**DE1_Appendix VI**

# Application of EMTP for Investigation of the Performance of LV Earthing Systems

## Table of Contents

1. Introduction ..... 3
2. EMTP application in conceptual TN and TT networks..... 4
2.1. TN System ..... 4
2.2. TT System ..... 7
3. Study Case LV network..... 11
4. Short discussion..... 44
5. Conclusions ..... 45

# 1. Introduction

The analysis of the grounding requirements and protection implications of the microgrids necessitates the use of suitable modelling and simulation tools. One appropriate package for this purpose is EMTP, which is extensively used for the analysis of power systems and networks of all voltage levels, primarily for the study of fast electromagnetic transients. EMTP can provide a simulation platform with proven accuracy and more than adequate modelling capabilities of the various system elements and network topologies. The potential of utilizing EMTP for the analysis of microgrid earthing and protection issues is being explored by ICCS/NTUA within WPE and results from its application are presented in this report.

EMTP is first applied for the simulation of the voltages and currents in conceptual networks with TN and TT earthing systems in case of earth faults and its results are compared with the standard engineering calculations performed by hand. Then, EMTP is applied to the realistic study case LV network elaborated by ICCS/NTUA, both in its state without any distributed energy sources and in its envisaged microgrid development, with dispersed microsources. The two main earthing systems considered are TN and TT, since only these are used in public distribution networks (the IT scheme is applied only in private installations with increased continuity of supply requirements). The objective of this step is to explore the efficiency of EMTP in simulating more extended networks, as well as to obtain results on the performance of the existing earthing arrangements of the network in grid-connected or isolated mode.

## 2. EMTP application in conceptual TN and TT networks

### 2.1. TN System

The simplified TN network structure is illustrated in Figure 1. When an insulating fault is present, the fault current Id is only limited by the impedance of the fault loop cables (see fig. 1):

$$Id = \frac{Uo}{Rph_1 + Rd + R_{PE}} \tag{2.1}$$

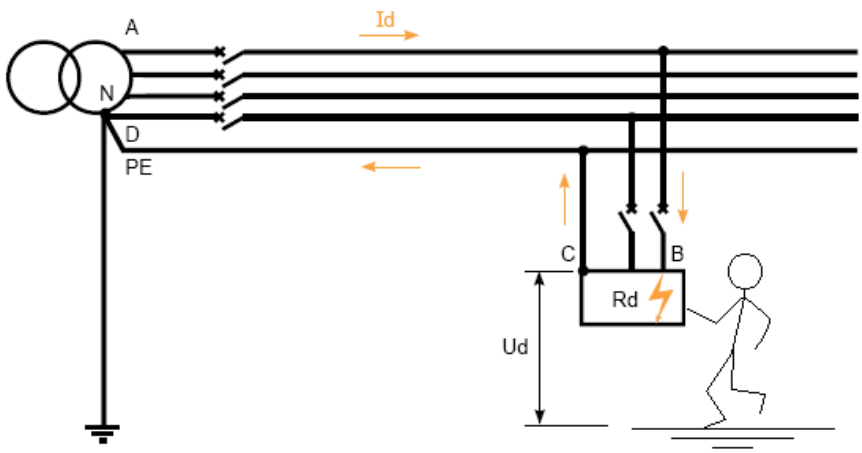



**Figure.1: TN Earthing System.**

For a feeder and a fault with Rd ≈ 0:

$$Id = \frac{0.8 \cdot Uo}{Rph_1 + R_{PE}} \tag{2.2}$$

where it is accepted that the impedances upstream the relevant feeder cause a voltage drop of around 20 % on phase-to-neutral voltage Uo, which is the nominal voltage between phase and earth. Id thus induces a fault voltage with respect to earth:

$$Ud = R_{PE} Id \tag{2.3}$$

Substituting Id from above, under the assumptions $R_{PE} = Rph$ and $Rd = 0$:

$$Ud = 0.8 \cdot Uo \frac{R_{PE}}{Rph_1 + R_{PE}} \Rightarrow Ud = \frac{0.8Uo}{2} \tag{2.4}$$

For 230/400 V networks, this voltage of around Uo/2 (if $R_{PE}$ = Rph) is dangerous since it exceeds the safety limit, even in dry atmospheres ($U_L$ = 50 V). The installation or part of the installation must then be automatically and promptly de-energised.

A simple circuit used to investigate the performance of the TN-S system is constructed using ATPDraw program and shown in Figure 2. The impedance of the voltage source in Figure 2 corresponds to a 400 kVA transformer with 1.13 p.u. resistance and 3.83 p.u. inductance (hence R = 0.0046 Ω, L = 0.048 mH). For the phase and neutral cables the series resistance is 0.320 Ω/km, the series inductance is 0.230 mH/km and the shunt capacitance 0.60 μF/km. The source neutral earthing resistance is 3Ω, whereas the load earthing resistance is 10 Ω. The RLC load consists of a 6.793 Ω resistance connected in series with a 16 mH inductance.

The time domain solution of the network for the fault shown is illustrated in Figure 3. The switch closes at the time of fault, which is 0.008 s from the start of the simulation.

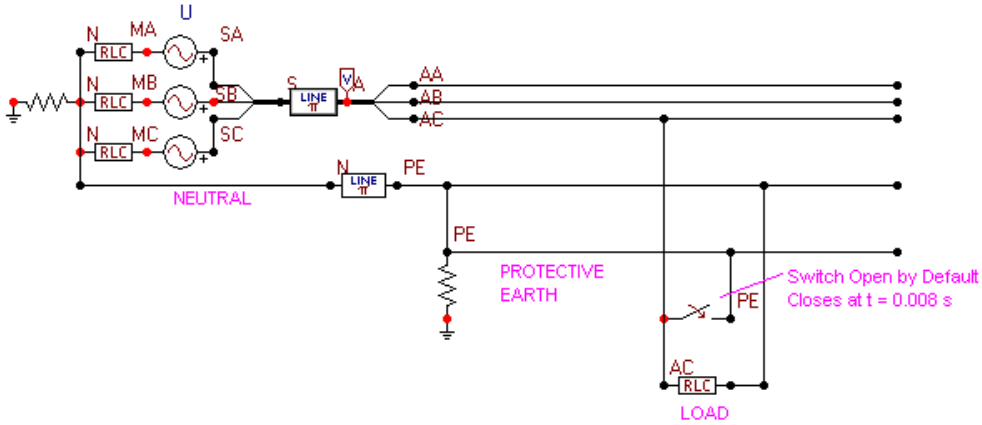



**Figure.2: ATP Draw representation of the TN-C-S Earthing System.**

Simulation results are in agreement with hand calculations. For example the max value of the total fault current Id can be estimated according to the previously proposed formula (2.1). In the TN-C-S example circuit shown in fig.2 the impedance of the neutral conductor needs to be added in the denominator resulting in the expression:

$$Id_{total} = \frac{Uo}{Rph_1 + Rd + R_{PE} + R_N} \tag{2.5}$$

It is:

$$Rph_1 + Rd + R_{PE} + R_N = \left(\left|0.018 + j \cdot 2\pi \cdot 50 \cdot 0.013 \cdot 10^{-3} + 0 + 0.018 + j \cdot 2\pi \cdot 50 \cdot 0.013 \cdot 10^{-3}\right|\right)\Omega = 0.037\Omega$$

Consequently, from (2.5) the max total fault current is:

$$Id_{total} = \frac{Uo}{Rph_1 + Rd + R_{PE} + R_N} \approx \frac{326.5986\ \text{V}}{0.037\Omega} = 8428\text{A}$$

where Uo = 230x$\sqrt{2}$ V.

More accurate calculation of $Id_{total}$ involves the synthesis of grounding resistances at “N” and “PE”, the fault loop cable impedances and the impedance of the source. The total fault loop current $Id_{total}$ can be calculated then as:

$$Id_{total} = \frac{Uo}{Z_{total}} \tag{2.6}$$

where $Z_{total} = Zph_1 + Zd + Z_{PE} + Z_N // (R_{NG} + R_{PEG}) + Z_{N-MC}$ (2.7)

$R_{NG}$ and $R_{PEG}$ are the grounding resistances of the grounding systems of the neutral and the protective earth, equal to 3Ω and 10Ω correspondingly.

Neglecting the capacitive term of the cables impedances it is :

$$Z_{total} = 0.018 + j \cdot 2\pi \cdot 50 \cdot 0.013 \cdot 10^{-3} + 0 + (0.018 + j \cdot 2\pi \cdot 50 \cdot 0.013 \cdot 10^{-3}) // 13 + 0.0046 + j \cdot 2\pi \cdot 50 \cdot 0.048 \cdot 10^{-3}$$

$$Z_{total} = (0.041 + j \cdot 0.023)\Omega$$

Substituting to (2.6) it is $Id_{total} = \frac{Uo}{Z_{total}} = \frac{326.5986V}{|0.041 + j \cdot 0.023|\Omega} = \frac{326.5986}{0.047} A = 6949A$

The ATP calculation for the total fault current results in a max value of $Id_{total}$ equal to 6984.7 A, as shown in Fig. 3.10.

The portion of $Id_{total}$ dispersed into the ground, $Id_{ToEarth}$ is calculated as $Id_{ToEarth} = Id_{total} \cdot \frac{Z_N}{R_{NG} + R_{PEG}} = 6949A \cdot 1.42 \cdot 10^{-3} = 9.866A$

And the max touch voltage Ud will be $Ud = Id_{ToEarth} \cdot R_{PEG} = 9.866A \cdot 10\Omega = 98.66V$

While from (2.4) it is Ud= 130.108V and from ATP calculations it is 99.026V as shown in fig. 3.1.

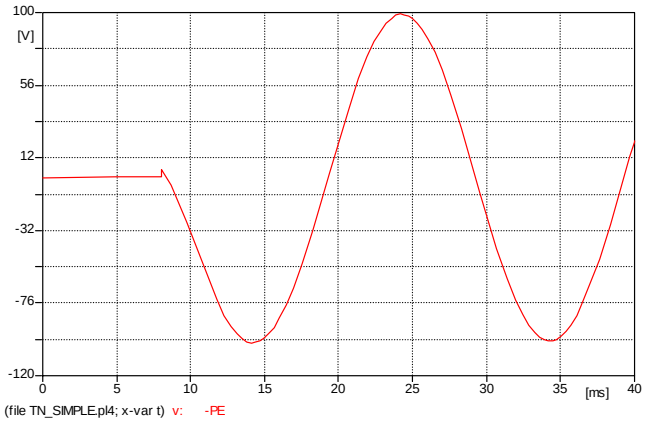



**Figure 3.1: Voltage to Earth at "PE".**

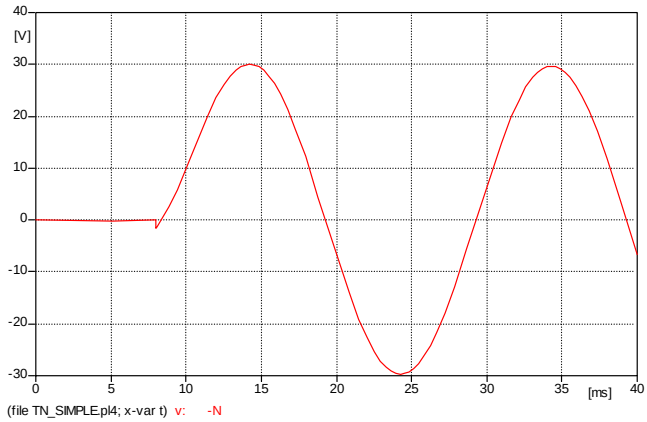



**Figure 3.2: Voltage to Earth at "N".**

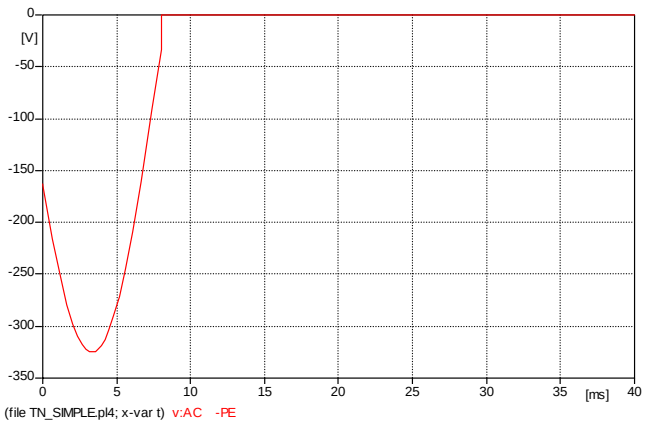



**Figure 3.3: Voltage difference at Load ends.**

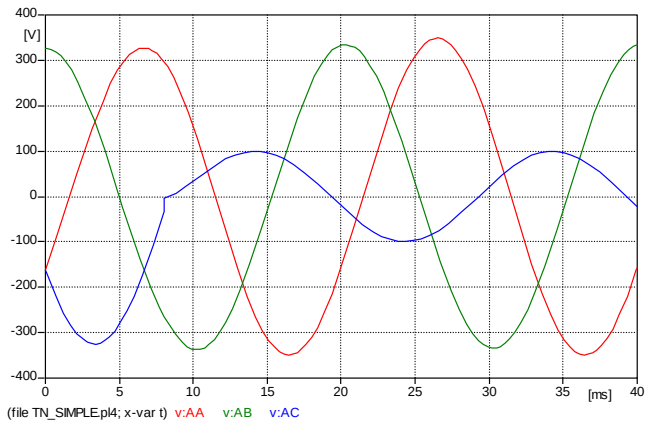
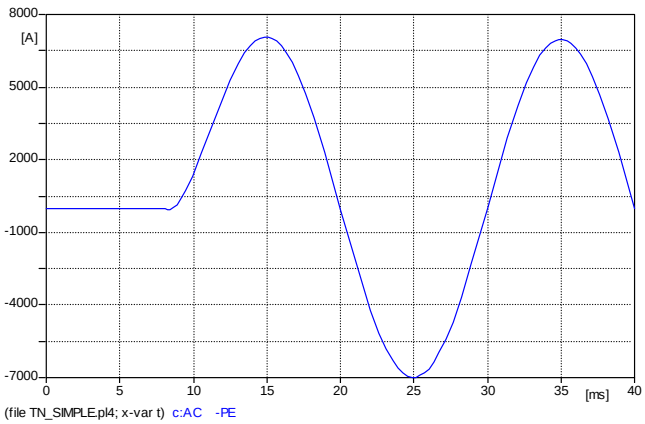



