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Research Article

Modelling and analysis of line-to-line short circuit fault in 154 kV high-voltage substation

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Abstract

In this study line-to-line short circuit currents that are likely to happen in 154 kV Van (a city at the east of Turkey) Substation are modelled by MATLAB Simulink program with actual parameters. Lines, power transformers, circuit breakers, and loads which are the main components of a substation are modelled under MATLAB/ Simulink. Actual parameters are used for simulation. In case of power transformer modelling calculations are done by taking factory test reports as a base and power transformer block parameter values are found. Load parameter values are taken from electricity meter in the substation. Since 154 kV Van substation is modelled alone, the effect of interconnected system is modelled by an ideal voltage source.

Keywords: Line-to-line fault, Short circuit currents, Fault analysis, MATLAB.

1. Introduction

Interruptions occur in electric power systems due to faults and human accidental interference. A power system fault is defined as any failure which interferes with the normal current flow. The fault phenomenon affects system's reliability, security, and energy quality, and can be considered stochastic (Efe, 2015). Different events such as lightning, insulation breakdown and trees falling across lines are common overhead power system fault causes. Fault analysis methods are important tools which are used by protection engineers to estimate power system currents and voltages during disturbances. It provides information for protection system setting, coordination and efficiency analysis studies (Filomena et.al 2011). The primary objective of any short-circuit analysis software tool is to calculate the fault currents and voltages. From the fault analysis results, circuit-breaker capacity and protective relay performance can be determined. In addition, the fault analysis is a pre-requisite for many power system studies such as transient stability and voltage sag analyses (Abdel-Akher et.al. 2010).

Assessment of the faults that give rise to the most serious events, and especially of the short-circuit currents, are of interest both to the manufacturer (for whom it is important to know the thermal effect, the electrodynamics stresses, and the over voltages associated with a short circuit), to the authority managing the electricity system (with regard to the designing and selectivity of protections) and to protection system designers (in order to pinpoint the values of the fault currents that enable microprocessor-based relays to be devised (Zaninelli et.al. 2000). Once a fault occurs in any load, the output currents become very large at the instant of fault because the load impedance is very small. To protect the switching devices from fatal failure, the output currents must be limited, and the fault branch should be quickly disconnected from the power supply as soon as possible. It is also desirable to recover the output voltages as soon as the fault has been cleared to keep the continuous supply (Pei et.al. 2012).

Short circuit currents are currents which occur from in normal operating conditions a negligible fault among conductors under applied voltage with different potentials. Short circuits occurs in degradation of insulation in cables and conductors or in inaccurate montage and facilities. Electricity facilities should be designed such that it can stand for thermic and dynamic forces during short circuit. Usage of digital computers lets the simple and certain simulation of system components, thus short circuit currents can be calculated accurately (Parise et.al 1995). When the electrical grid is in short circuit state in course of switching of circuit breakers' pole or reclosing and mixture of phases one after another causes peak currents which exceed test value (Kersten et.al. 1991).

Power transformers are required and important components of the power systems. Lately %70-80 faults in transformers occur from short circuits between windings (Butler-Purry et.al. 2003). Circuit breakers are used for system and engine protection in case of short circuit and overload conditions (Mützel et.al. 2007).

Short circuit calculations are necessary in case of power system design. Because selecting the electrical equipment and system topology not only depends on continuous state rated voltage and currents. If internal arcing occurs in an electrical installation, it may seriously damage the equipment and the installation building, and even endanger the maintenance personnel as well as the reliability of the electric power supply. In order to investigate the consequences of the internal arcing in an electrical installation, the fault arc current and the arc power must be known [Zhang et.al. 2008]. In addition, currents and voltages occur from short circuit events also should be taken into account in hardware selection. In short circuit calculations, two short circuit currents with different amplitudes are calculated.

Line-to-line short circuit fault is caused by some sort of connection between phases, like wind, some object

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that bridges two phases, etc (EPRI.1997:2-37). They cause imbalance in the system and havethe most severe impact on generators. Fault currents are typically high.

