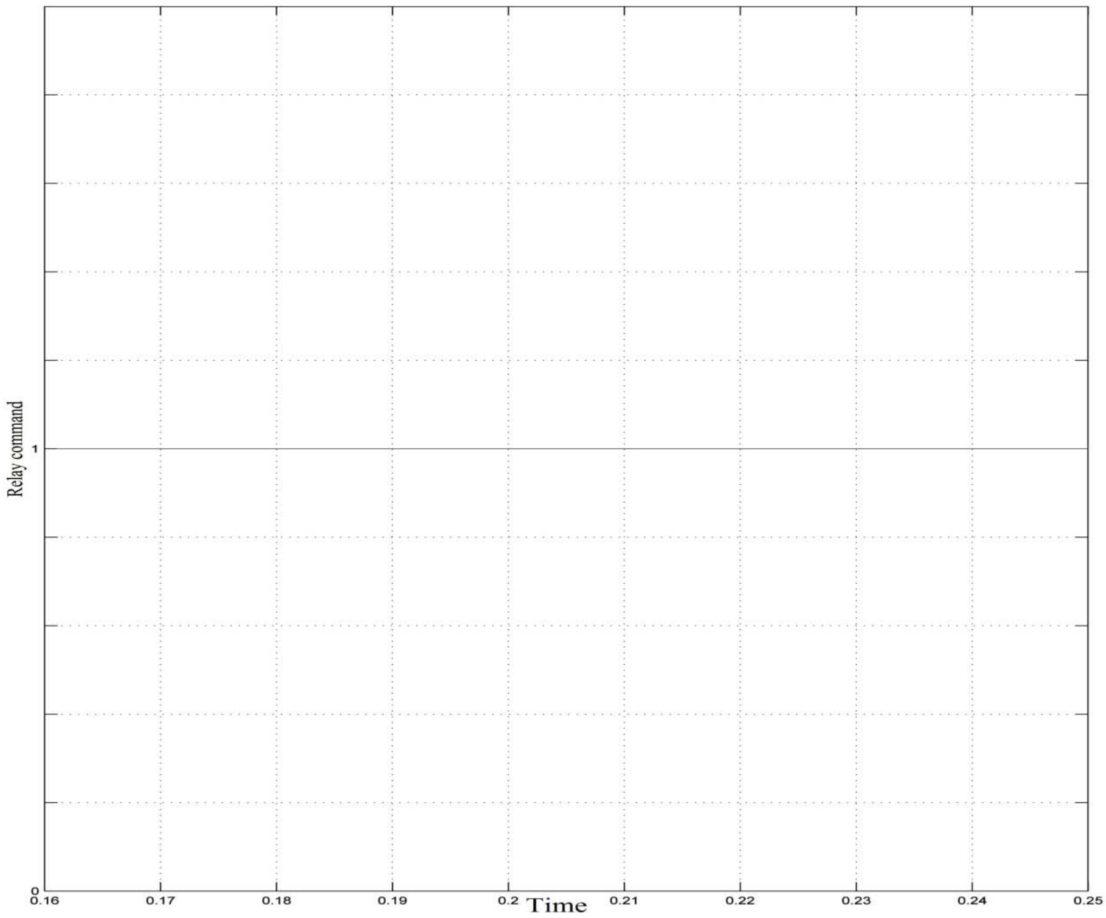


Figure 4.23: Relay operation command at in zone fault in Siemens algorithm.

4.4 General electric Multilin

The presented algorithm in section 2.6.2 of chapter 2 is simulated in this section. This algorithm is investigated for three fault conditions, normal condition, out of zone single line to ground fault and in zone single line to ground fault. Figures 4.28, 4.35 and 4.40 show the differential current waveforms and magnitudes. GE algorithm operates by comparing magnitude of differential current and restraint current. As it mentioned in chapter 2, if magnitude of differential current is more than magnitude of restraint current, then the relay operates. Otherwise the relay does not operate.

4.4.1 Normal condition

Figure 4.24 shows the sample network connected in normal condition without earth fault. Figure 4.25 shows simulation of the relay algorithm.

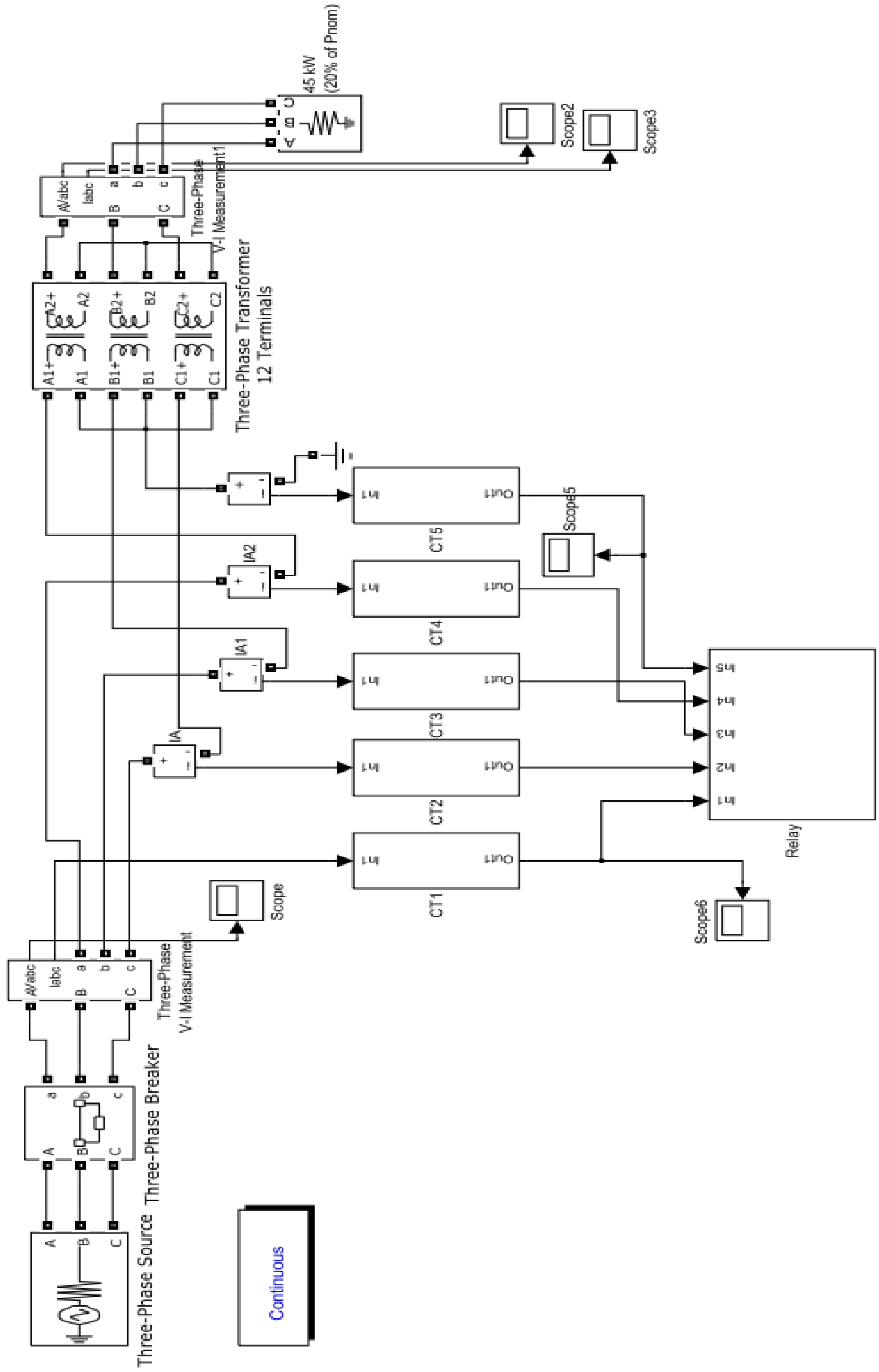


Figure 4.24: GE relay connected to the network.