**Figure 3.4: Voltage to Earth of Phases A, B and C.**



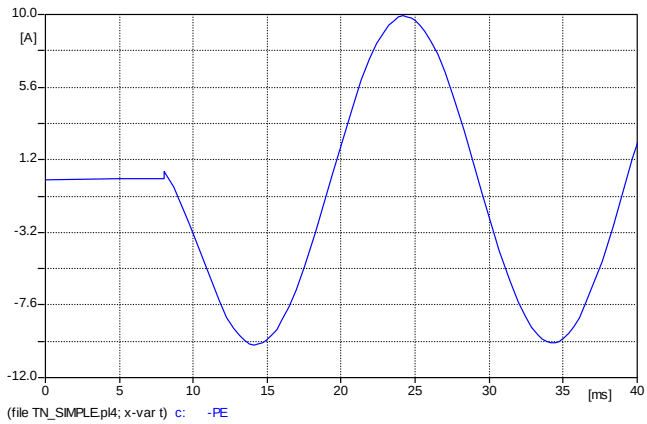



**Figure 3.5:Branch current at the fault loop("AC to PE").**

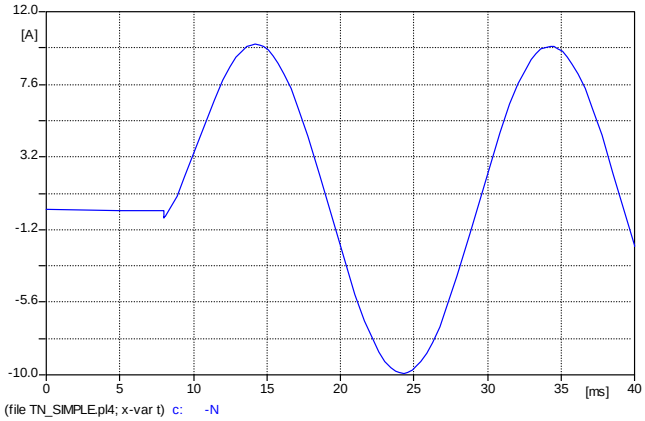



**Figure 3.6:Current to earth from the PE earthing.**

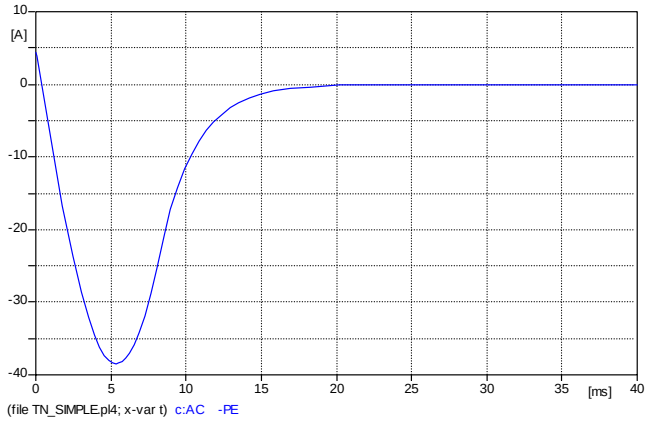



**Figure 3.7: Current to Earth from Node "N".**

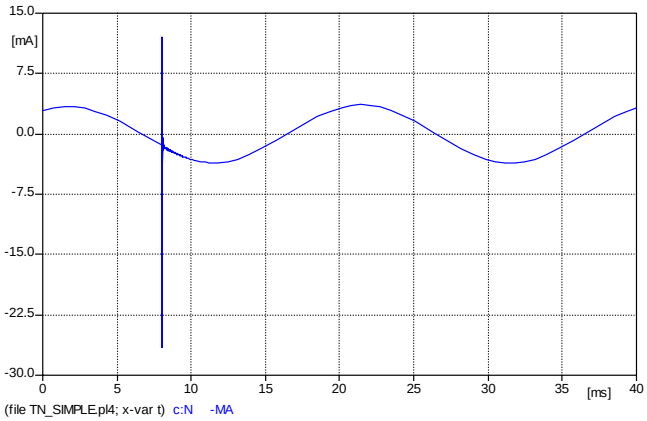



**Figure 3.8: Branch current along the Load.**

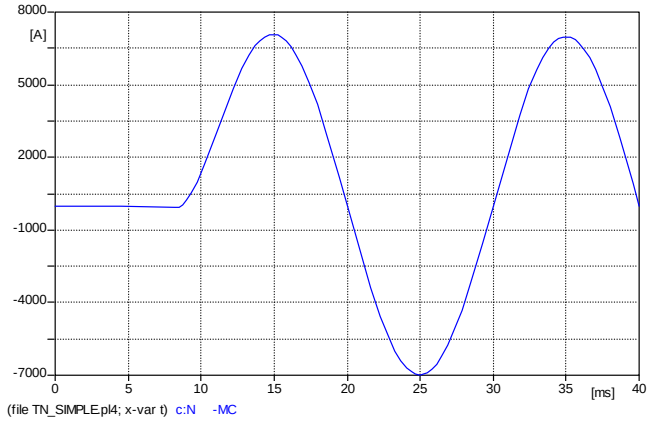



**Figure 3.9: "N to MA" branch current.**

**Figure 3.10: Branch current at the fault loop.**

**Figure 3. EMTP simulation results for the TN-C-S network of Figure 2.**

## 2.2. TT System

The TT network structure is illustrated in Figure 4. When an insulation fault occurs, the fault current Id is mainly limited by the earth resistances (if the earth connection of the frames and the earth connection of the neutral are not associated). Assuming that the fault impedance is negligible, the fault current is:

$$Id \approx \frac{Uo}{Ra + Rb} \tag{2.8}$$

This fault current induces a fault voltage in the earth resistance of the applications:

$$Ud = Ra\ Id, \text{ or } Ud = \frac{Uo \cdot Ra}{Ra + Rb} \tag{2.9}$$

As earth resistances are normally low and of similar magnitude (≈1-10 Ω), this voltage of the order of Uo/2 (for equal resistances) and therefore dangerous. The part of the installation affected by the fault must be automatically disconnected.

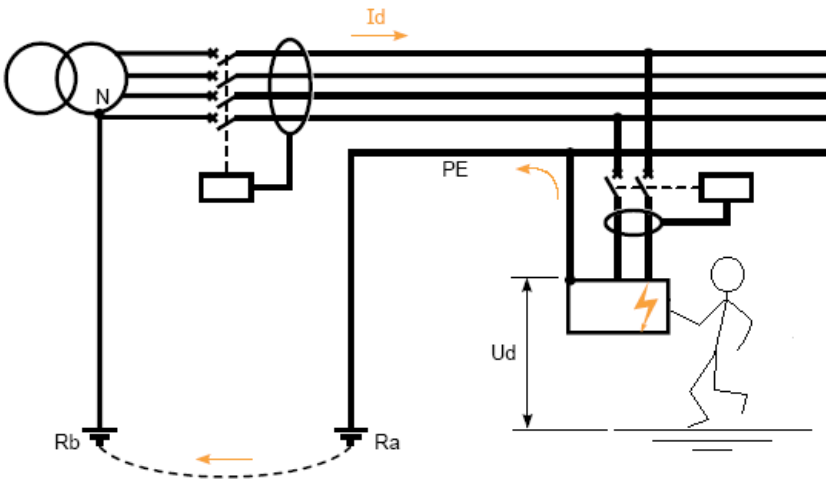



**Figure 4: TT Earthing System.**

The simple circuit used to investigate the performance of the TN-S system is constructed using ATPDraw program and shown in Figure 5. The input data for this circuit are the same as for the TN case of the previous section. The time domain solution of the network for the fault shown is illustrated in the diagrams of Figure 6.

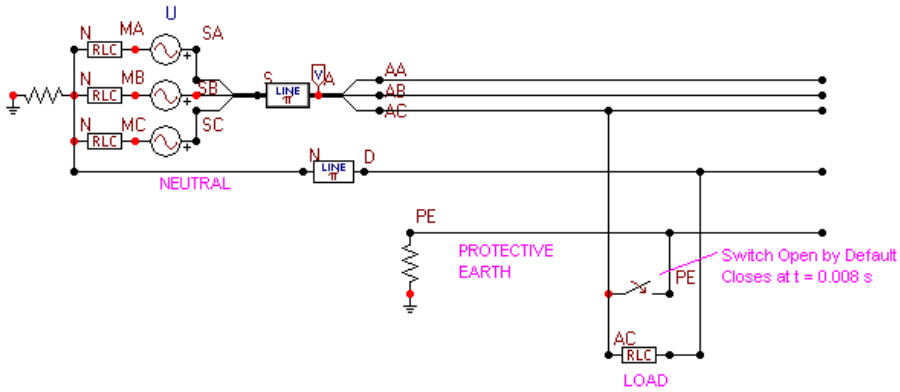



**Figure 5: ATP Draw representation of the TT Earthing System.**

Simulation results are in agreement with hand calculations. The max value of the fault current Id dispersed to ground can be estimated according to the previously proposed formula (2.8):

$$Id_{ToEarth} \approx \frac{Uo}{Ra + Rb} = \frac{230\sqrt{2}V}{13\Omega} = 25.021A \qquad (2.10)$$

More accurate calculation of $Id_{ToEarth}$ involves the synthesis of grounding resistances at "N" and "PE", the fault loop cable impedances the impedance of the source and the impedance of the load. The total fault loop current $Id_{total}$ can be calculated then as:

$$Id_{total} = \frac{Uo}{Z_{total}} \qquad (2.11)$$

where $Z_{total} = Zph_1 + Z_{N-MC} + (Z_N + Z_{LOAD})//(R_{NG} + R_{PEG} + Zd)$ (2.12)

$R_{NG}$ and $R_{PEG}$ are the grounding resistances of the grounding systems of the neutral and the protective earth, equal to 3Ω and 10Ω correspondingly.

Neglecting the capacitive term of the cables impedances it is :

$$Z_{total} = \left(0.018 + j \cdot 2\pi \cdot 50 \cdot 0.013 \cdot 10^{-3}\right) + \left(0.0046 + j \cdot 2\pi \cdot 50 \cdot 0.048 \cdot 10^{-3}\right) +$$
$$+ \left[\left(0.018 + j \cdot 2\pi \cdot 50 \cdot 0.013 \cdot 10^{-3}\right) + \left(6.793 + j \cdot 2\pi \cdot 50 \cdot 16 \cdot 10^{-3}\right)\right] // 13\Omega$$
$$Z_{total} = \left(5.011 + j \cdot 2.054\right)\Omega \qquad (2.13)$$

Consequently the max current along the phase cable will be

$$Id_{total} = \frac{Uo}{Z_{total}} = \frac{326.5986V}{\left|5.011 + j \cdot 2.054\right|\Omega} = 60.307A$$

The ATP calculation results in 60.532A maximum current along the phase cable, as shown in fig.6.6 The total current $Id_{total}$ is divided in two parts with the ratio

$$(Z_N + Z_{LOAD}) // (R_{NG} + R_{PEG} + Zd) = 1.535 \qquad (2.14)$$

Consequently the max fault current $Id_{ToEarth}$ dispersed into the ground through the grounding systems of the neutral and the protective earth is calculated 23.789 A

The ATP calculation results in max $Id_{ToEarth}$ = 25.077A as shown in figures 6.7 and 6.8.

Consequently the max touch voltage will be equal to $Ud = Id_{ToEarth} \cdot R_{PEG}$ = 250.77V while from (2.9) it equals 250.207 and from ATP calculation it is 249.92 V as shown in fig.6.1.