2. Mathematical Calculation of Line-to-Line Fault Currents

A line-line fault is an accidental low-resistance connection established between two points of different potential in an electric network or system. General view of line-to-line short circuit fault is given in figure 1. Fault impedance between conductors is denoted by Z_f.

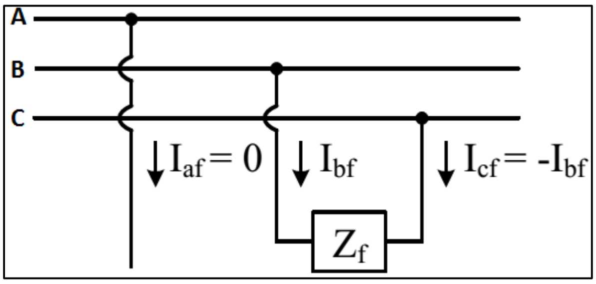


Figure 1. General view of line-to-line short circuit fault

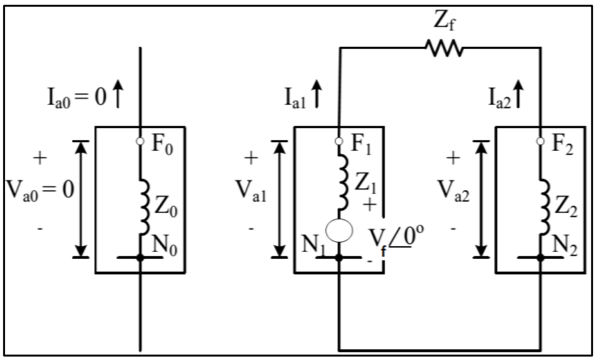


Figure 2. Sequence network diagram of line-to-line short circuit fault

From figure 1;

$$I_{af} = 0 \tag{1}$$

$$I_{bf} = -I_{cf} \tag{2}$$

can be obtained. From sequence network diagram that is given in figure 2;

$$I_{a0} = 0 \tag{3}$$

$$I_{a1} = -I_{a2} = \frac{V_f \angle 0^o}{Z_1 + Z_2 + Z_f} \tag{4}$$

If $Z_f = 0$ then;

$$I_{a1} = -I_{a2} = \frac{V_f \angle 0^o}{Z_1 + Z_2} \tag{5}$$

In general form it can be written;

$$\begin{bmatrix} I_{af} \\ I_{bf} \\ I_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \tag{6}$$

If equations (3) and (4) are substituted into equation (6), the fault currents for B and C phases can be obtained as follows;

$$I_{bf} = -I_{cf} = \sqrt{3} I_{a1} \angle -90^o \tag{7}$$

It is known that;

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ V_f \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \tag{8}$$

If the equations (3) and (4) are substituted into (8);

$$\begin{aligned} V_{a0} &= 0 \\ V_{a1} &= V_f - Z_1 I_{a1} \\ V_{a2} &= -Z_2 I_{a2} = Z_2 I_{a1} \end{aligned} \tag{9}$$

Also it is known;

$$\begin{bmatrix} V_{af} \\ V_{bf} \\ V_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} \tag{10}$$

So substituting equation 9 into 10 then;

$$\begin{aligned} V_{af} &= V_{a1} + V_{a2} = V_f + I_{a1}(\mathrm{Z}_2 - \mathrm{Z}_1) \\ \mathrm{V}_{bf} &= a^2 V_{a1} + a V_{a2} = a^2 + I_{a1}(\mathrm{aZ}_2 - \mathrm{a}^2\mathrm{Z}_1) \\ \mathrm{V}_{cf} &= a V_{a1} + a^2 V_{a2} = a + I_{a1}(\mathrm{a}^2\mathrm{Z}_2 - \mathrm{aZ}_1) \end{aligned} \tag{11}$$

Finally, line-to-line voltages for a line-to-line short circuit fault can be expressed as

$$\begin{aligned} V_{ab} &= V_{af} - V_{bf} \\ V_{bc} &= V_{bf} - V_{cf} \\ V_{ca} &= V_{cf} - V_{af} \end{aligned} \tag{12}$$

3. Simulation and Fault Analysis

Single line diagram of Van 154 kV Substation is given in figure 3. This diagram is taken as base for modelling the system under MATLAB / Simulink platform. Also the simulation model is given in figure 4.