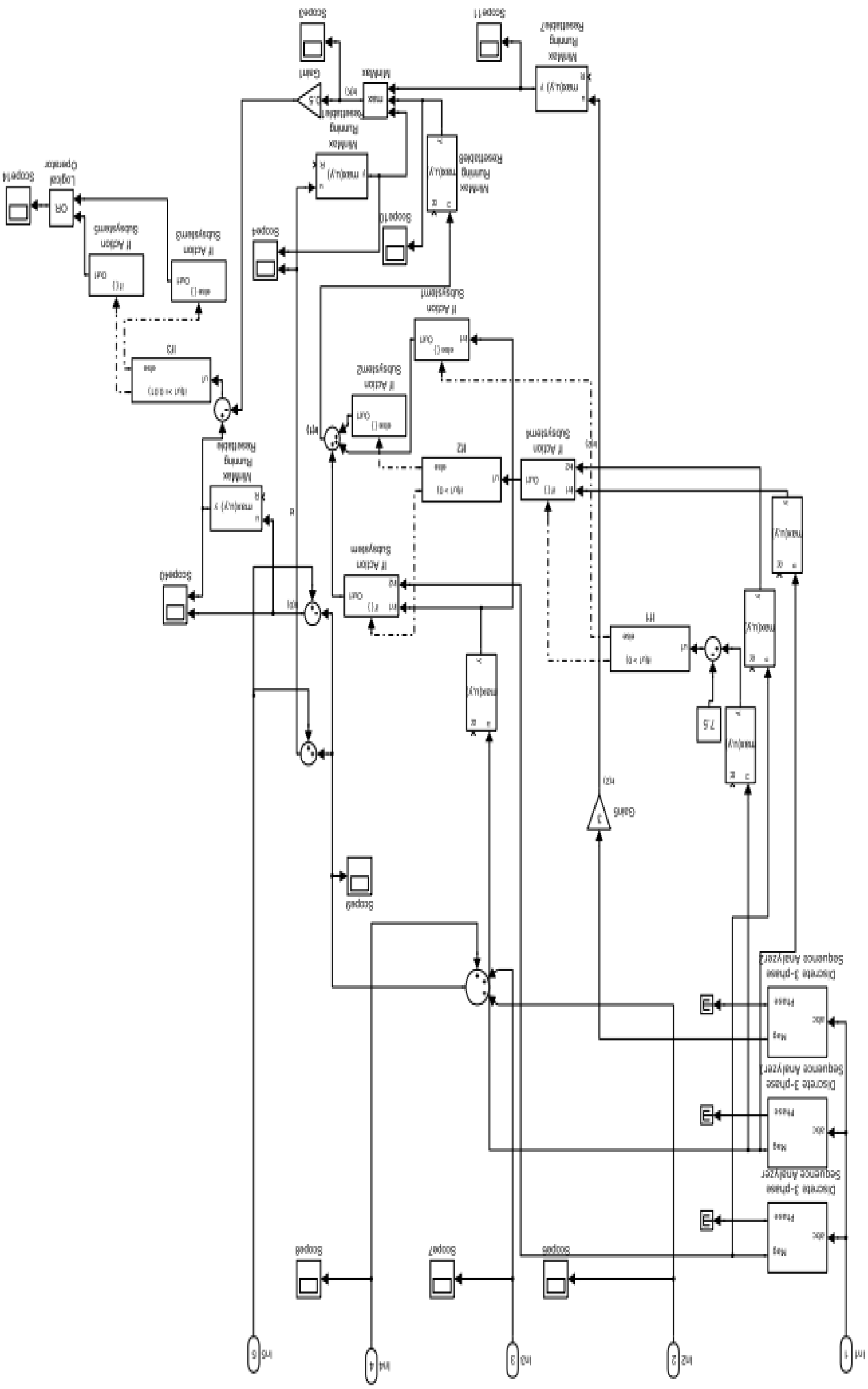


Figure 4.25: GE REF algorithm simulation.

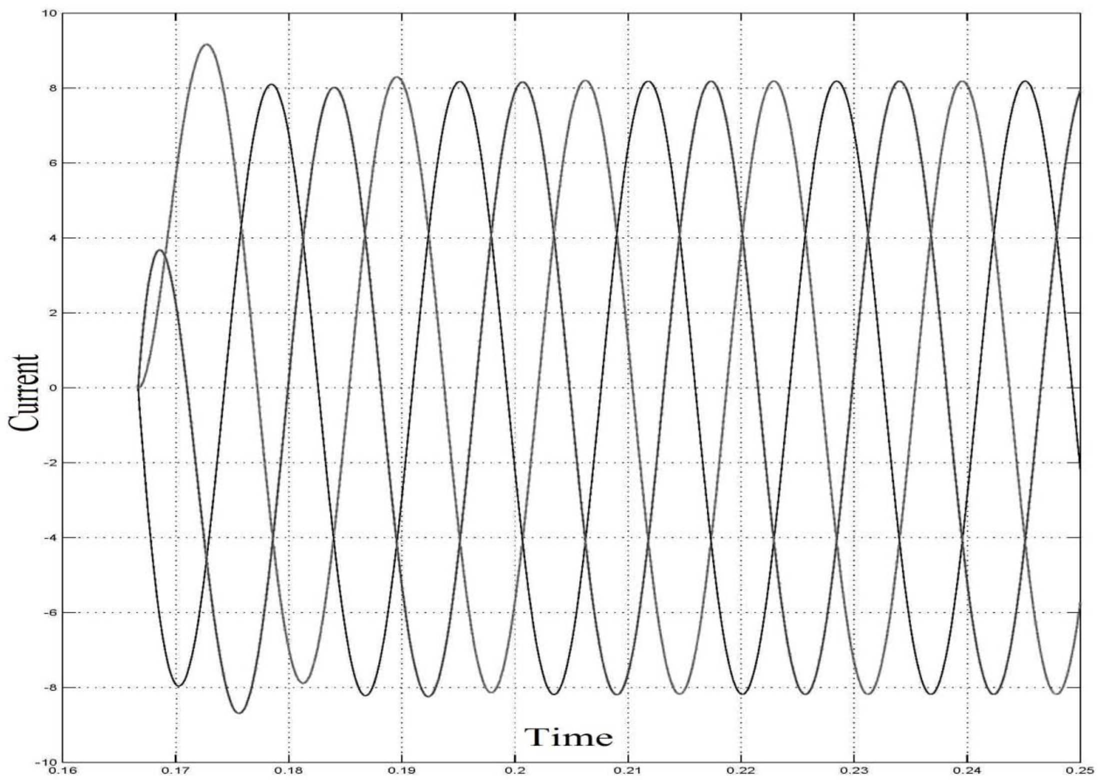


Figure 4.26: Three phase current at normal condition in GE algorithm.

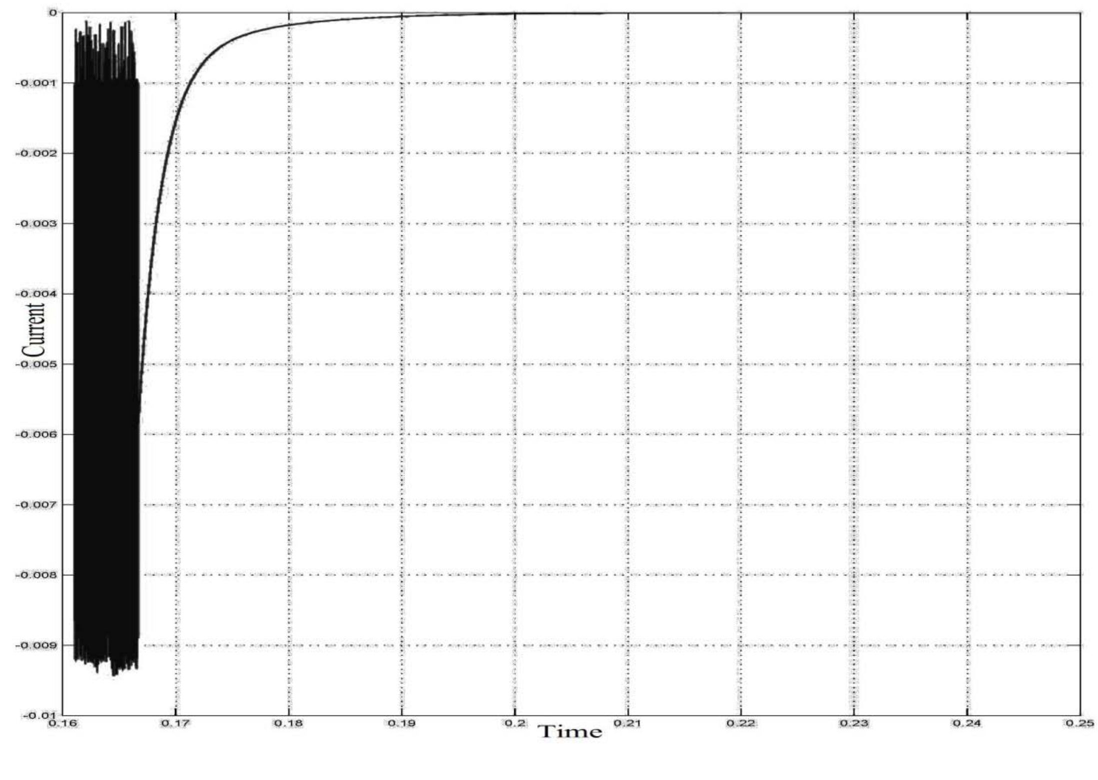


Figure 4.27: Star point current at normal condition in GE algorithm.