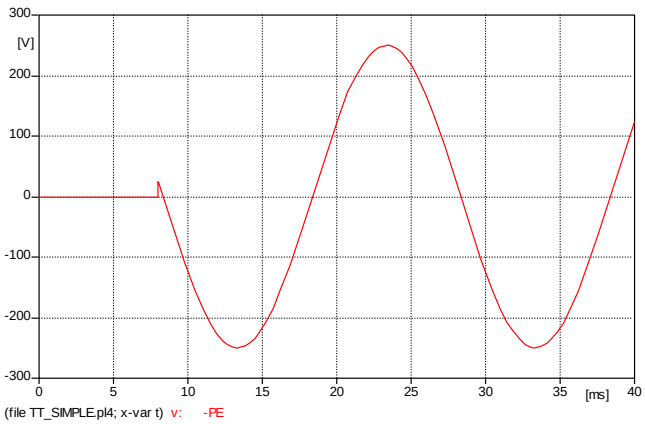



**Figure 6.1: Voltage to Earth at "PE".**

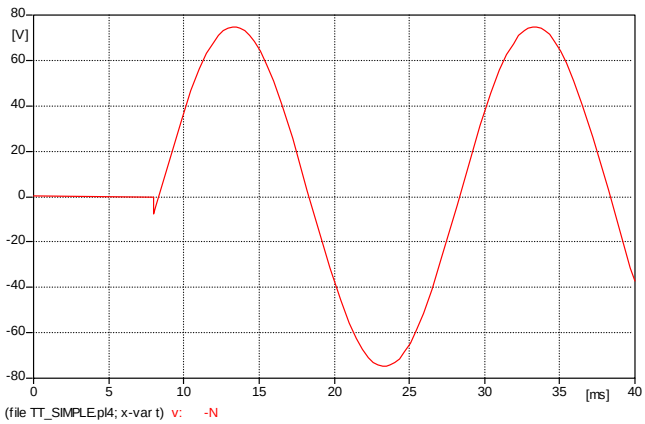



**Figure 6.2: Voltage to Earth at "N".**

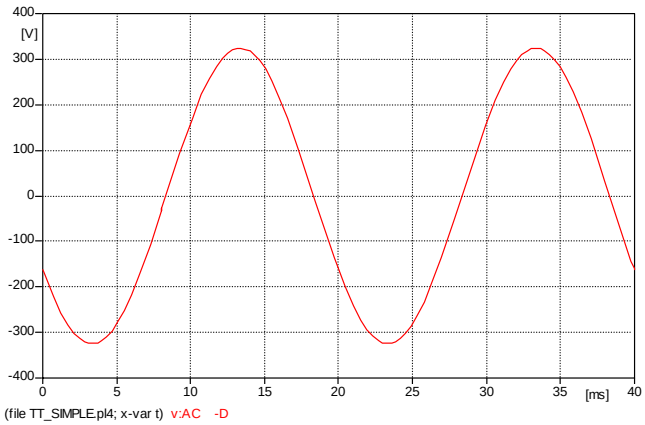



**Figure 6.3: Voltage difference between Load ends.**

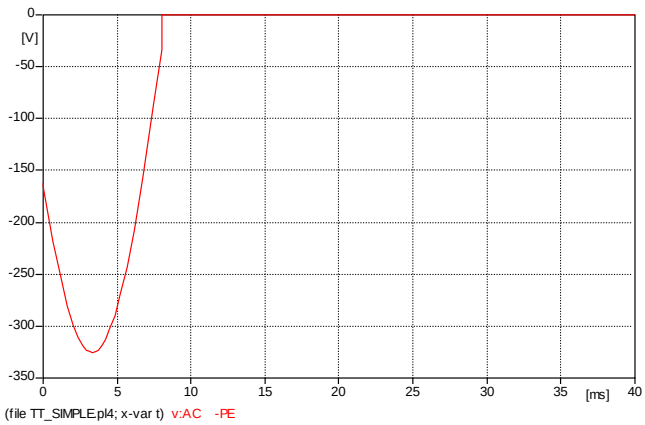



**Figure 6.4: Voltage difference between "AC" and "PE".**

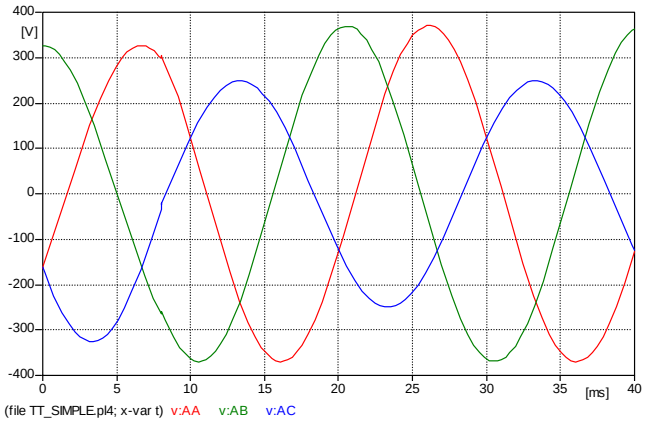



**Figure 6.5: Phase Voltages to Earth.**

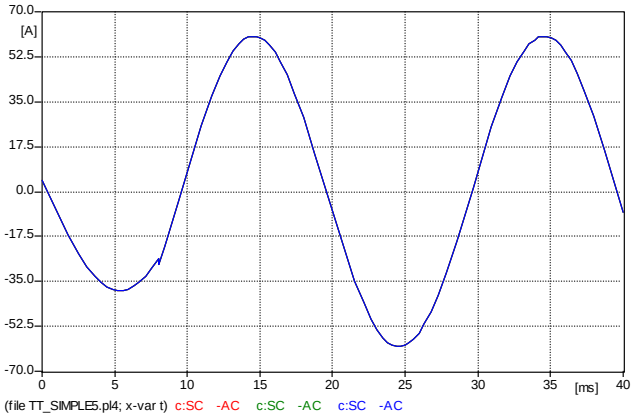



**Figure 6.6: Branch Current along the phase cable.**

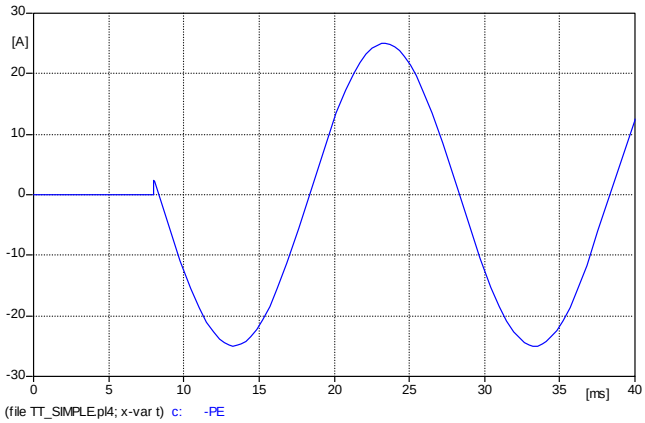



**Figure 6.7: Current to earth from PE earthing.**

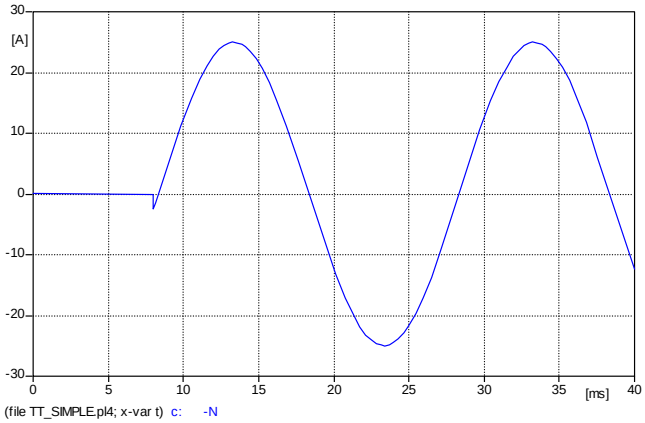



**Figure 6.8: Current to earth from Neutral Earthing.**

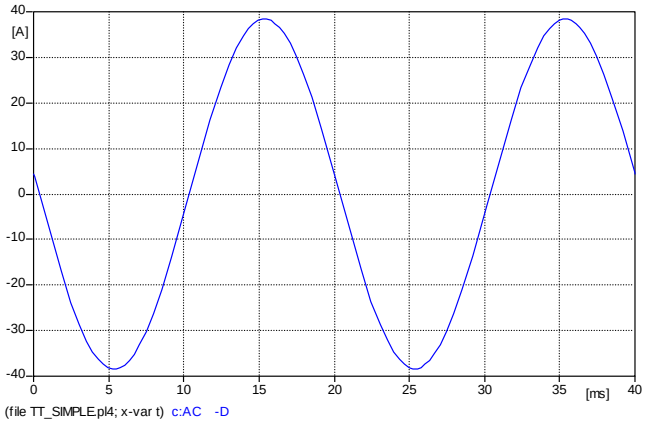



**Figure 6.9: Branch current along the Load.**

**Figure 6. EMTP simulation results for the TT network of Figure 5.**

## 3. Study Case LV network

In Fig. 10 the LV study case network considered is illustrated. Line parameters used are according to the following table.

| Line type | R (Ω/km) | X (Ω/km) | $R_n$ (Ω/km) |
|---|---|---|---|
| Overhead - Twisted cable 4x120 $mm^2$ Al | 0.284 | 0.083 | 0.284 |
| Overhead - Twisted cable 3x70 $mm^2$ Al + 54.6 $mm^2$ AAAC | 0.497 | 0.100 | 0.630 |
| Overhead – Conductors 4x50 $mm^2$ Al | 0.397 | 0.279 | |
| Overhead – Conductors 4x35 $mm^2$ Al | 0.574 | 0.294 | |
| Overhead – Conductors 4x16 $mm^2$ Al | 1.218 | 0.318 | |
| Underground – XLPE cable 3x150 $mm^2$ Al + 50 $mm^2$ Cu | 0.264 | 0.071 | 0.387 |
| Connection - Cable 4x6 $mm^2$ Cu | 3.410 | 0.094 | |
| Connection - Cable 4x16 $mm^2$ Cu | 1.380 | 0.085 | |
| Connection - Cable 4x25 $mm^2$ Cu | 0.870 | 0.083 | |
| Connection - Cable 3x50 $mm^2$ Al + 35 $mm^2$ Cu | 0.462 | 0.077 | 0.526 |
| Connection - Cable 3x95 $mm^2$ Al + 35 $mm^2$ Cu | 0.410 | 0.071 | 0.524 |

The faults considered are single phase to ground faults, which are the most common, in the consumer premises. The two extreme cases of fault at the ends of the LV feeder are examined.

The analysis includes the two basic operating modes, that is grid-connected and isolated from the network. In the latter case, the most grave scenario is considered where not only the interconnection breaker is open but also the cable neutral is interrupted, due to damage of cable, which results in losing the low earthing resistance of the MV/LV substation.

In the grid-interconnected mode, microsources are not taken into account since their contribution to the fault is very small compared to the network's (one order of magnitude in general). In the isolated mode, the network is assumed to be fed by a 50 kVA three-phase central inverter (batteries or flywheel) installed at Node 2. The inverter provides a neutral conductor earthed at the supply point of the installation (earthing resistance 10 Ω). Other microsources are not included, mainly because suitable EMTP models were not available. For the central inverter two distinct cases have been analysed: a) without restriction on its fault current magnitude b) with restriction on the fault current magnitude, taken equal to three times the its rated current.

Based on the above, the following four cases are simulated in the following:

1. First Case: TN-S type of grounding. Short circuit at load 1. Grid-connected mode with no micro-sources in the network.
2. Second Case: TN-S type of grounding. Short circuit at load 5. Grid-connected mode with no micro-sources in the network
3. Third Case: TN-S type of grounding. Short circuit at load 1. Isolated mode with a 50 kVA central inverter at Node 2, without current limit.
4. Fourth Case: TN-S type of grounding. Short circuit at load 1. Isolated mode with a 50 kVA central inverter at Node 2, with current limit equal to $3I_n$.
5. Fifth Case: TT type of grounding. Short circuit at load 5. Grid-connected mode with no micro-sources in the network.

6. <u>Sixth Case:</u> TT type of grounding. Short circuit at load 5. Isolated mode with a 50 kVA central inverter at Node 2, without current limit.