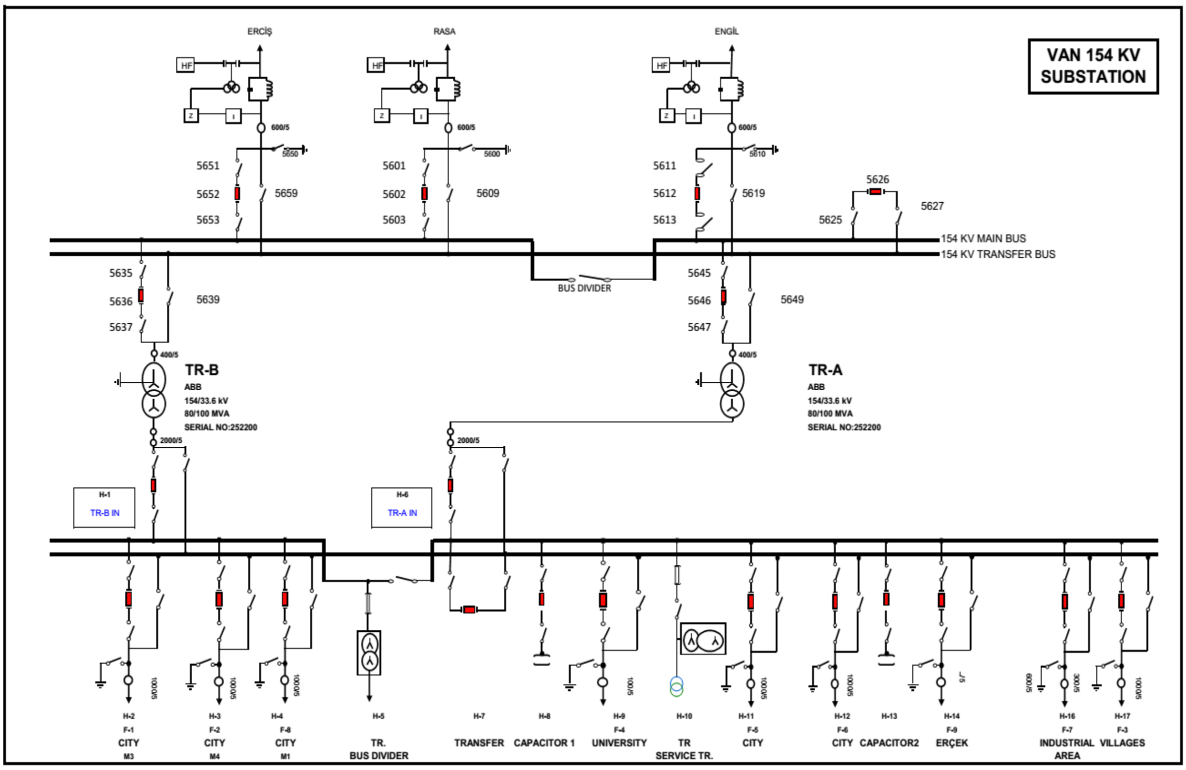


Figure 3. Single line diagram of study system