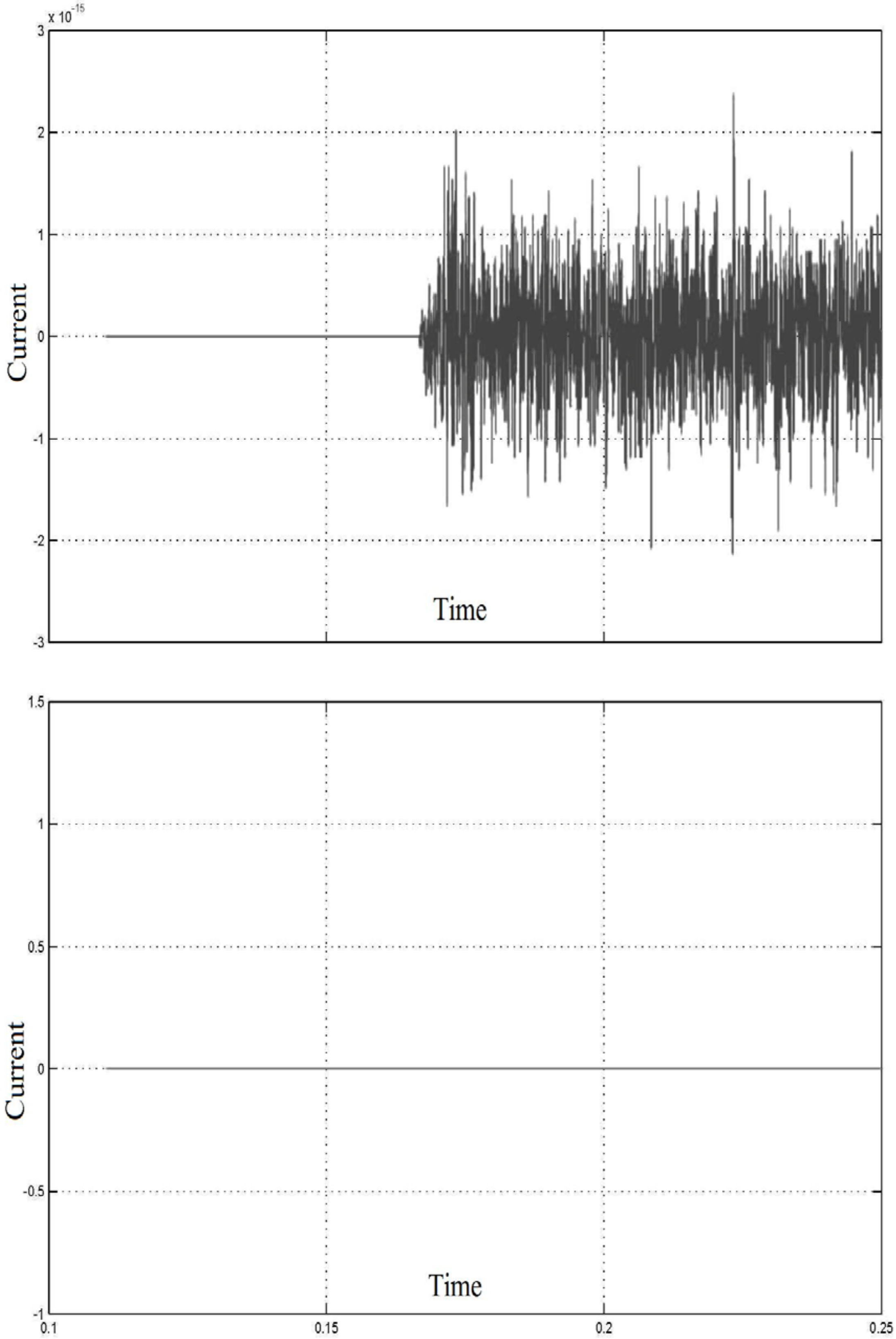


Figure 4.28: Differential current waveform (above) and magnitude (below) at normal condition in GE algorithm.

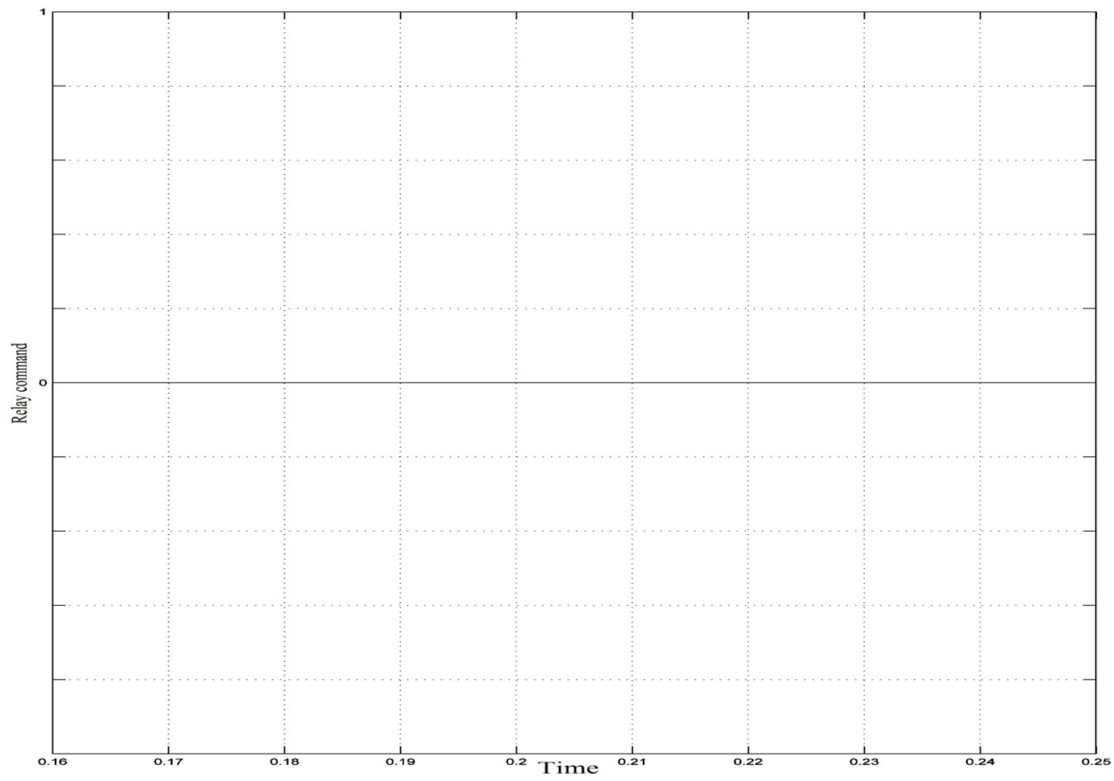


Figure 4.29: Relay operation command at normal condition in GE algorithm.

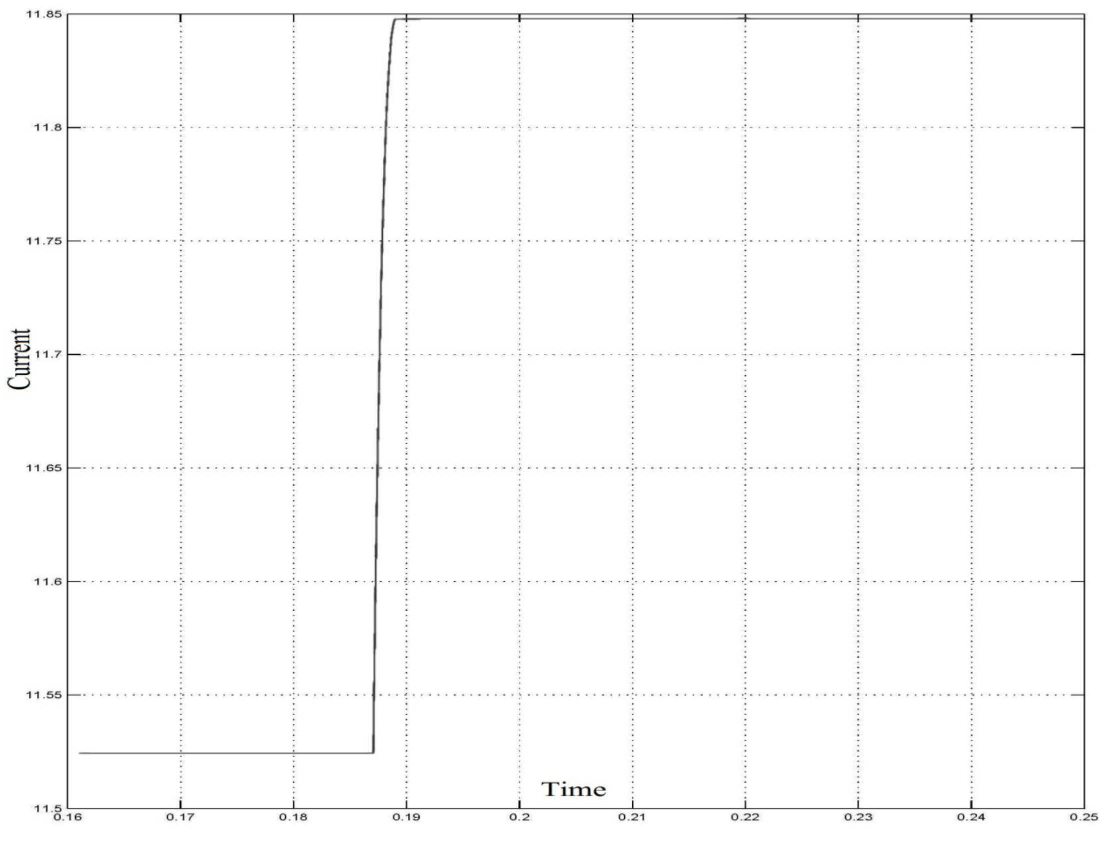


Figure 4.30: Restraint current at normal condition in GE algorithm.