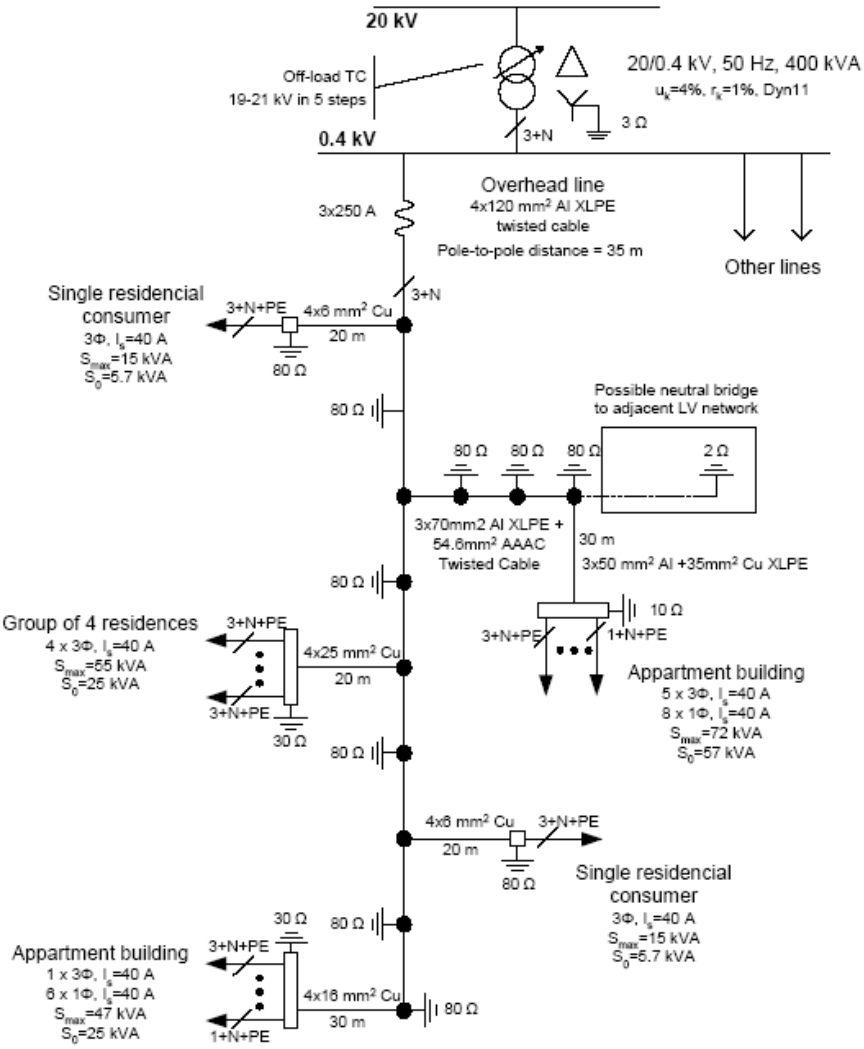



**Figure.10: One line diagram of the LV network used for simulations**

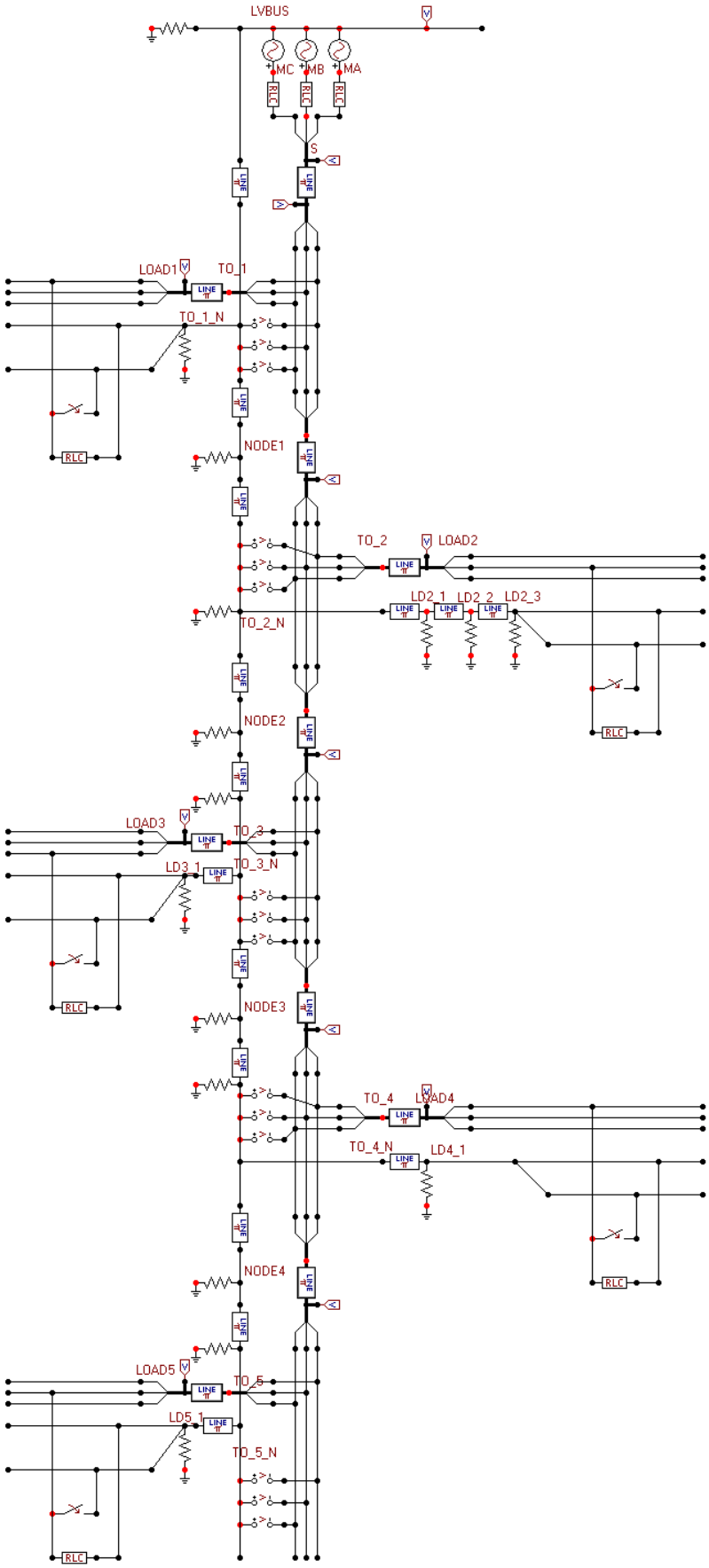



**Figure 11: ATPDraw circuit representation of the LV network that is used to simulate the first examined case.**

## Simulation Results - 1st Case

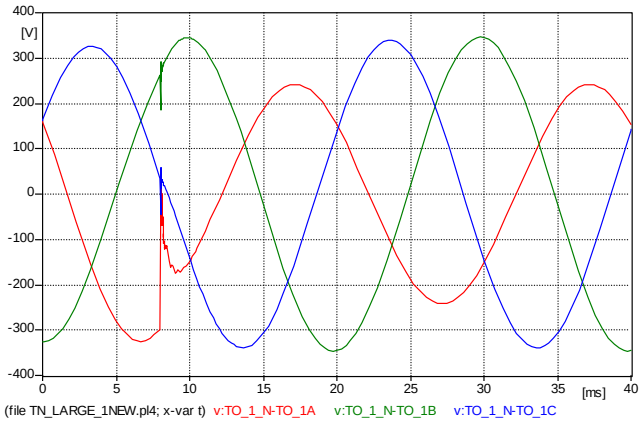



**Figure 12.1: Phase to Neutral Voltages at "TO_1_N"**

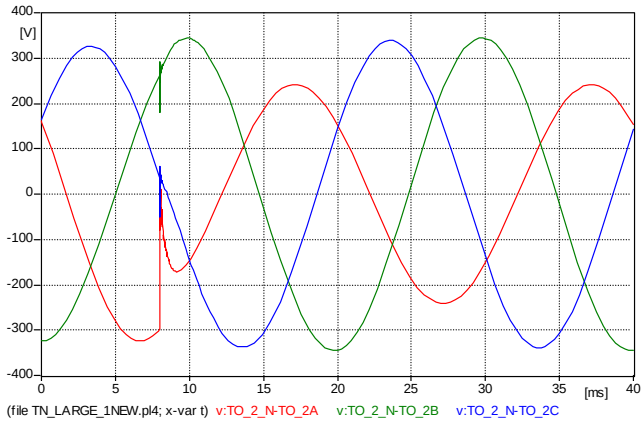



**Figure 12.2: Phase to Neutral Voltages at "TO_2_N"**

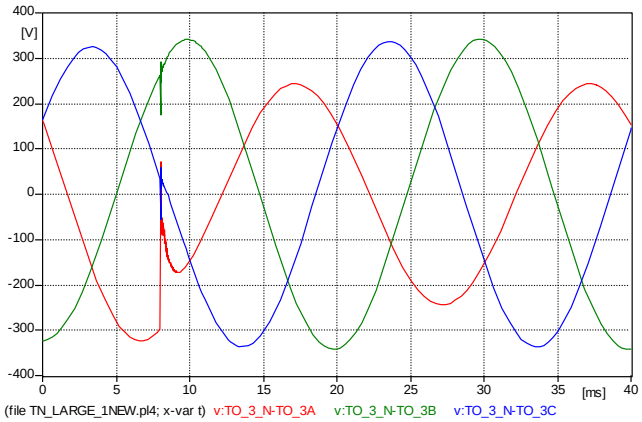



**Figure 12.3: Phase to Neutral Voltages at "TO_3_N"**

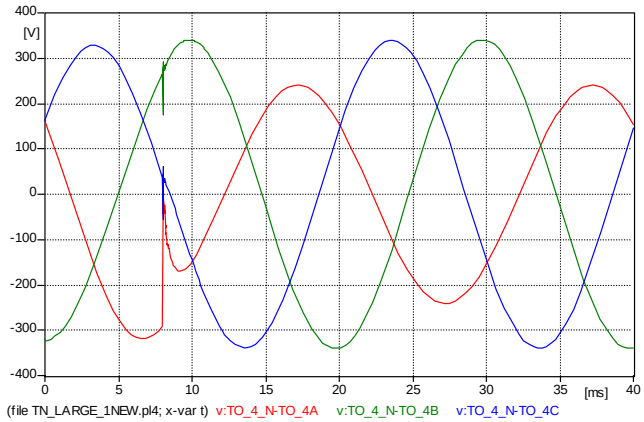



**Figure 12.4: Phase to Neutral Voltages at "TO_4_N"**

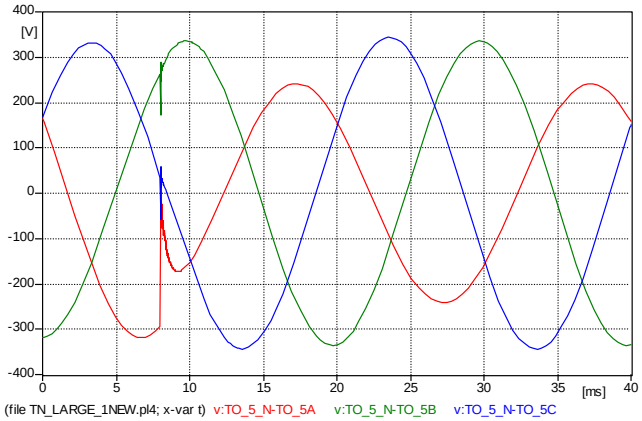



**Figure 12.5: Phase to Neutral Voltages at "TO_5_N"**

**Figure 12: Phase to Neutral Voltages at various nodes of the circuit**

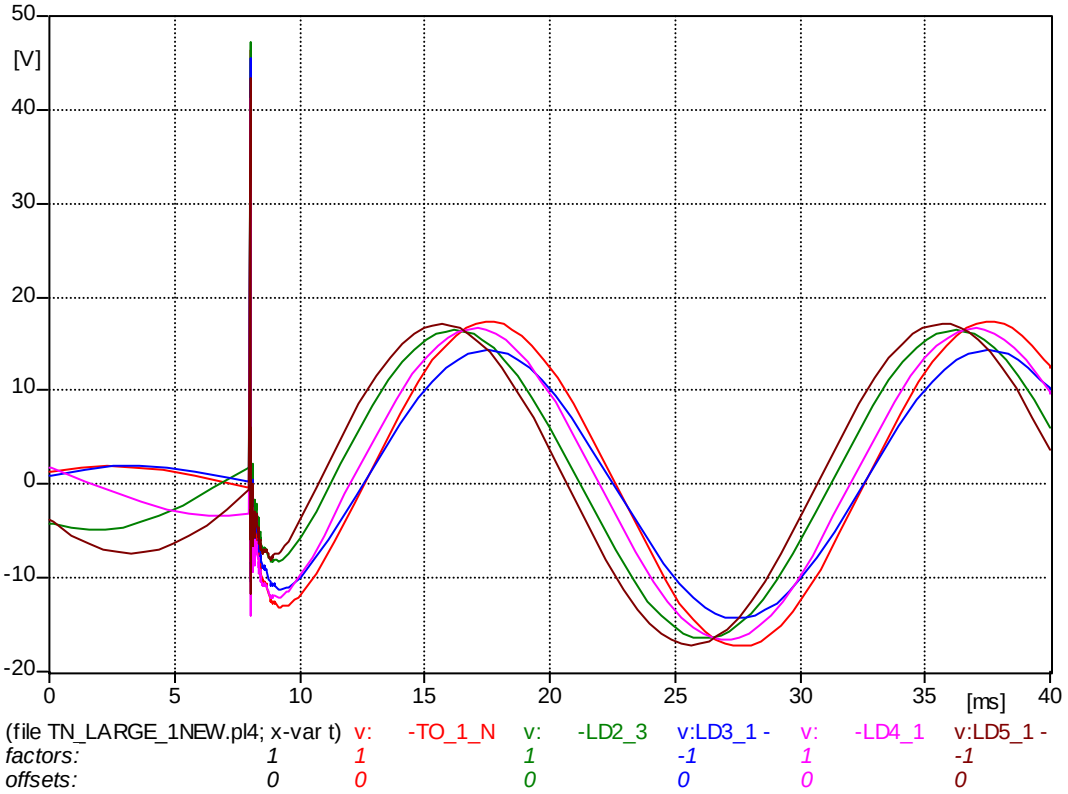



**Figure 13: Neutral and PE to Earth Voltage at 1,2,3,4 and 5**

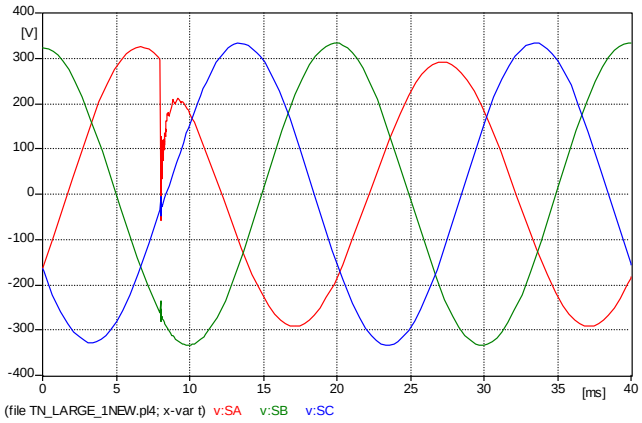



**Figure 14.1: Phase Voltages to Earth at "S"**

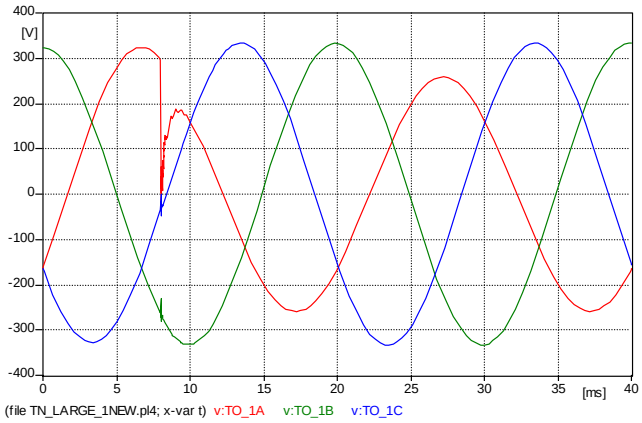



**Figure 14.2: Phase Voltages to Earth at "TO_1"**

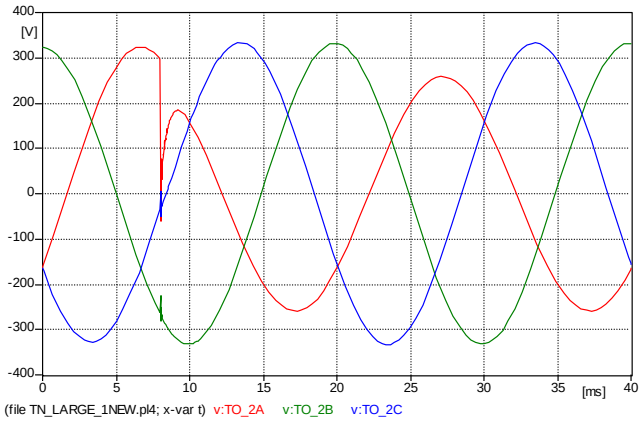



**Figure 14.3: Phase Voltages to Earth at "TO_2"**

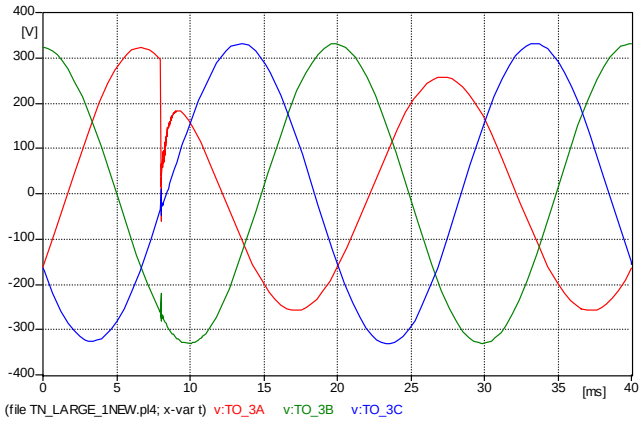



**Figure 14.4: Phase Voltages to Earth at "TO_3"**

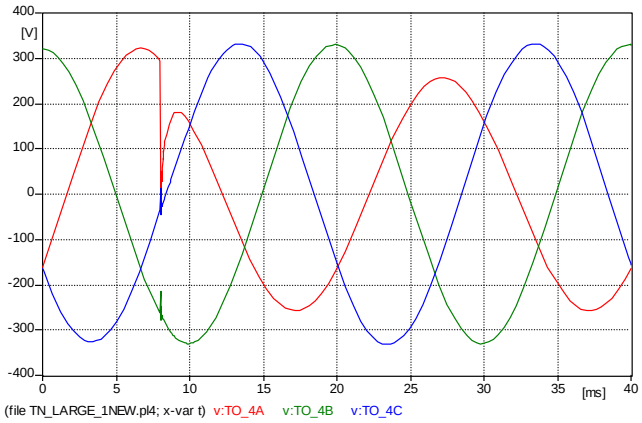