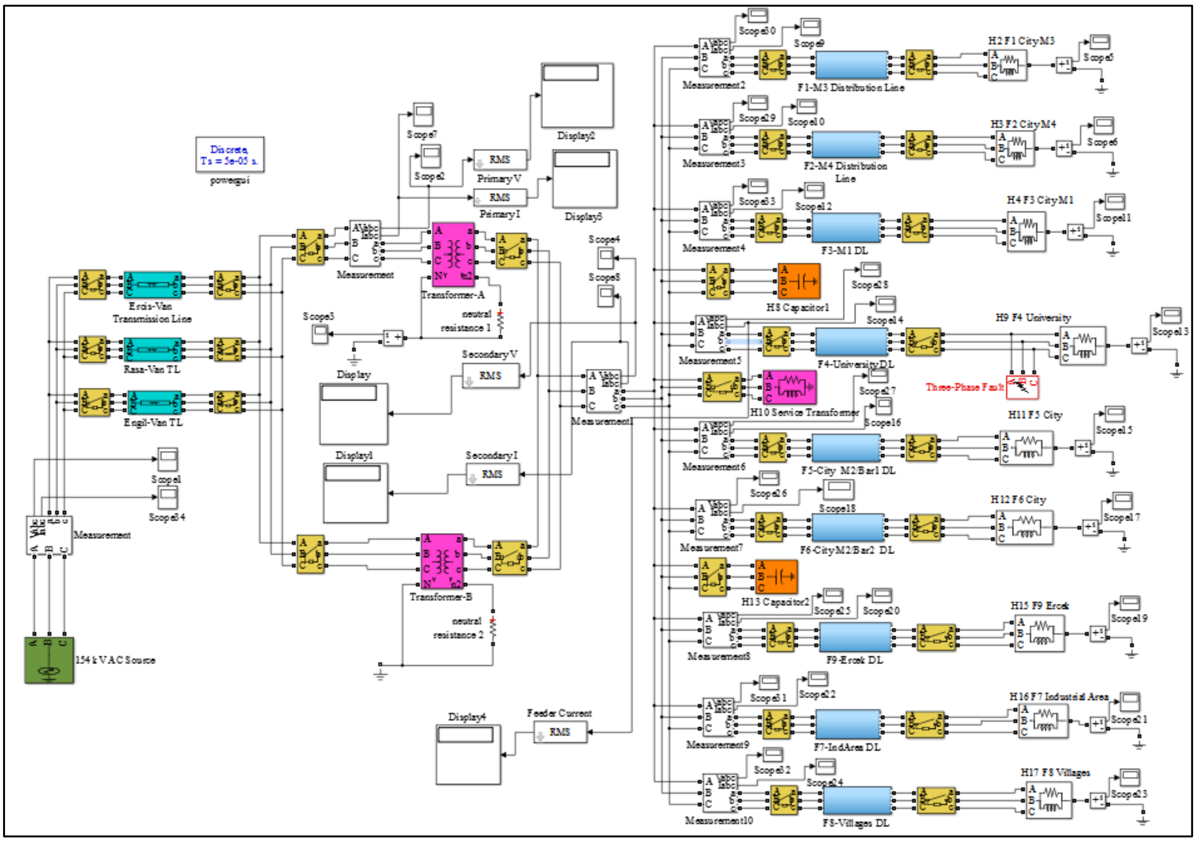


Figure 4. MATLAB / Simulink Model of the system when fault occurs at 33.6 kV side