4.4.2 Out of zone fault

This case investigates the GE algorithm with single line to ground fault out of zone. The three phase current, star point current, differential current (waveform and magnitude), restraint current and relay operation command are shown in the following figures.

In this case the relay should not operate and algorithm should restrain the operation of the relay. This simulation proves that the relay does not operate outside of protection zone fault.

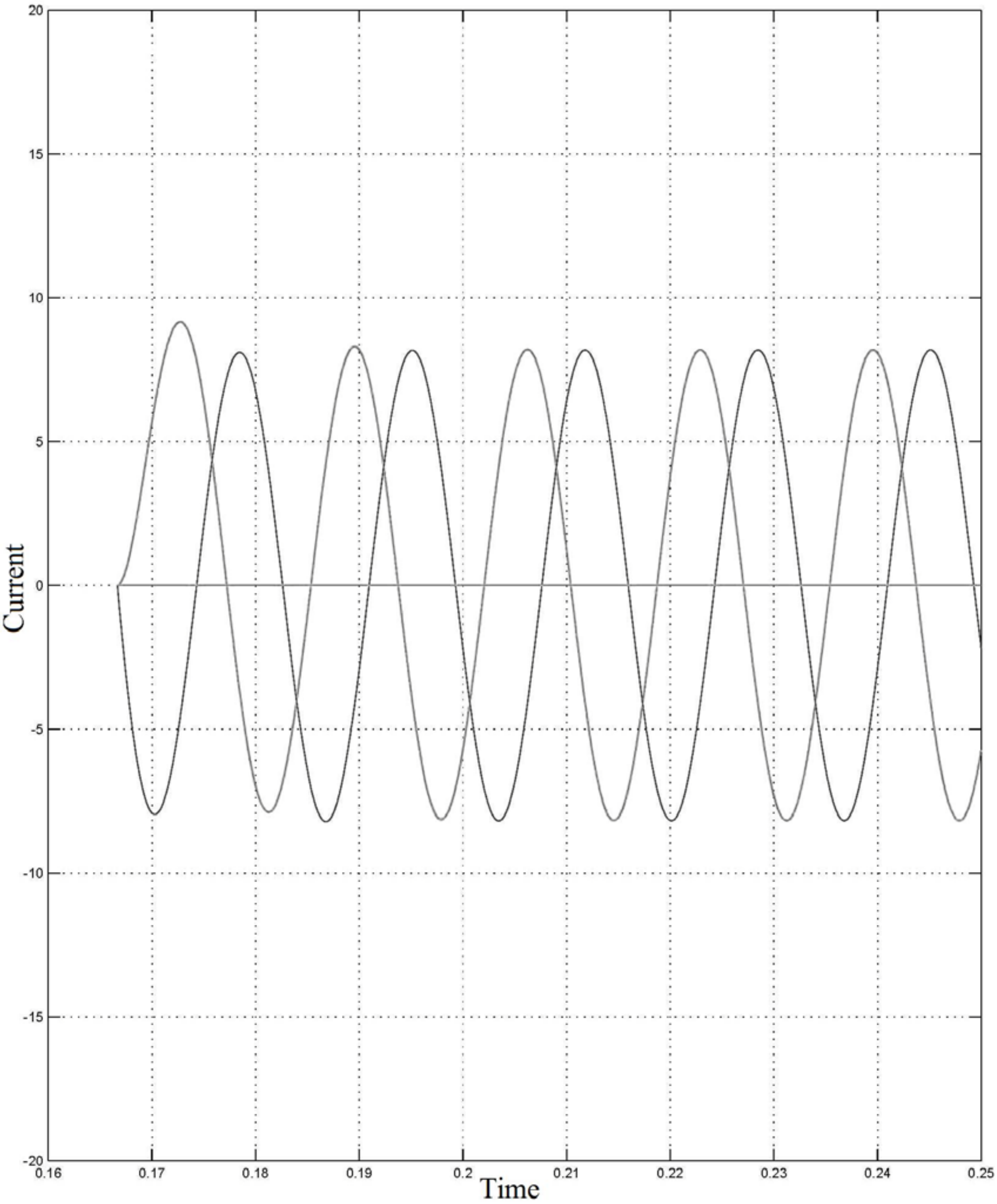


Figure 4.31: Three phase current at out of zone fault in GE algorithm.

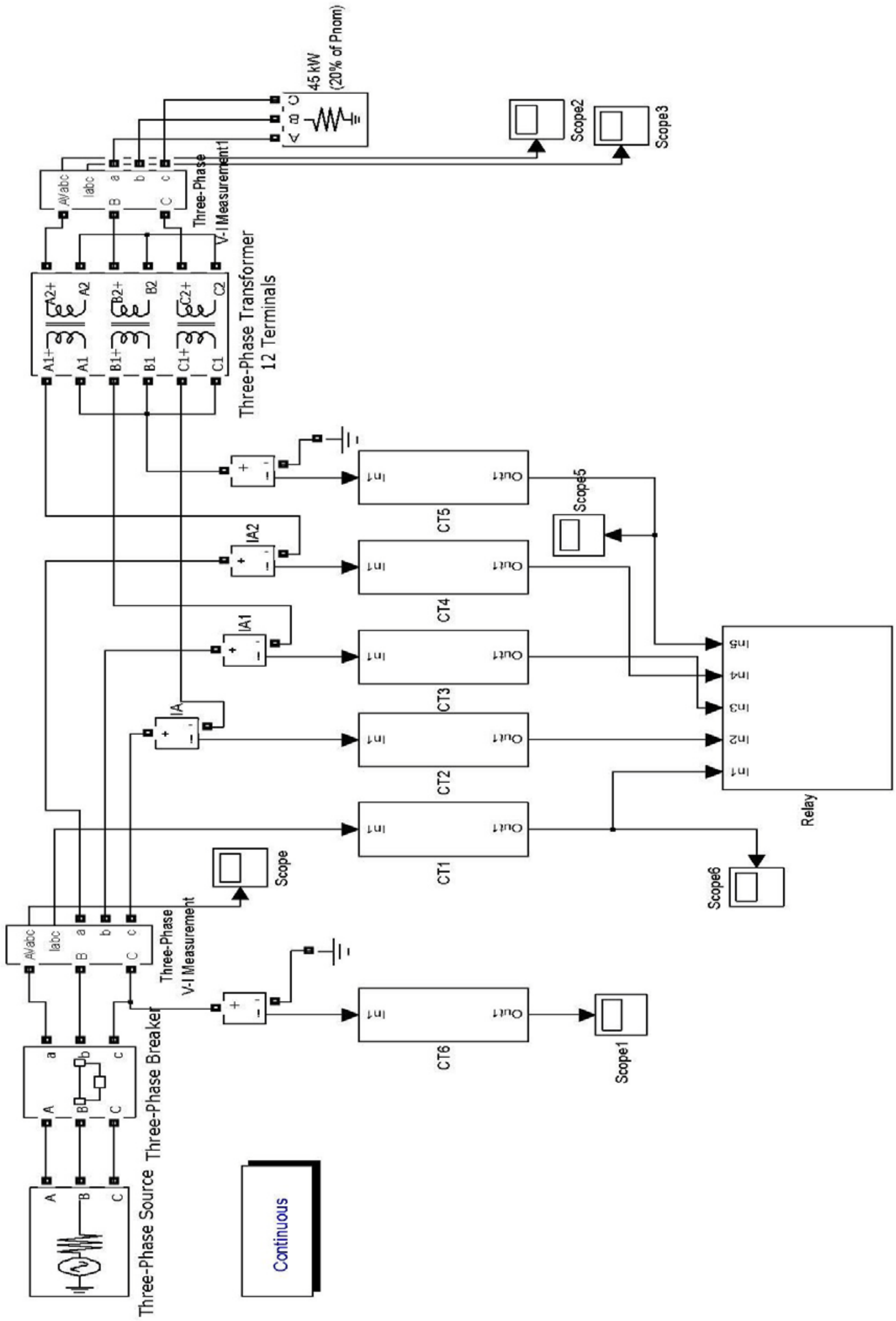


Figure 4.32: Out of zone fault in GE REF algorithm simulation.