**Figure 14.5: Phase Voltages to Earth at at "TO_4"**

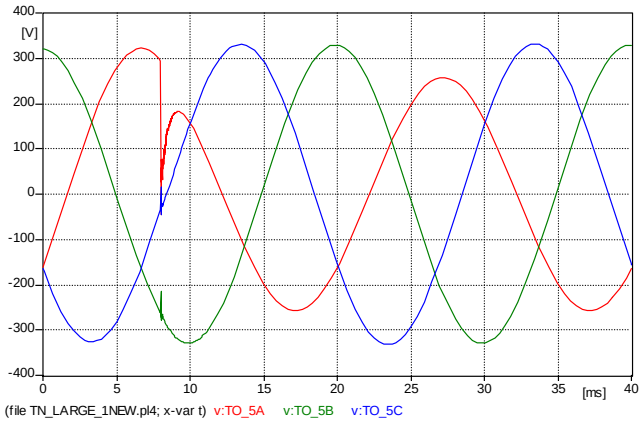



**Figure 14.6: Phase Voltages to Earth at "TO_5"**

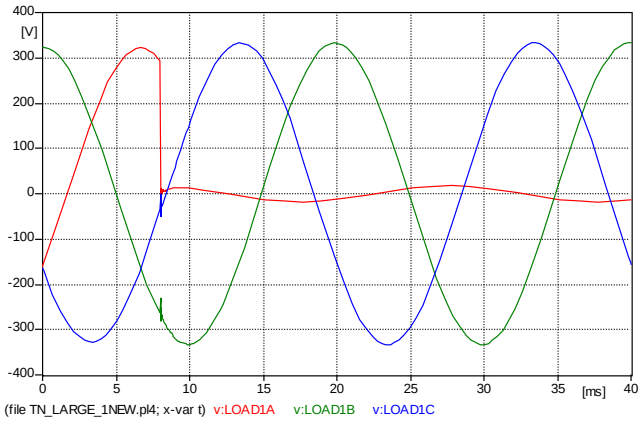



**Figure 14.7: Phase Voltages to Earth at "LOAD1"**

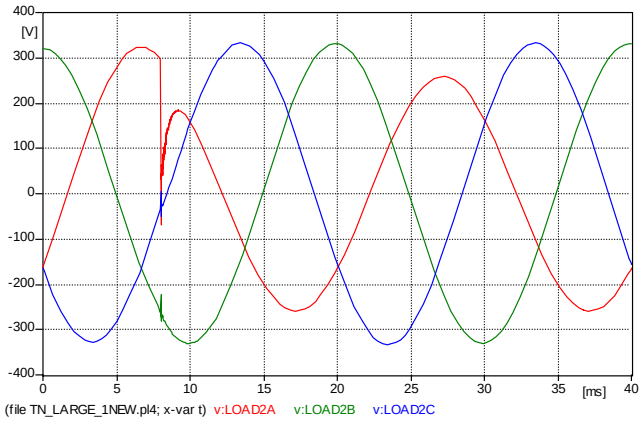



**Figure 14.8: Phase Voltages to Earth at "LOAD2"**

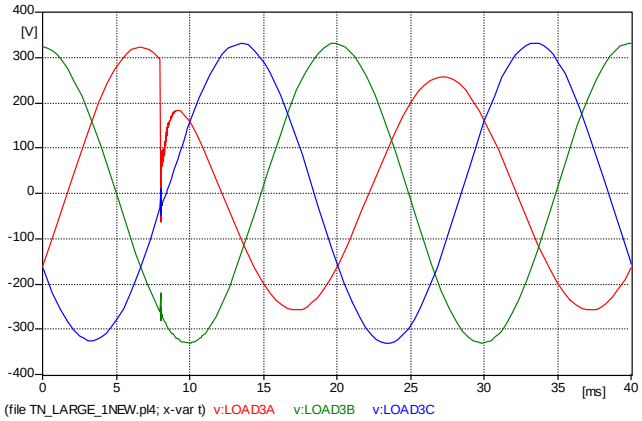



**Figure 14.9: Phase Voltages to Earth at "LOAD3"**

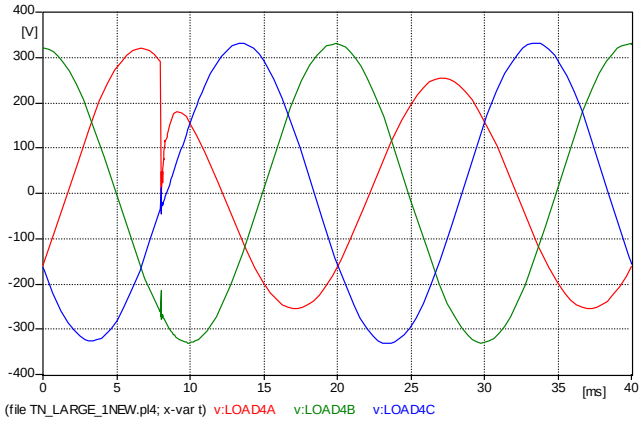



**Figure 14.10: Phase Voltages to Earth at "LOAD4"**

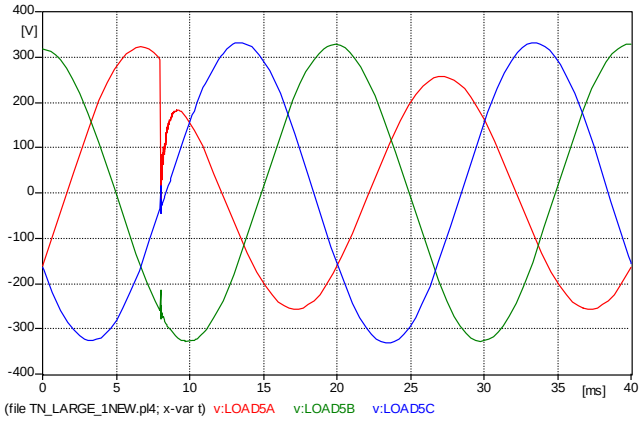



**Figure 14.11: Phase Voltages to Earth at "LOAD5"**

**Figure 14: Phase Voltages to Earth at various nodes of the circuit**

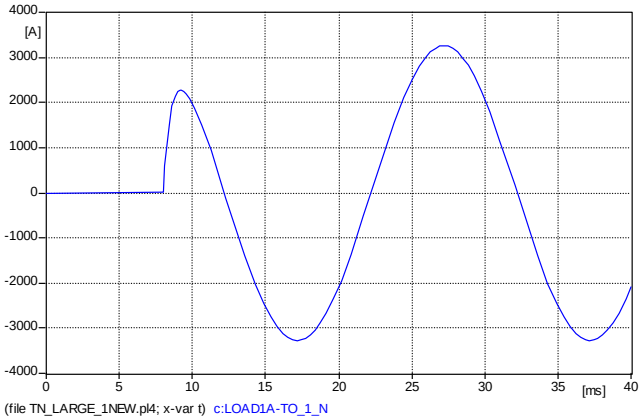



**Figure 15.1: Fault Current**

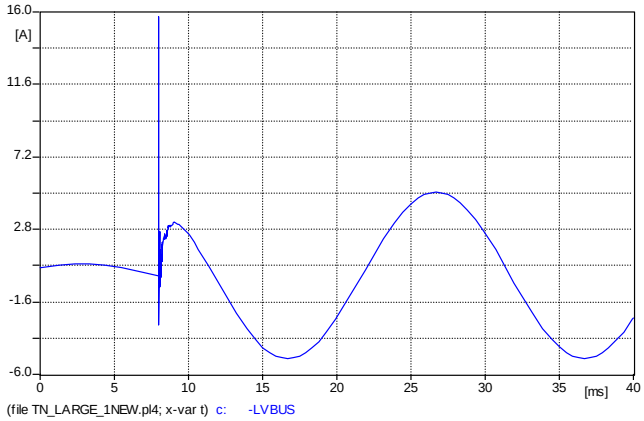



**Figure 15.2: Current to earth through "LVBUS" earthing resistance**

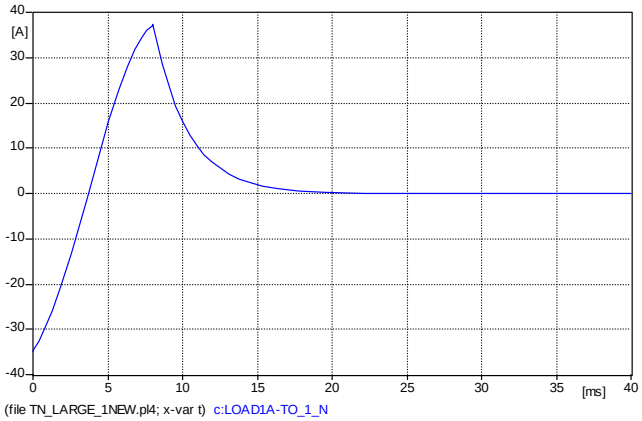



**Figure 15.3: Current along Load 1**

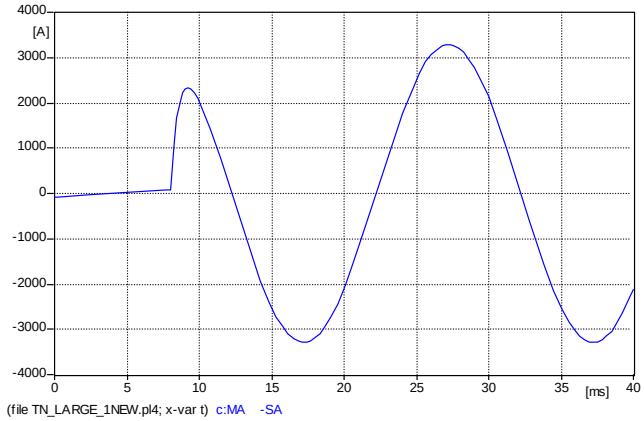



**Figure 15.4: Fault current at phase A of the source**

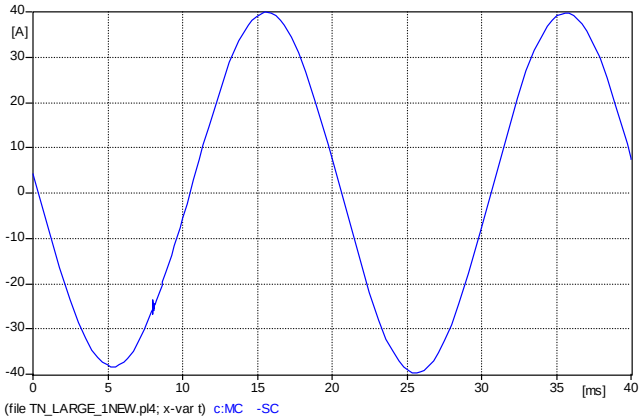



**Figure 15.5: Current at phase C of the source**

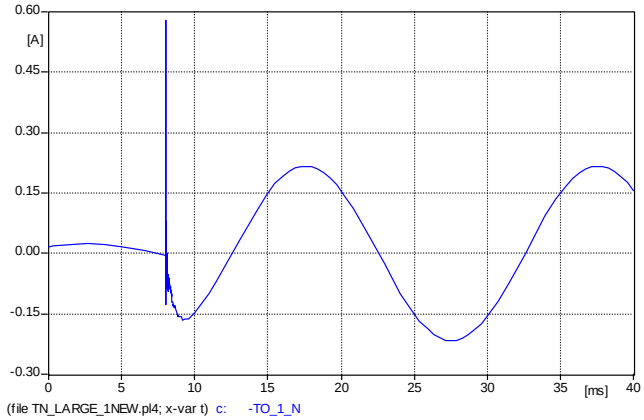



**Figure 15.6: Current to the ground at "TO_1_N"**

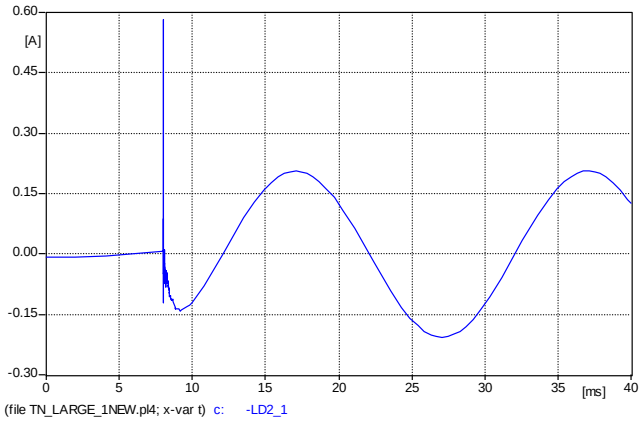