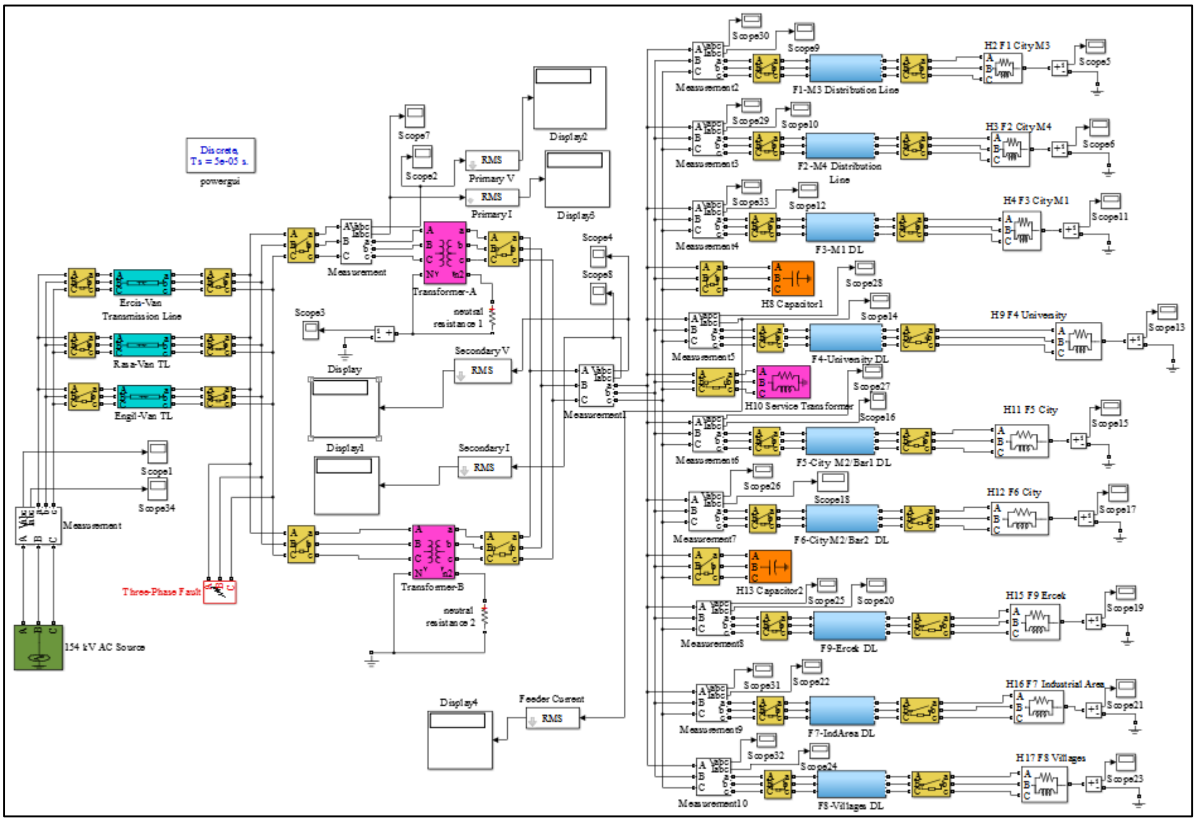


Figure 5. MATLAB / Simulink Model of the system when fault occurs at 154 kV side

Table 1 describes the loading values of distribution lines. These are actual values and taken directly from 154 kV Van Substation feeders. Also feeders are described by their actual names in system.

Table 1. Loading values of study system.

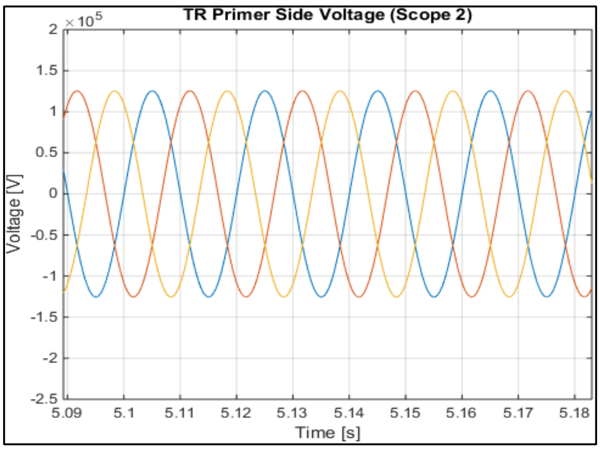
FEEDER	P (MW)	Q(MVAR)
H-2F-2 CITY M3	17	1.7
H-3 F-2 CITY M4	25	2.5
H-4 F-3 CITY M1	20	2
H-8 CAPACITOR 1	0	10
-9 F-4 UNIVERSITY	2.2	0.22
H-10 SERVICE TR	0.1	0.04
H-11 F-5 CITY M2	29	2.9
H-12 F-6 CITY M2	15	1.5
H-13 CAPACITOR 2	0	10
H-15 F-9 ERÇEK	12	1.2
H-16 F-7 IND. AREA	0.3	0.03
H-17 F-8 VILLAGES	6	0.6