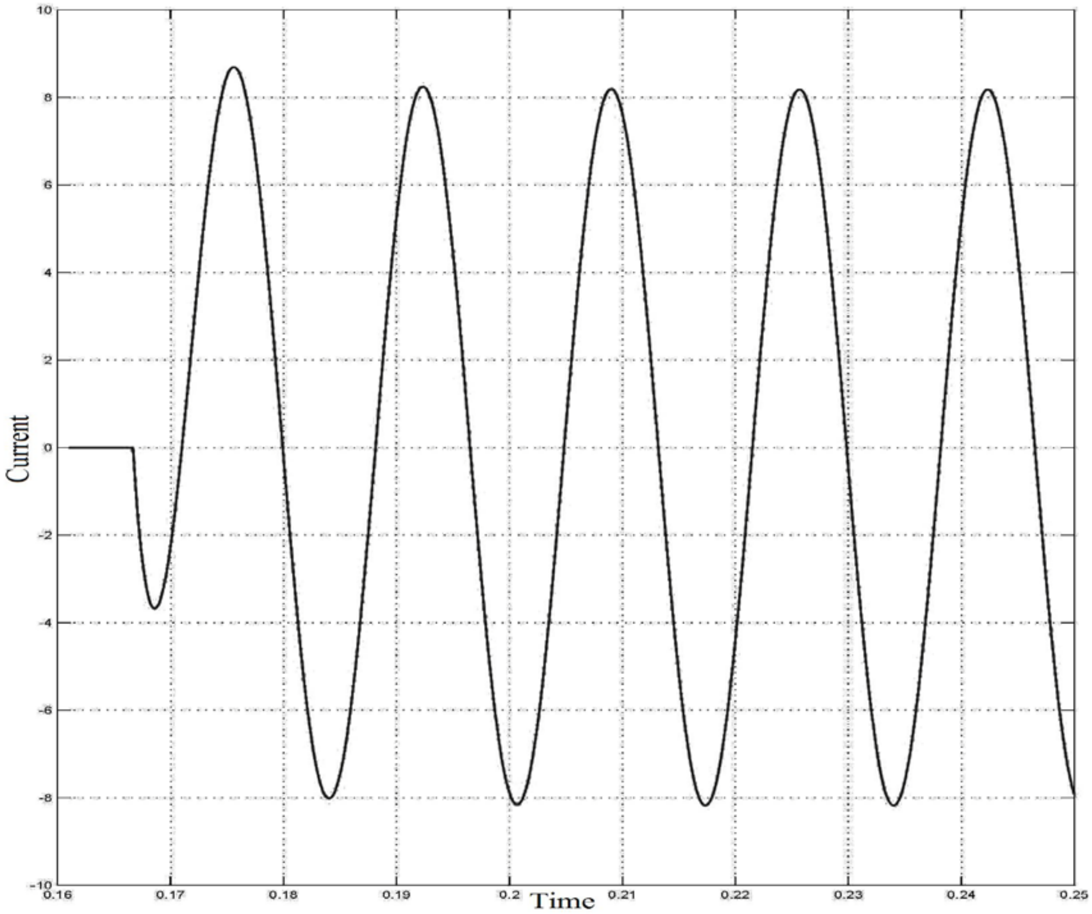


Figure 4.33: Star point current at out of zone fault in GE algorithm.

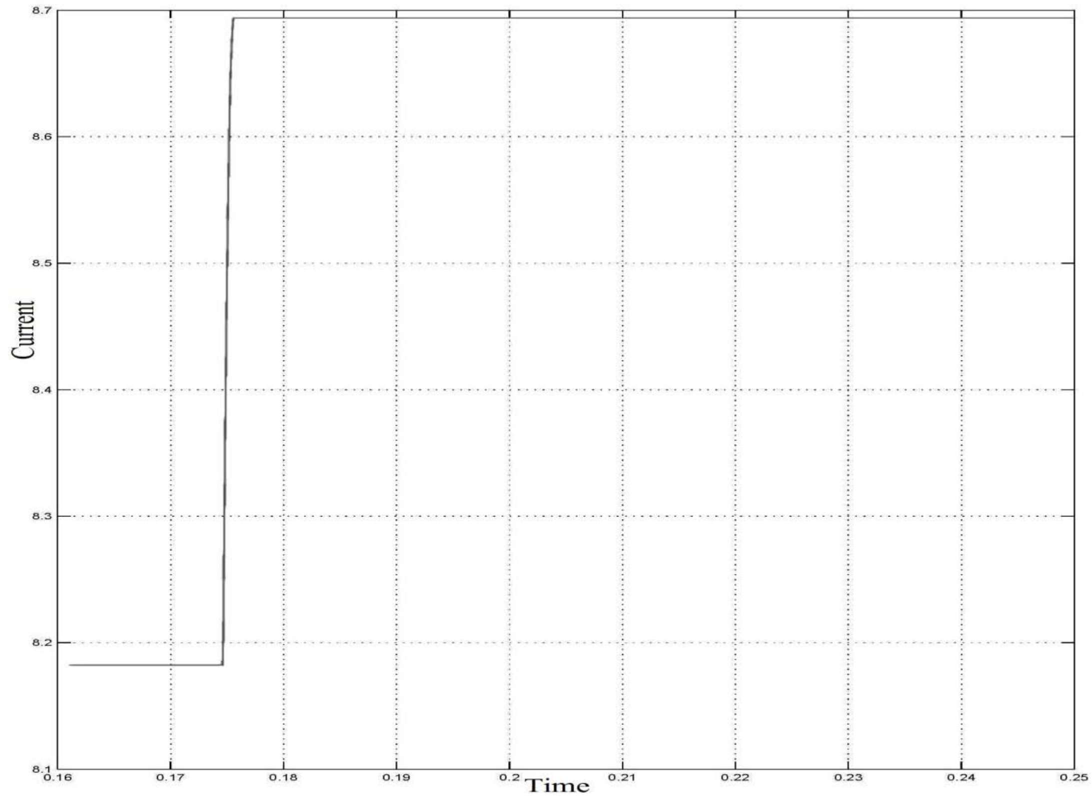


Figure 4.34: Restraint current at out of zone fault in GE algorithm.