**Figure 15.7: Current to the ground at "LD2_1"**

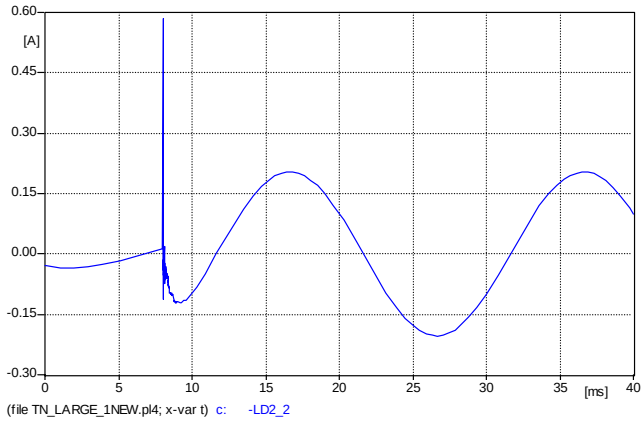



**Figure 15.8: Current to the ground at "LD2_2"**

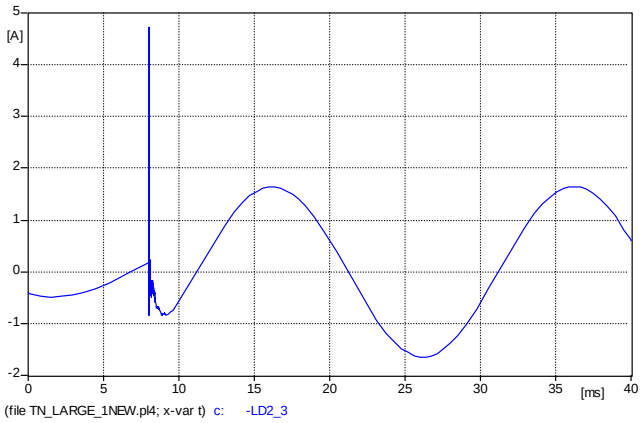



**Figure 15.9: Current to the ground at "LD2_3"**

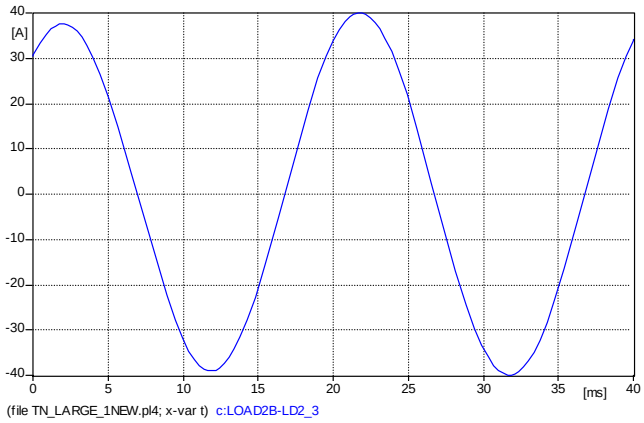



**Figure 15.10: Current along load 2**

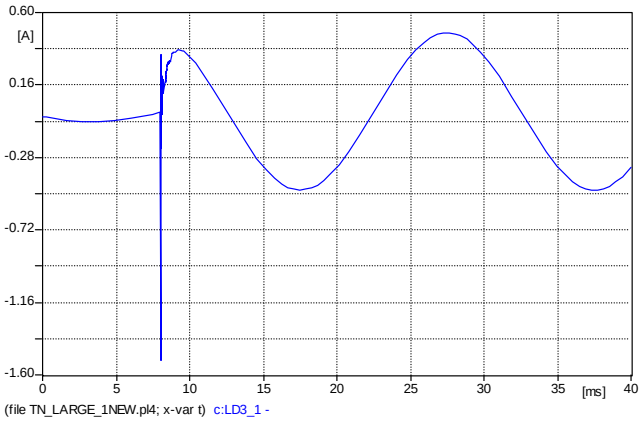



**Figure 15.11: Current to the ground at "LD3_1"**

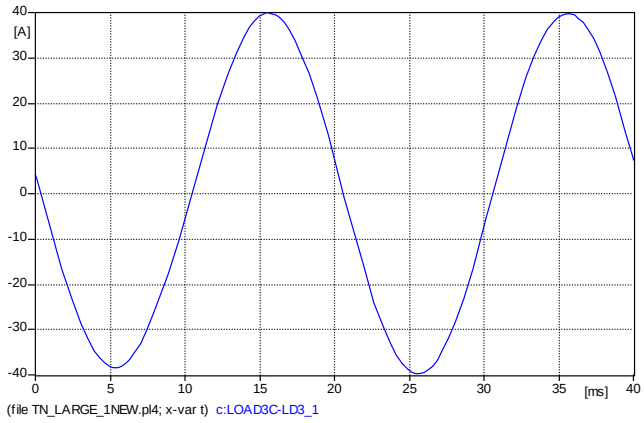



**Figure 15.12: Current along load 3**

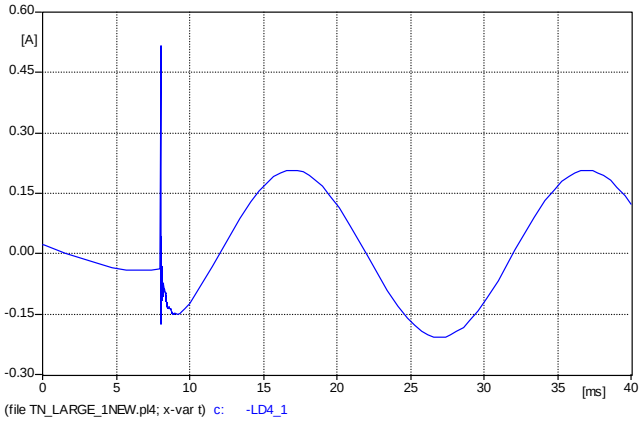



**Figure 13.13: Current to the ground at "LD4_1"**

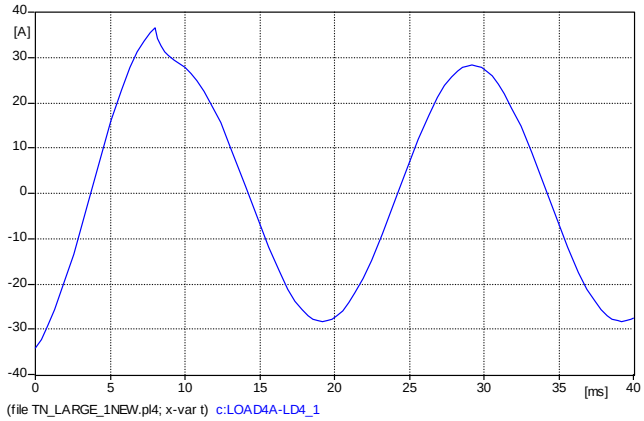



**Figure 14.14: Current along load 4**

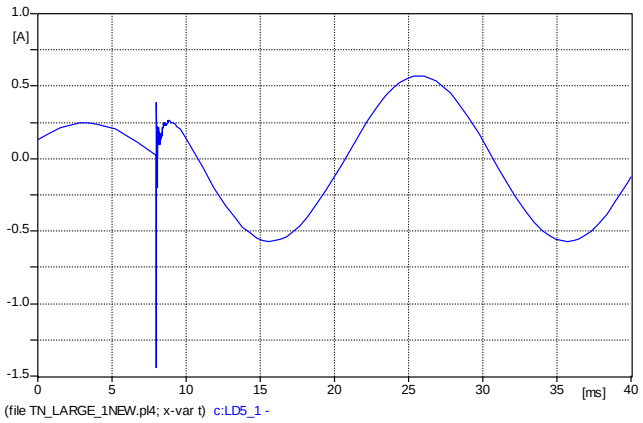



**Figure 15.15: Current to the ground at "LD5_1"**

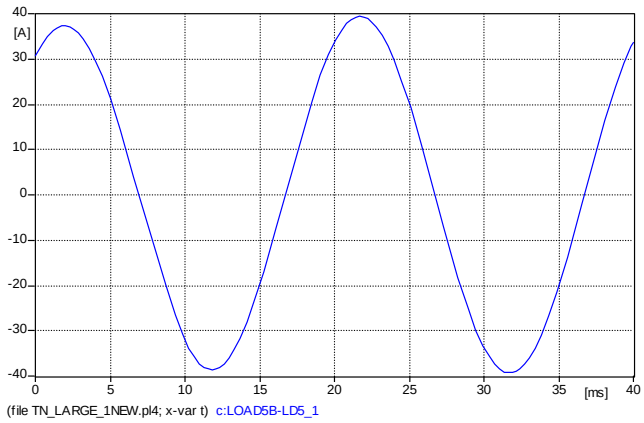



**Figure 15.16: Current along load 5**

**Figure 15: Branch Currents**

## Simulation Results – 2nd Case

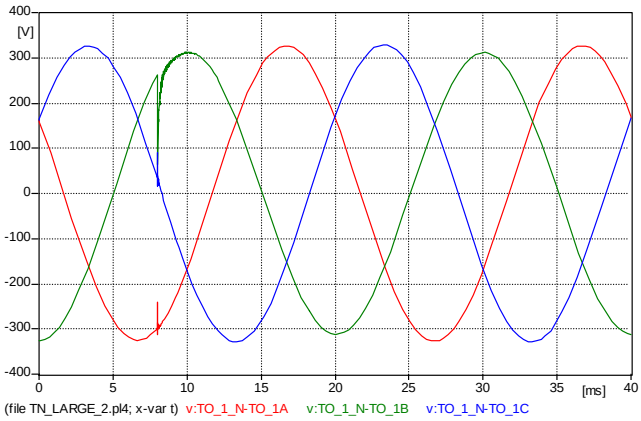



**Figure 16.1: Phase to Neutral Voltages at "TO_1_N"**

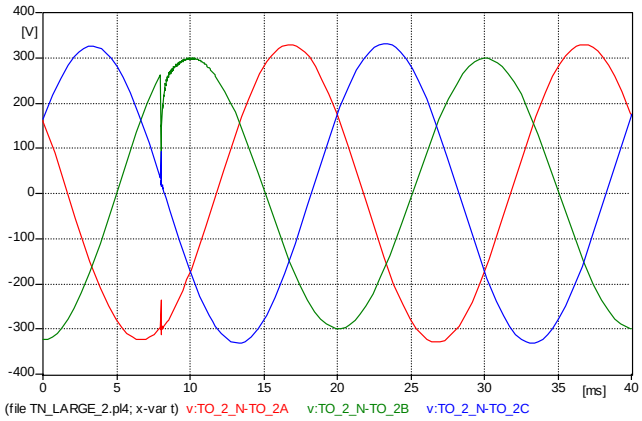



**Figure 16.2: Phase to Neutral Voltages at "TO_2_N"**

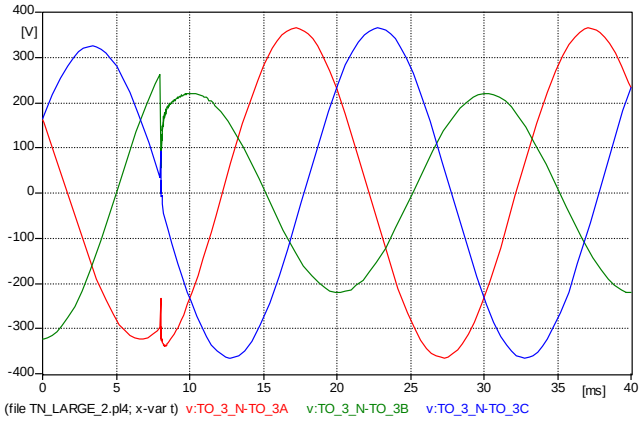



**Figure 16.3: Phase to Neutral Voltages at "TO_3_N"**

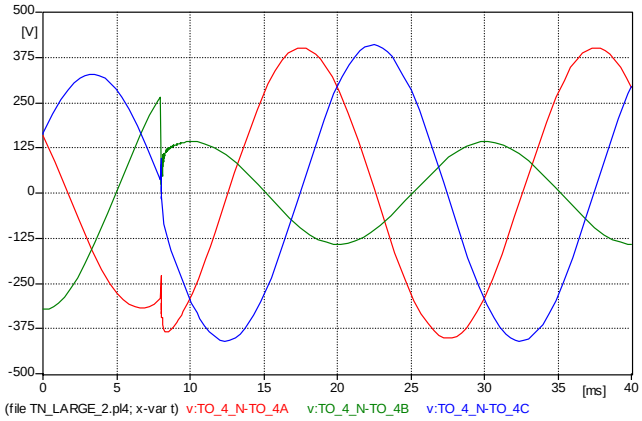



**Figure 16.4: Phase to Neutral Voltages at "TO_4_N"**

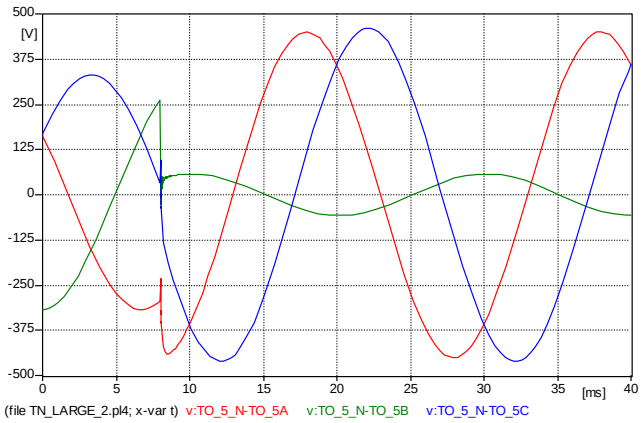