4. Simulation Results

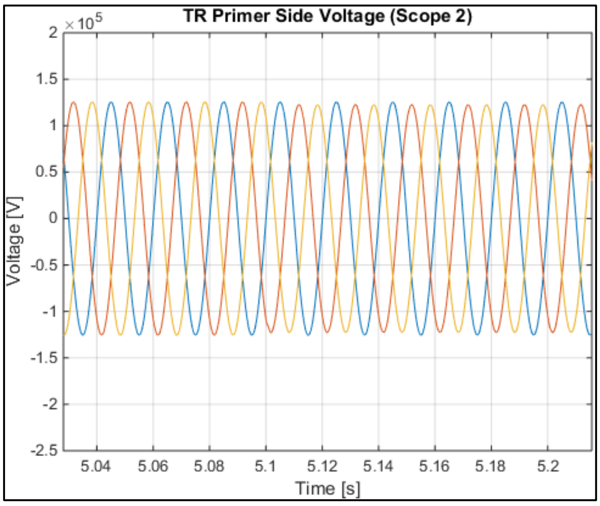
Effects of line-to-line short circuit fault at various points of the system are given comparative by normal operation conditions graphs as follows. Two case studies are performed for analysis. In the first case, it is assumed that fault between B and C phases occur on F4 feeder at the secondary side (33.6 kV) of substation. In the second case, fault between B and C phases occur same as case study one at primary side (154 kV) of substation. Fault started at 5.1th second of simulation.

Case Study 1. Seconder (33.6 kV) Side Fault

It is assumed that fault between B and C phases occur on F4 feeder at the secondary side (33.6 kV) of substation. Graphs are obtained via measurement blocks at various points of system and discussed comparatively by normal operation conditions.

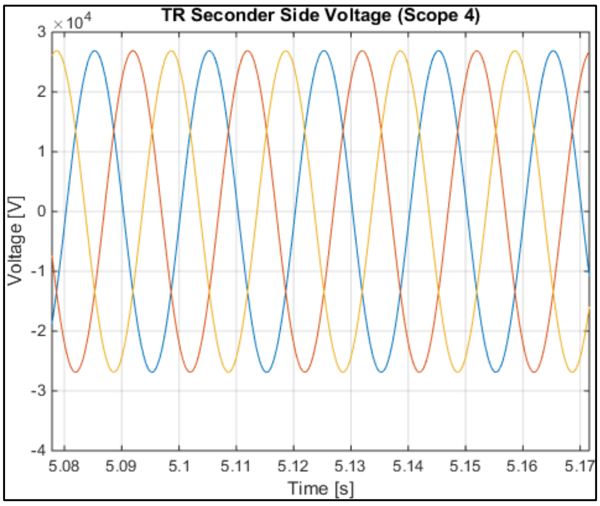


(a)

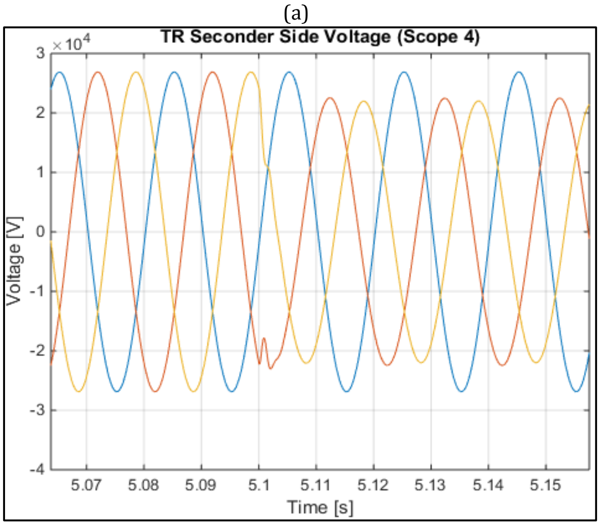


(b)