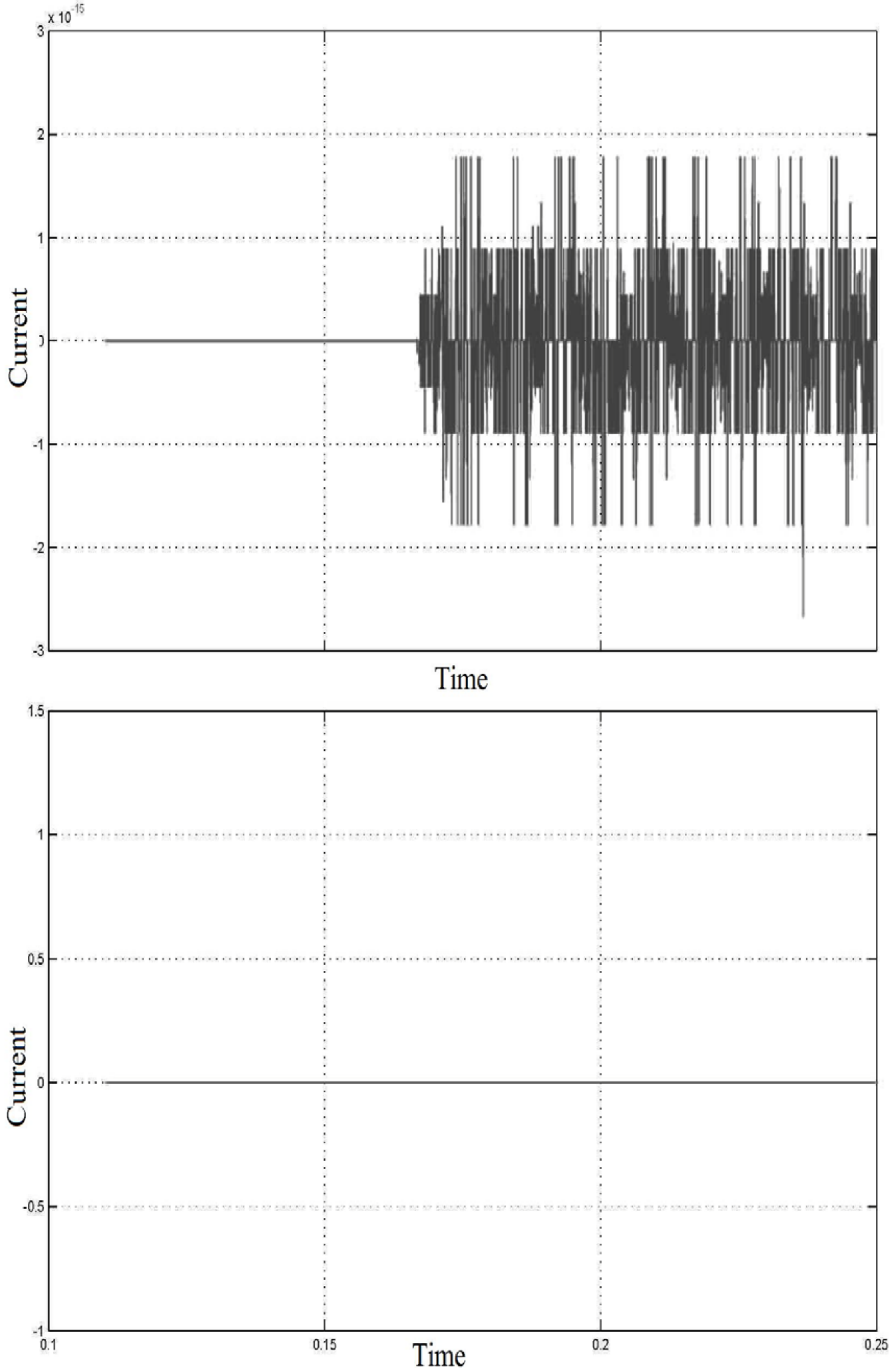


Figure 4.35: Differential current waveform (above) and magnitude (below) at out of zone fault in GE algorithm.

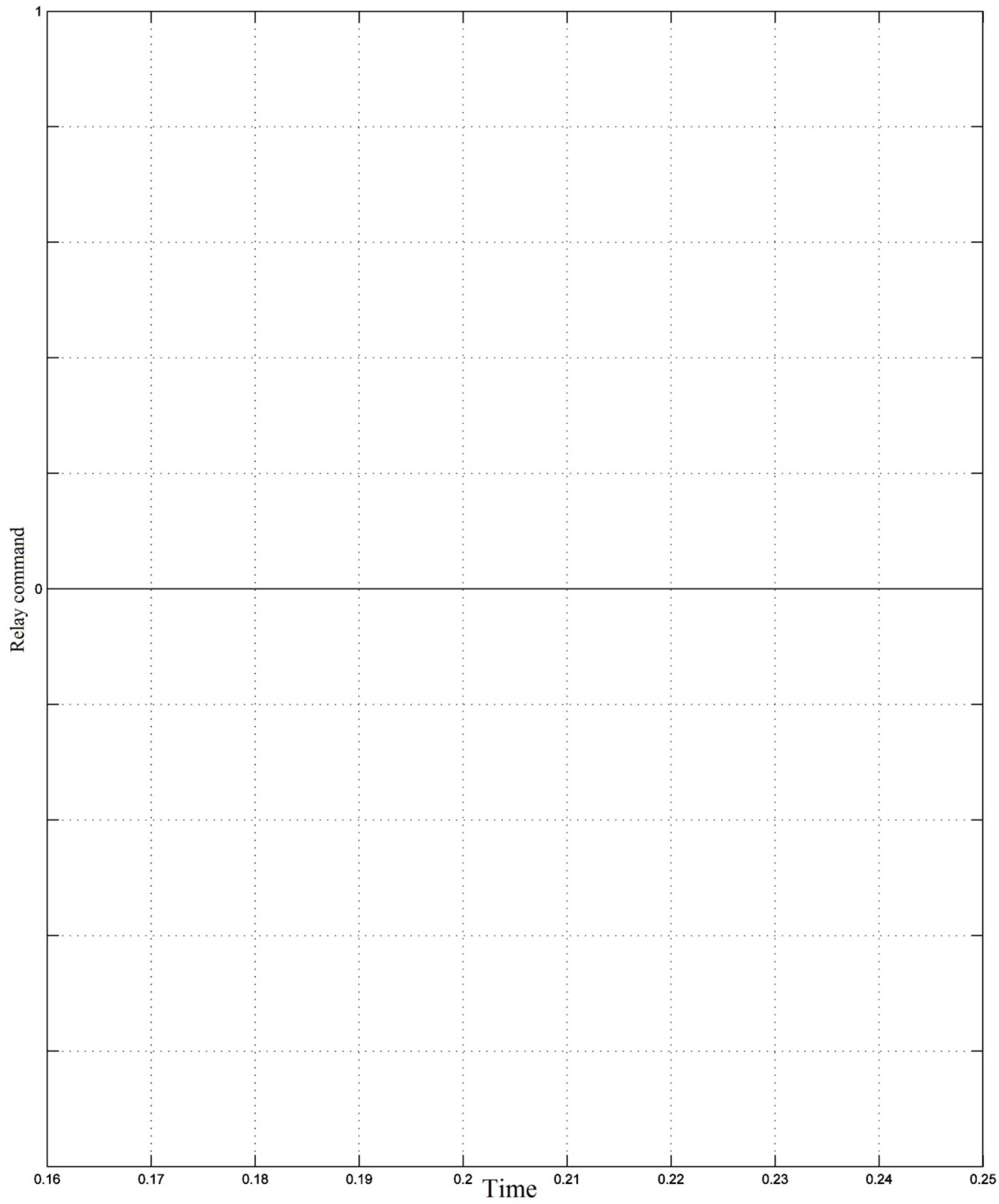


Figure 4.36: Relay operation command at out of zone fault in GE algorithm.

4.4.3 In zone fault

In this case, the restricted earth fault relay should operate. Following simulation proves that the relay operates when the single line to ground occurs inside of protection zone.