**Figure 16.5: Phase to Neutral Voltages at "TO_5_N"**

**Figure 16: Phase to Neutral Voltages at various nodes of the circuit**

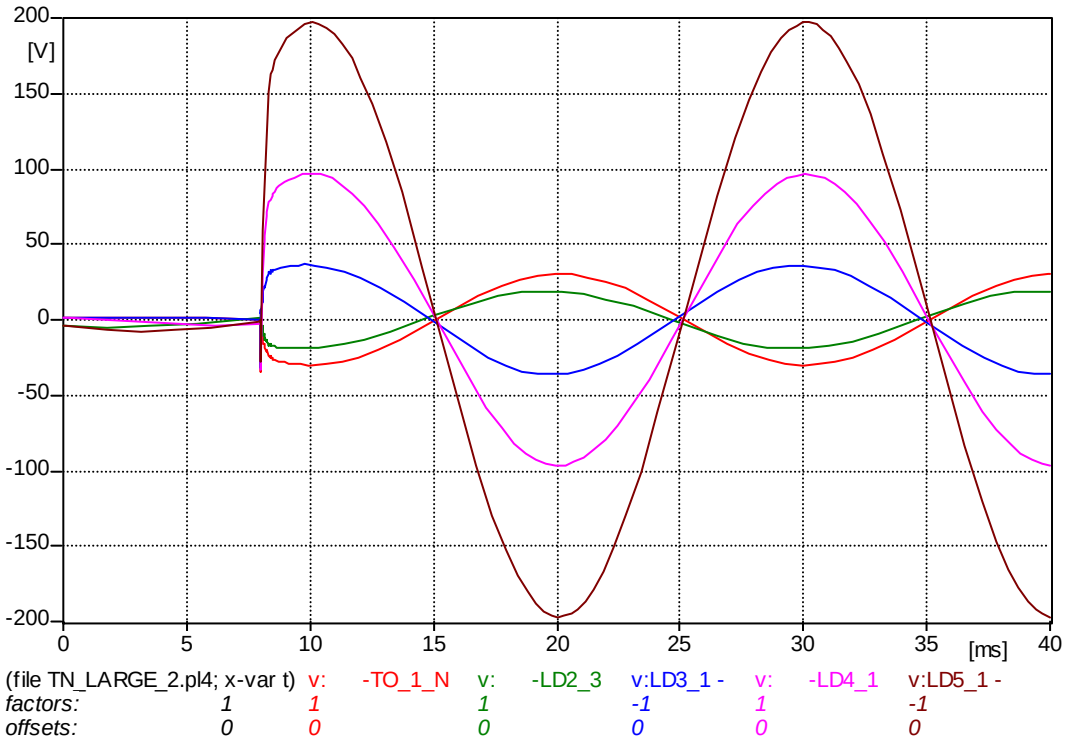



**Figure 17: Neutral and PE to Earth Voltage at 1,2,3,4 and 5**

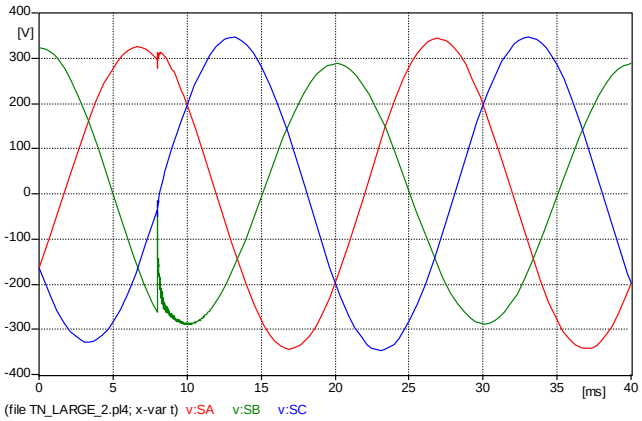



**Figure 18.1: Phase Voltages to Earth at "S"**

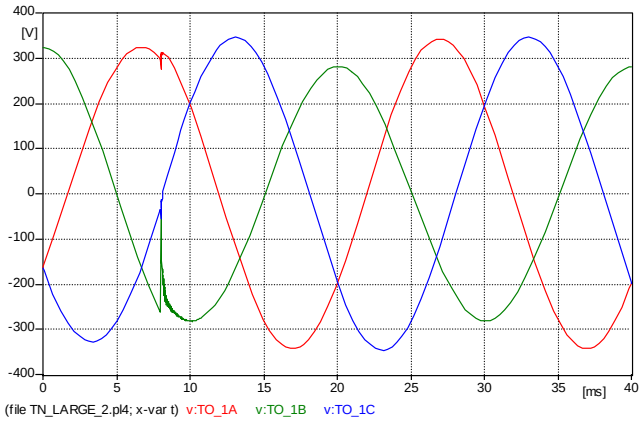



**Figure 18.2: Phase Voltages to Earth at "TO_1"**

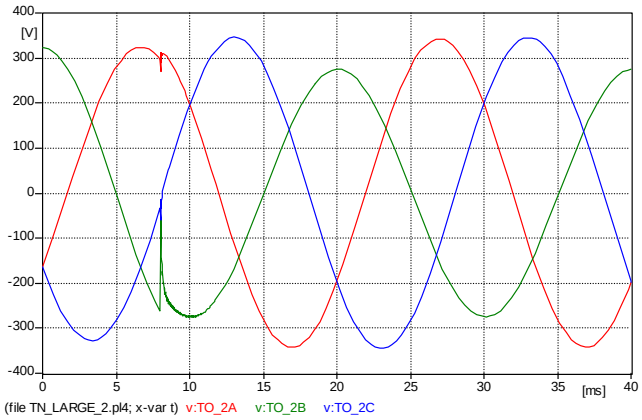



**Figure 18.3: Phase Voltages to Earth at "TO_2"**

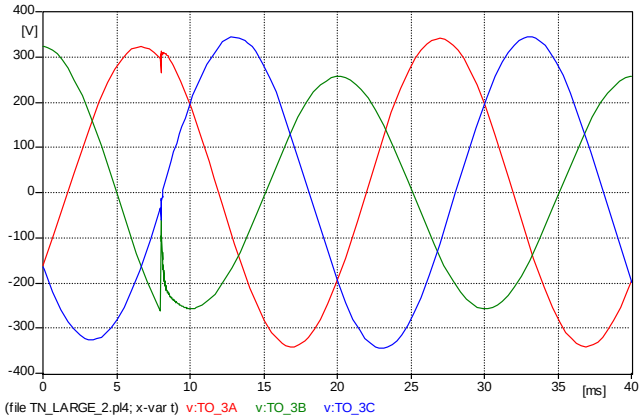



**Figure 18.4: Phase Voltages to Earth at "TO_3"**

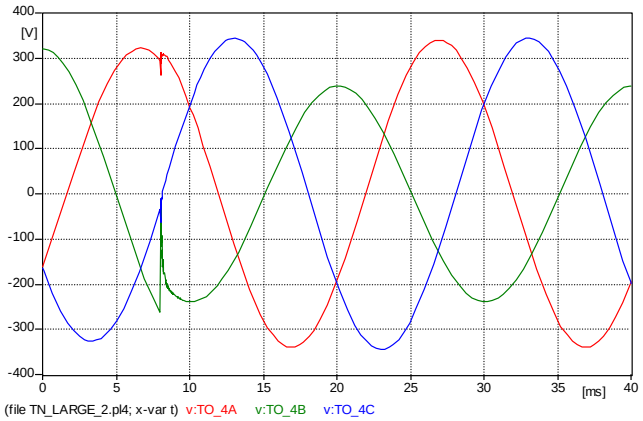



**Figure 18.5: Phase Voltages to Earth at "TO_4"**

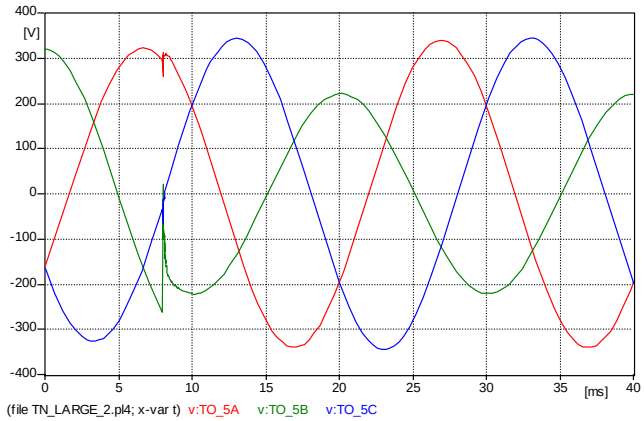



**Figure 18.6: Phase Voltages to Earth at "TO_5"**

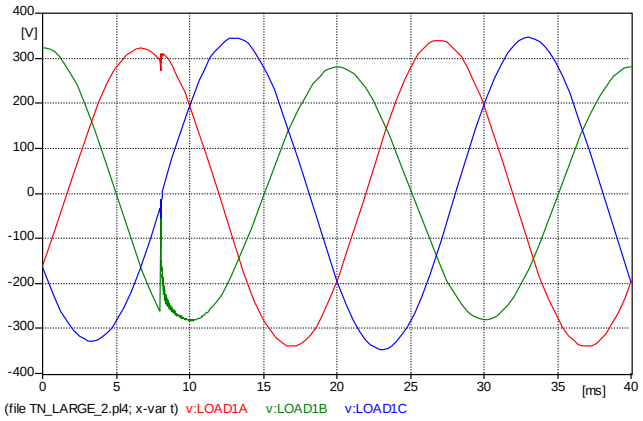



**Figure 18.7: Phase Voltages to Earth at "LOAD1"**

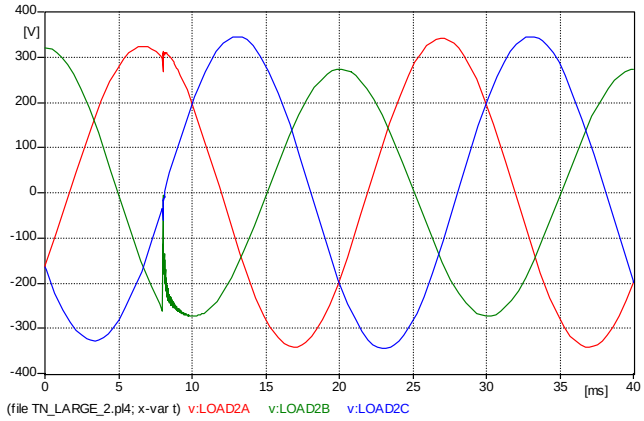



**Figure 18.8: Phase Voltages to Earth at "LOAD2"**

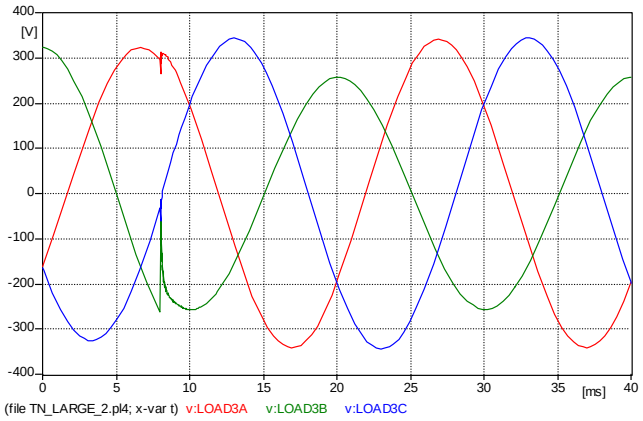



**Figure 18.9: Phase Voltages to Earth at "LOAD3"**

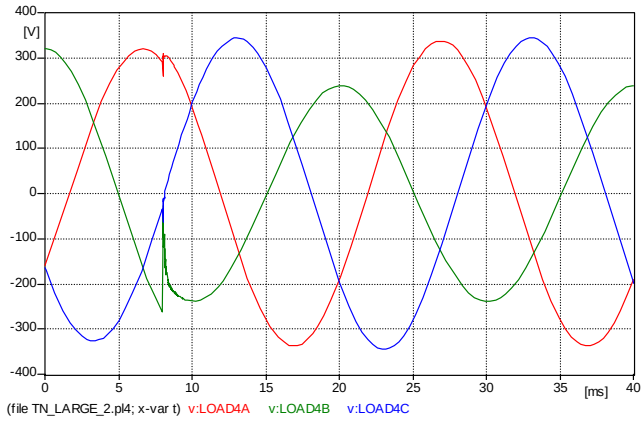



**Figure 18.10: Phase Voltages to Earth at "LOAD4"**

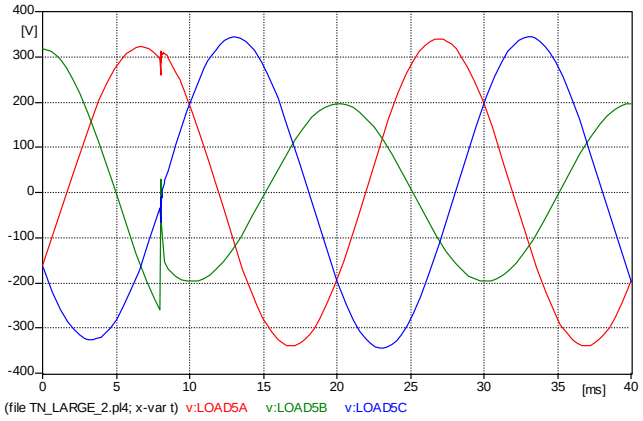



**Figure 18.11: Phase Voltages to Earth at "LOAD5"**

**Figure 18: Phase Voltages to Earth at various nodes of the circuit**

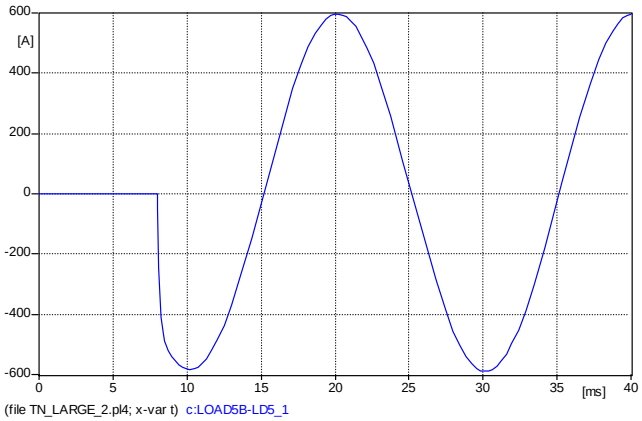