Figure 6. Substation primer side voltage a) normal operation b) fault condition

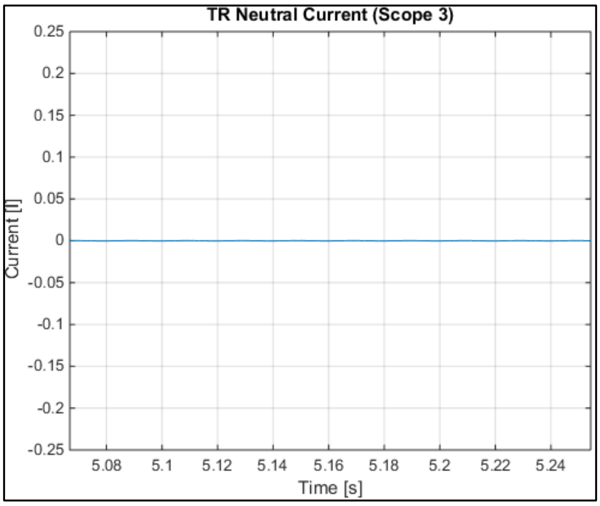


(a)



(b)

Figure 7. Substation seconder side voltage a) normal operation b) fault condition



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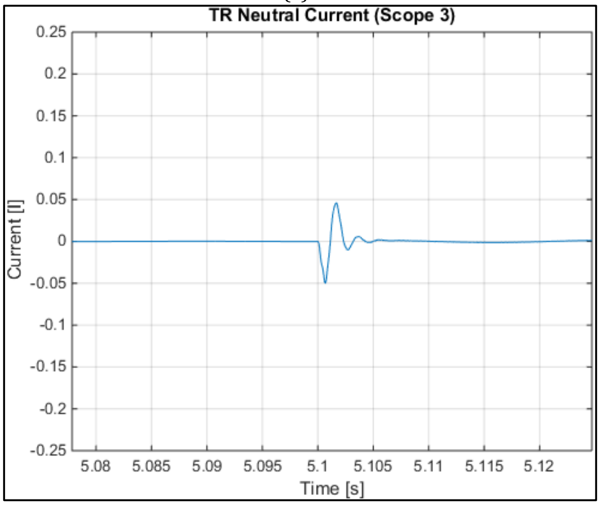
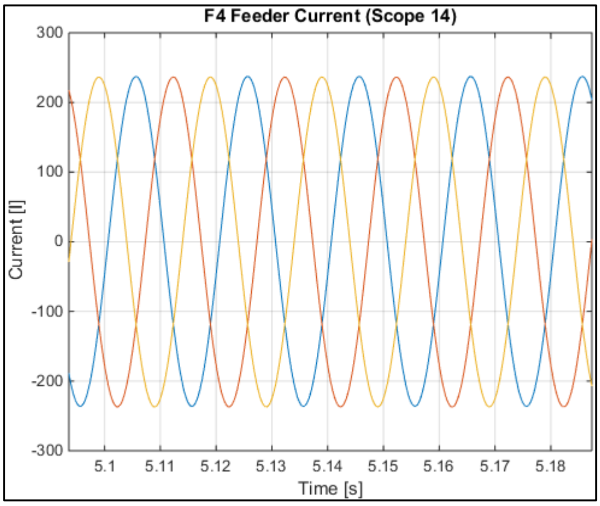
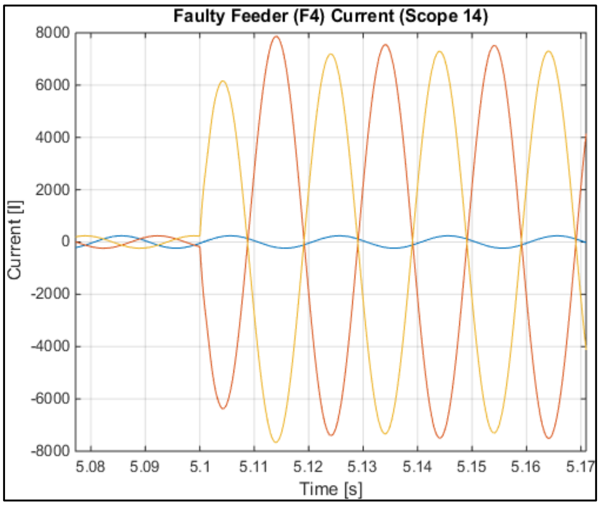