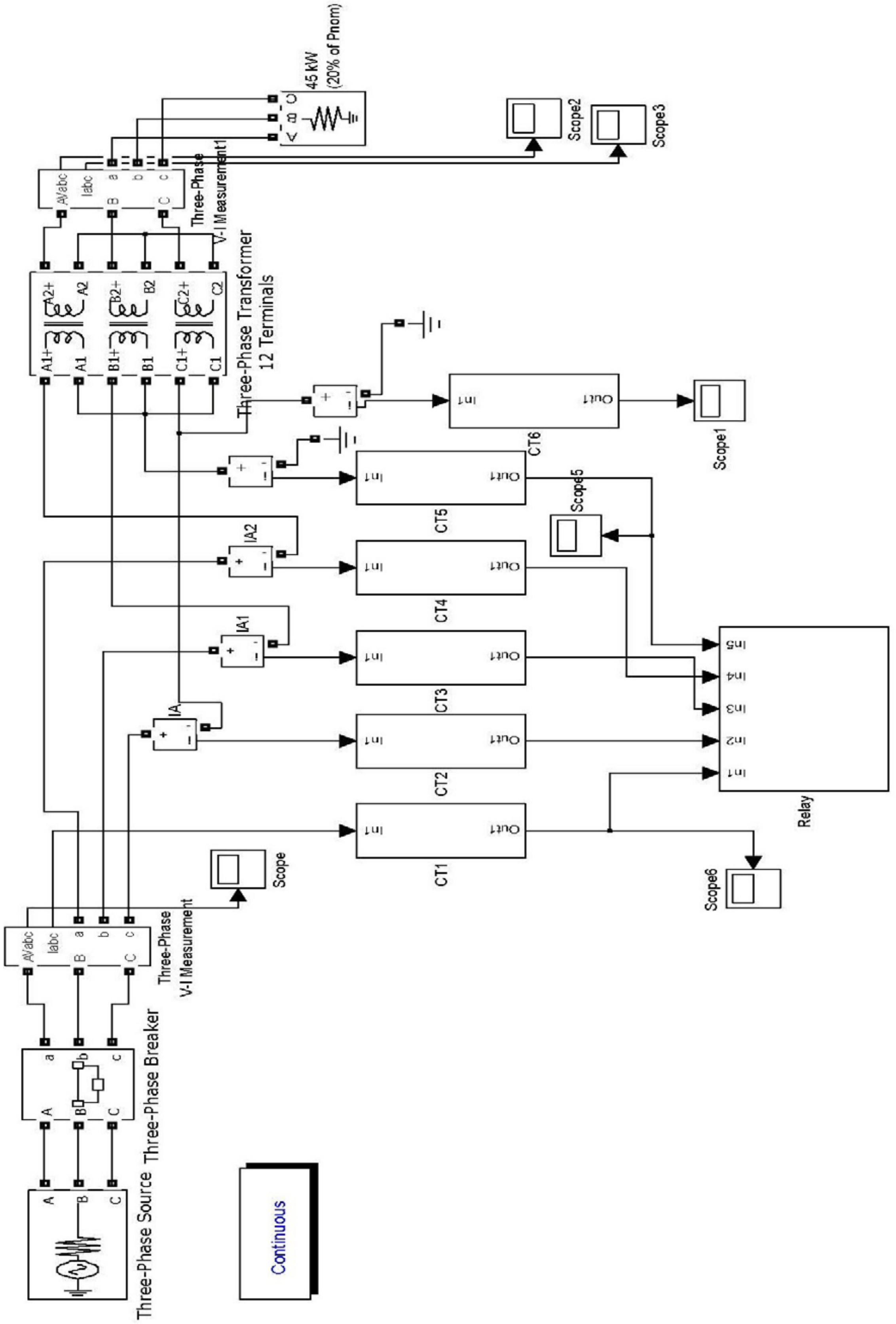


Figure 4.37: In zone fault in GE REF algorithm simulation.

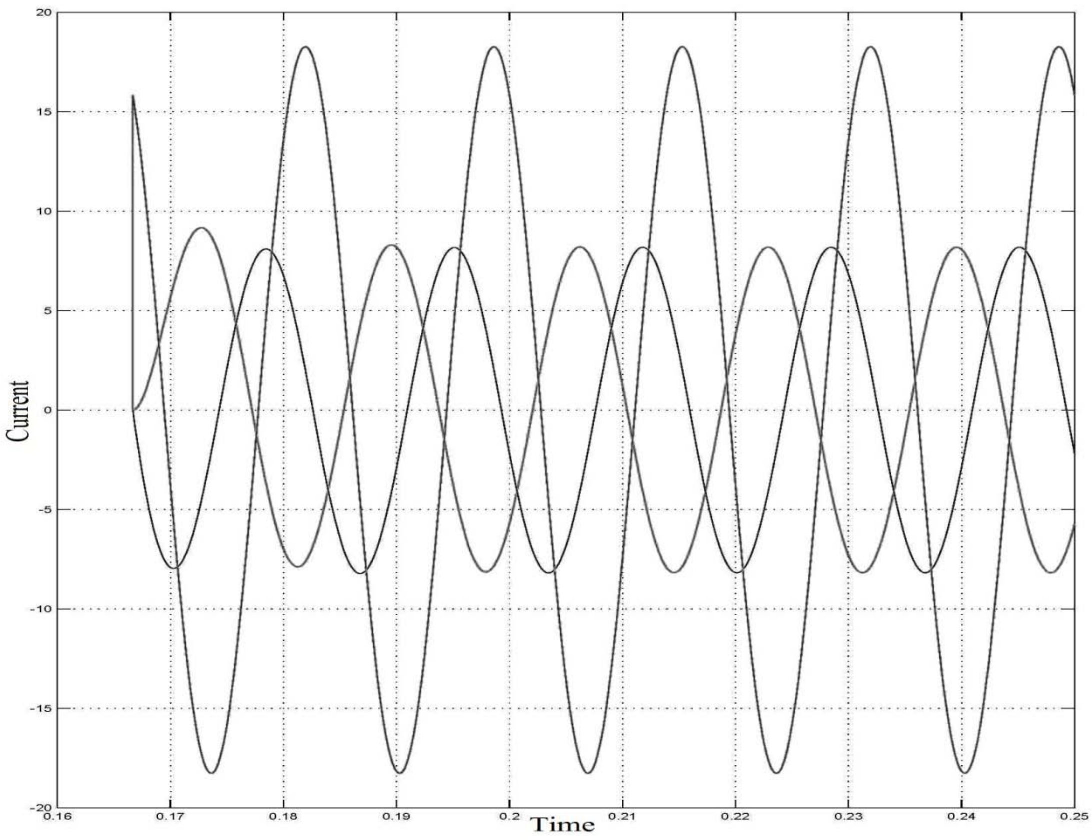


Figure 4.38: Three phase current at in zone fault in GE algorithm.

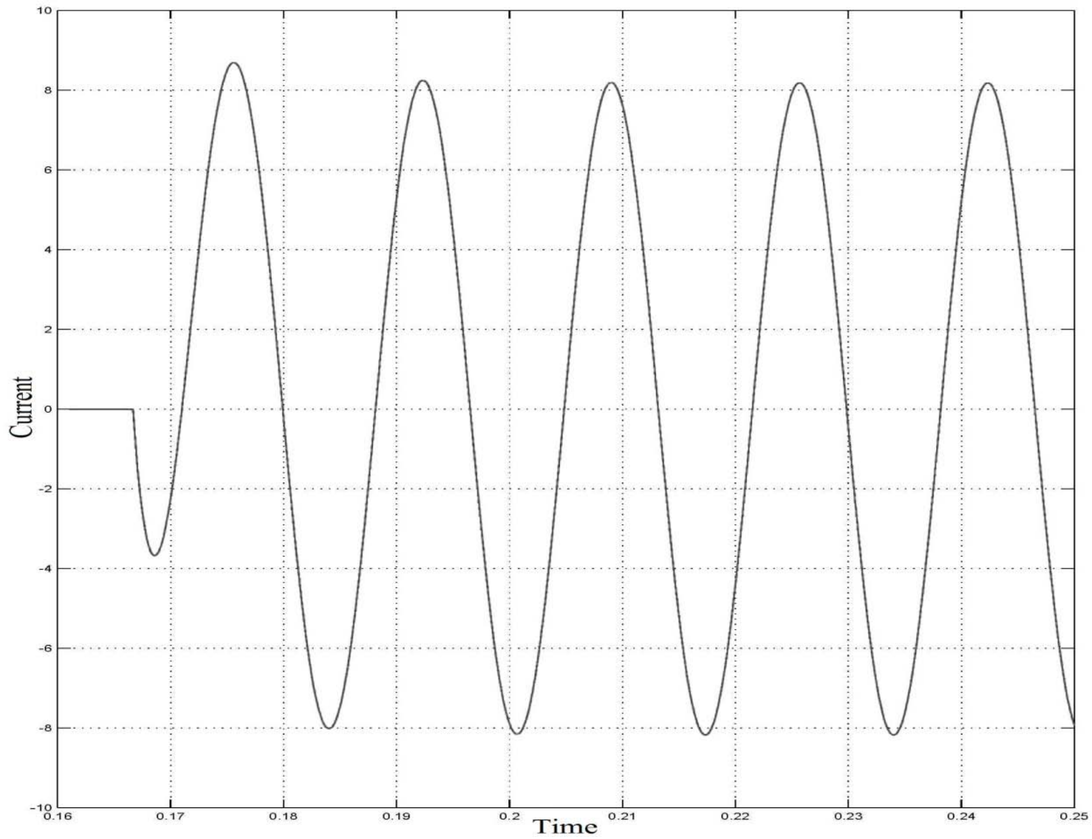


Figure 4.39: Star point current at in zone fault in GE algorithm.

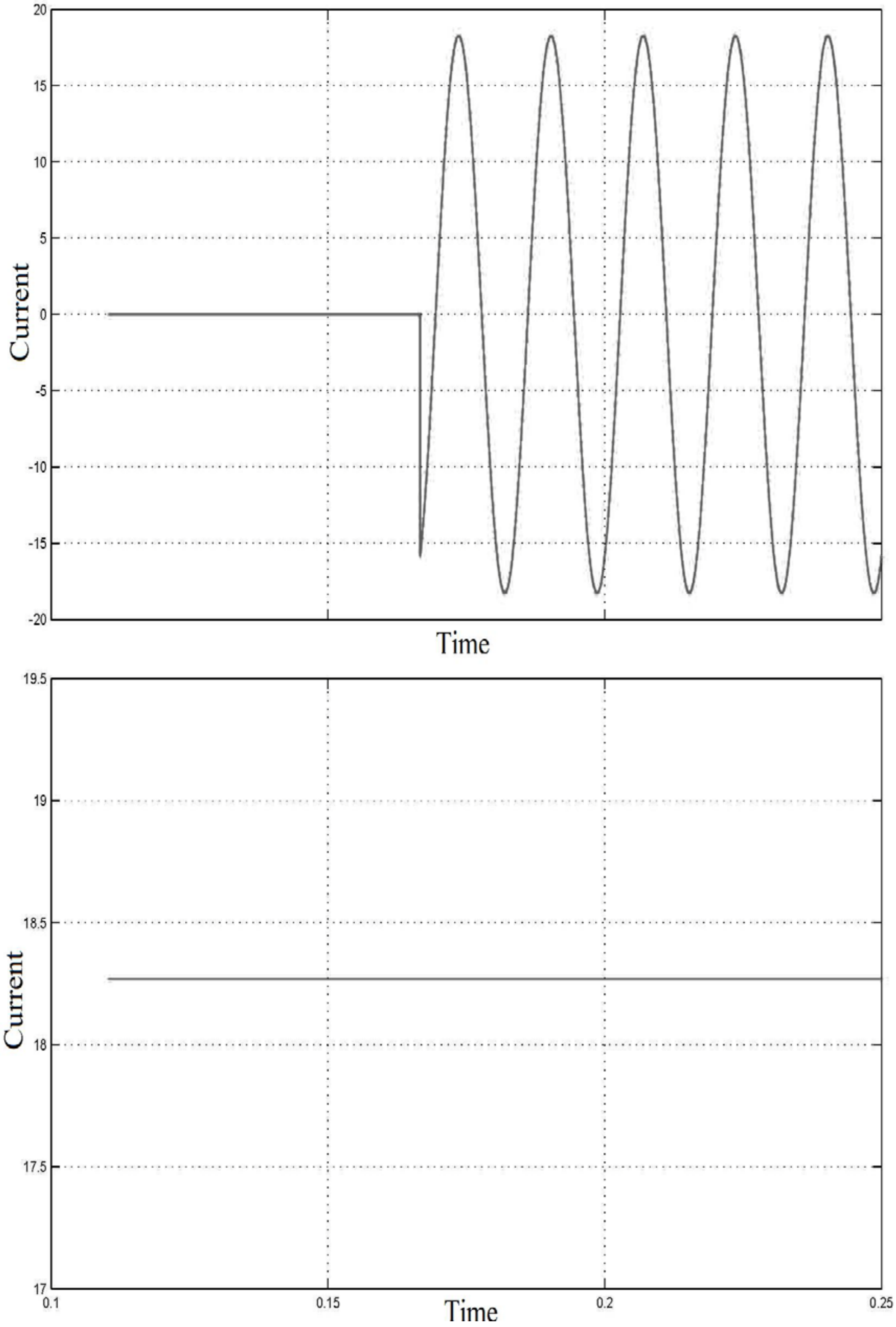
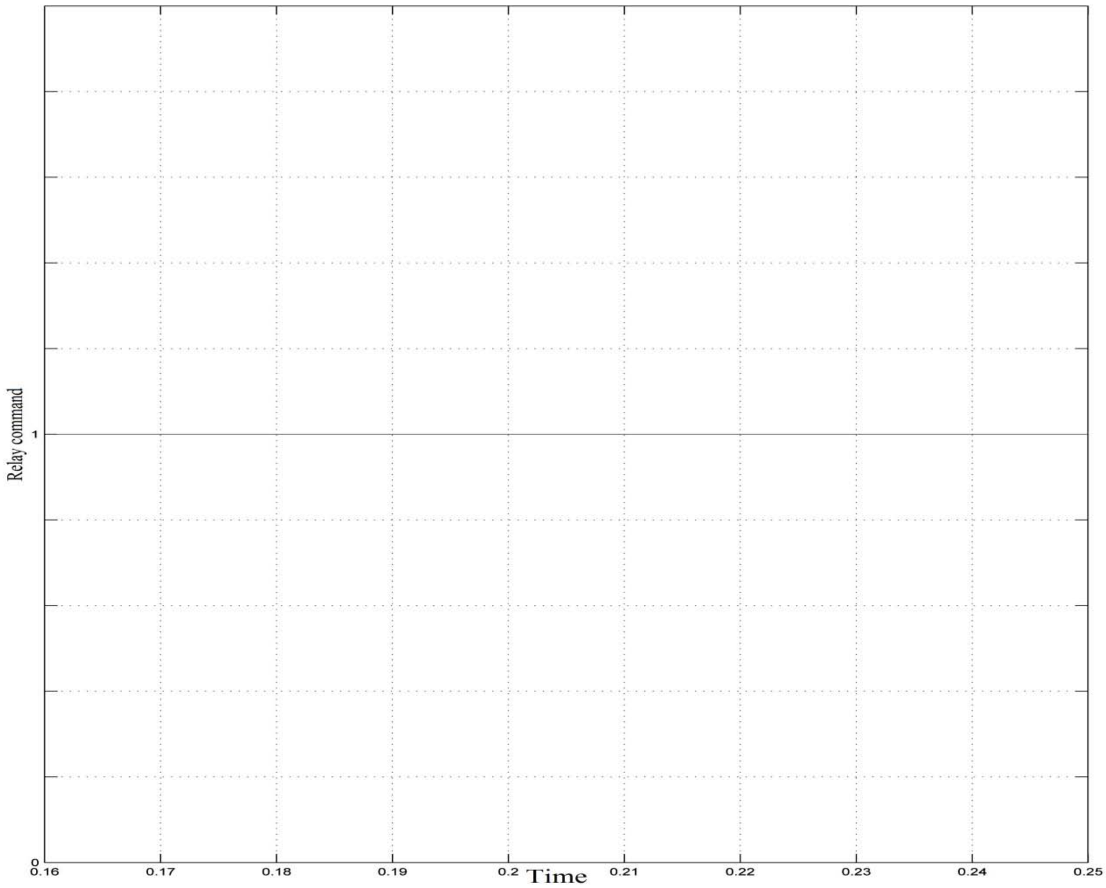


Figure 4.40: Differential current waveform (above) and magnitude (below) at in zone fault in GE algorithm.



4.41: Relay operation command at in zone fault in GE algorithm.

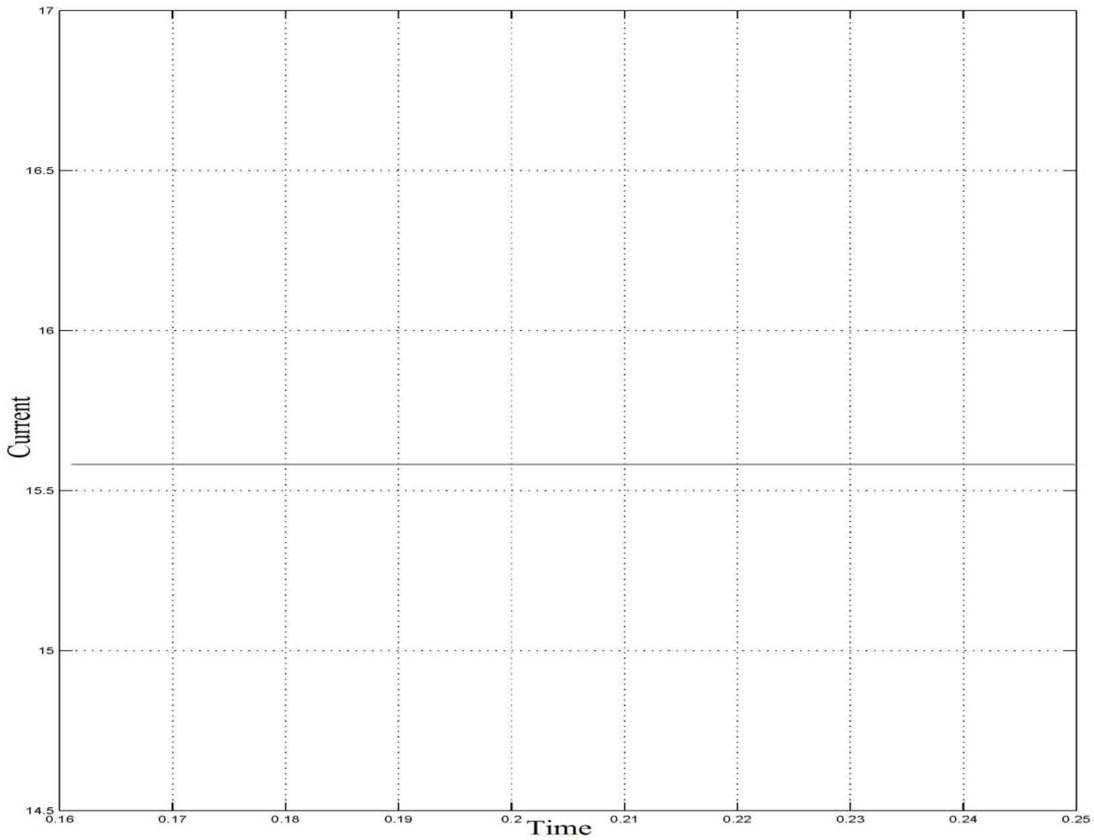


Figure 4.42: Restraint current at in zone fault in GE algorithm.