(b)

Figure 10. Transformer neutral current a) normal operation b) fault condition

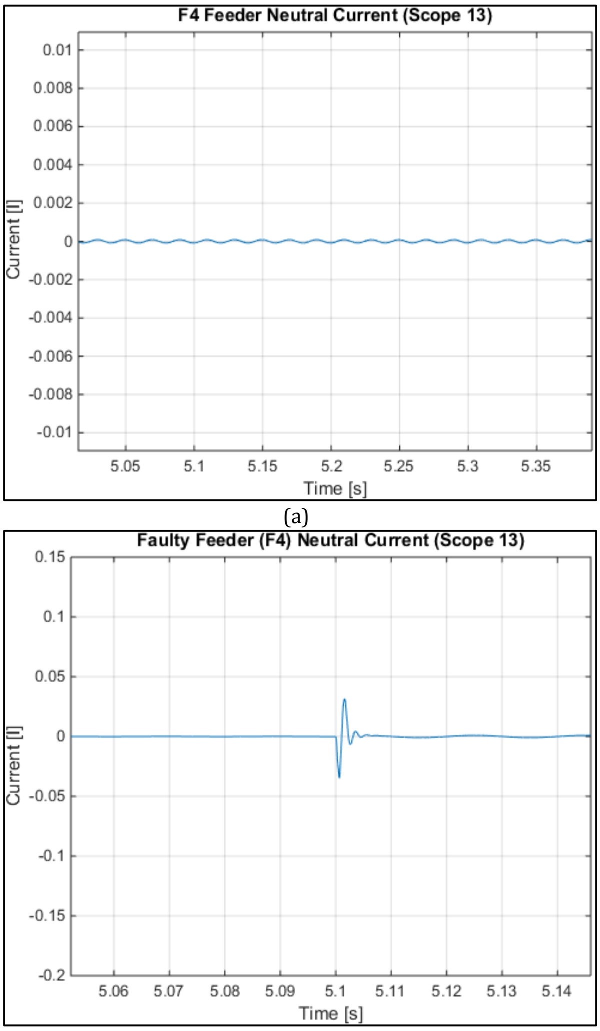


(a)



(b)

Figure 11. Faulty feeder current a) normal operation b) fault condition



(b)

Figure 12. Faulty feeder neutral current a) normal operation b) fault condition

5. Discussion and Conclusion

In this study phase-to-phase short circuit currents at 154 kV Van substation are examined using MATLAB Simulink.

Phase-to-phase faults at 154 kV Van substation input (154 kV side) and output (33.6 kV side) feeders are modelled as an example. Current and voltage graphs, current and voltage values are obtained from different points of substation according to simulation results. This study differs from other studies on substation Simulink modelling such that all short circuit types are examined by both modelling on primary and secondary side of the substation.

Substation input and output voltage levels are observed to decrease according to the results of 154 kV Van substation modelling. Decrease of voltage level during short circuit causes degradation in energy continuity and quality.

Results of this study can guide engineers and power system designers for important points which have to pay attention on, especially during design stage of power systems.

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