**Figure 19.1: Fault Current**

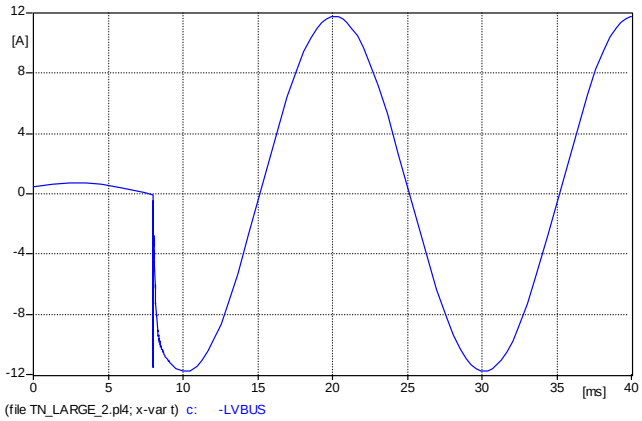



**Figure 19.2: Current to earth through "LVBUS" earthing resistance**

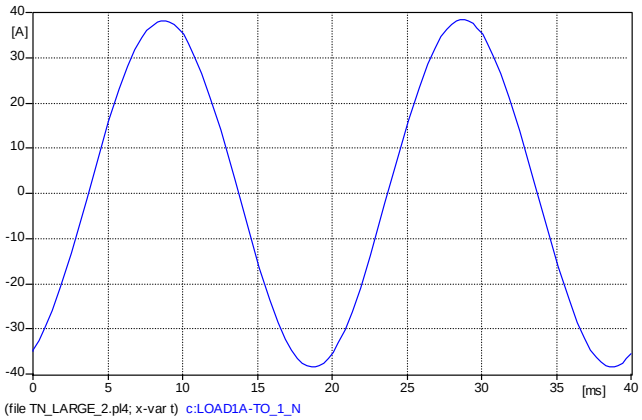



**Figure 19.3: Current along Load 1**

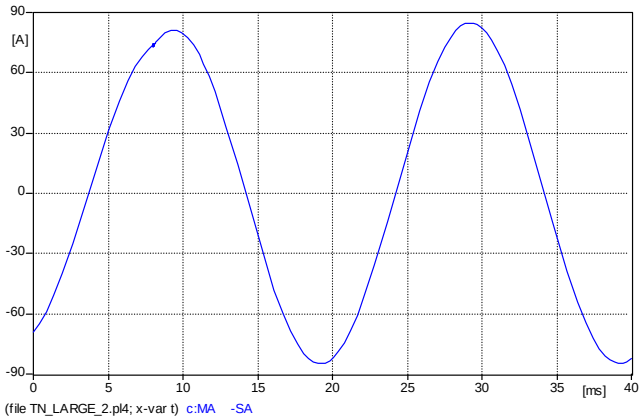



**Figure 19.4: Current at phase A of the source**

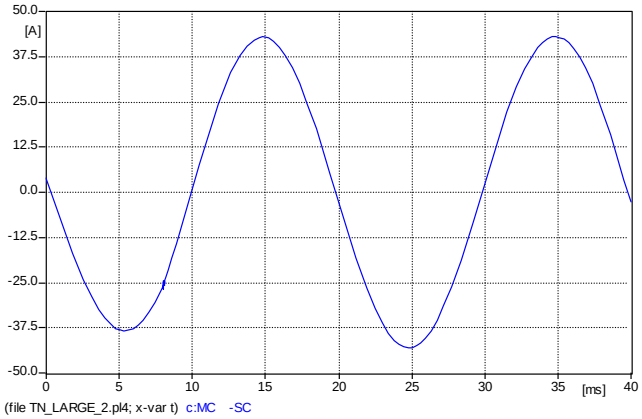



**Figure 19.5: Current at phase C of the source**

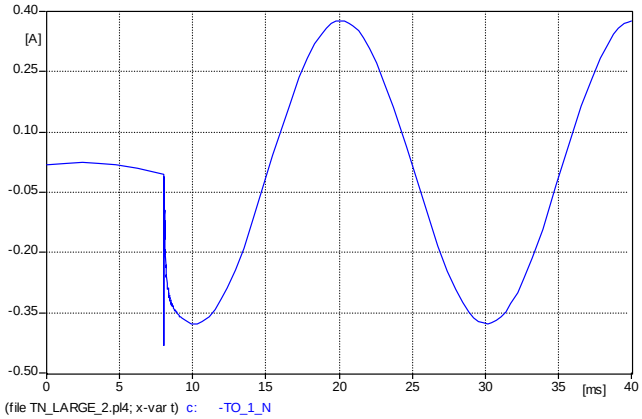



**Figure 19.6: Current to the ground at "TO_1_N"**

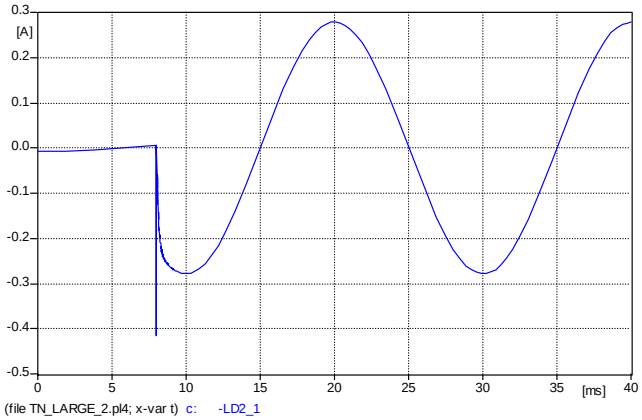



**Figure 19.7: Current to the ground at "LD2_1"**

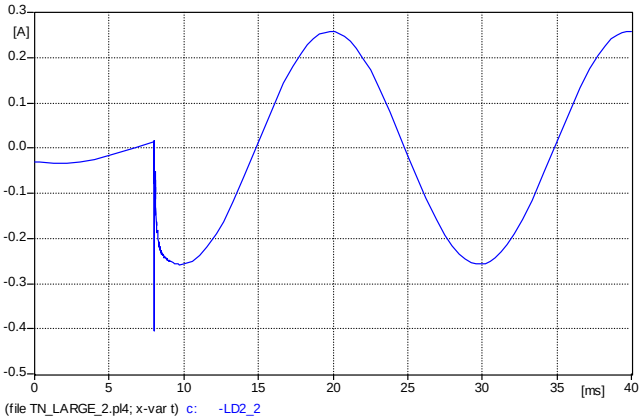



**Figure 19.8: Current to the ground at "LD2_2"**

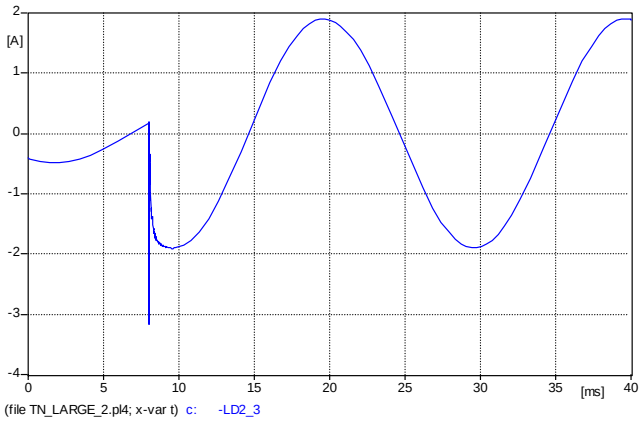



**Figure 19.9: Current to the ground at "LD2_3"**

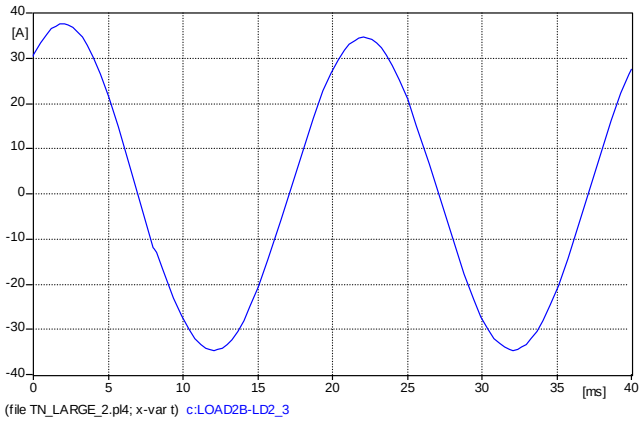



**Figure 19.10: Current along Load 2**

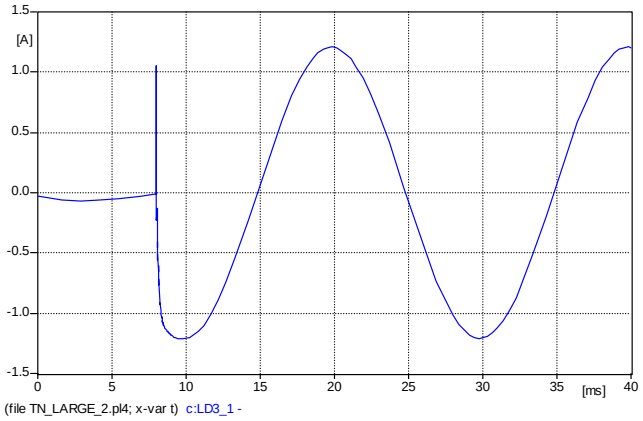



**Figure 19.11: Current to the ground at "LD3_1"**

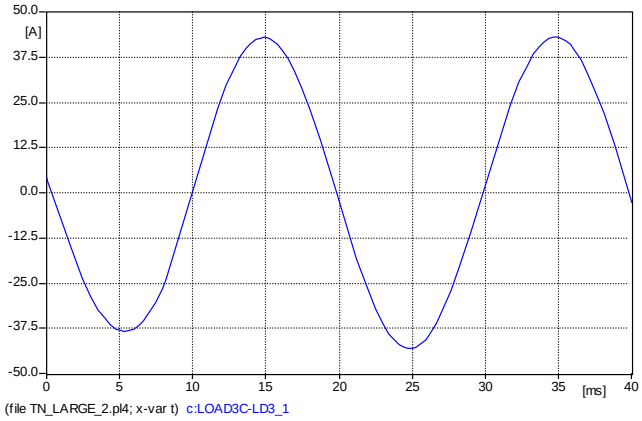



**Figure 19.12: Current along Load 3**

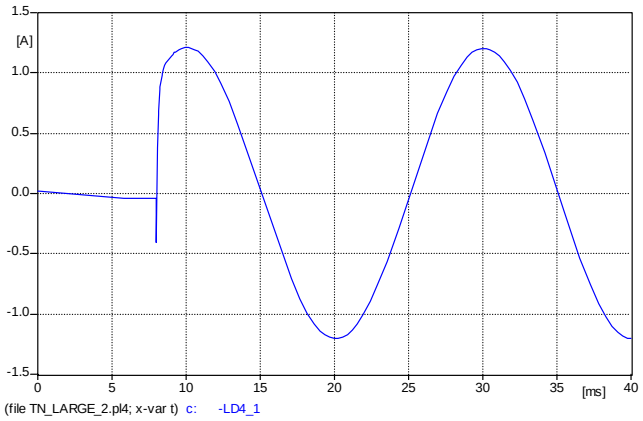



**Figure 19.13: Current to the ground at "LD4_1"**

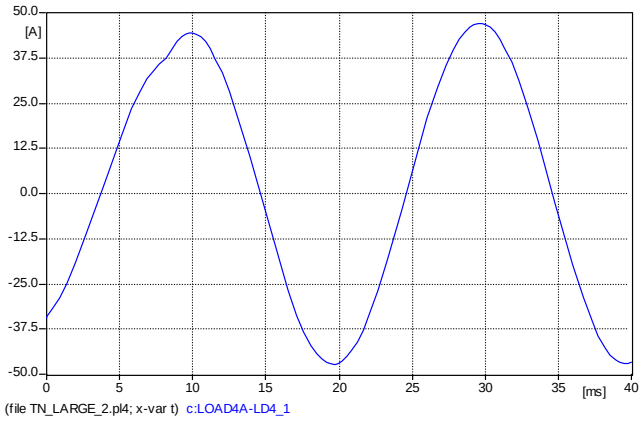



**Figure 19.14: Current along Load 4**

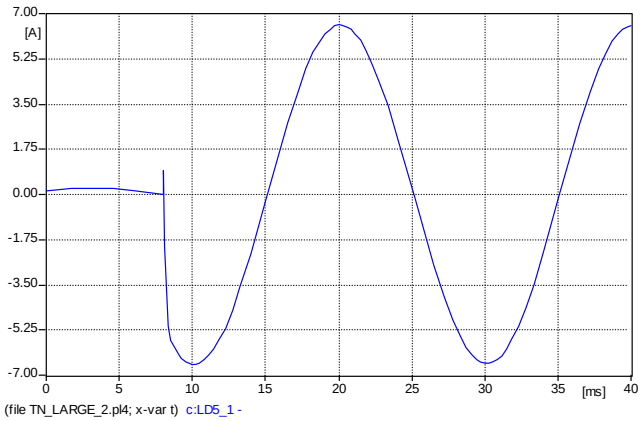



**Figure 19.15: Current to the ground at "LD5_1"**

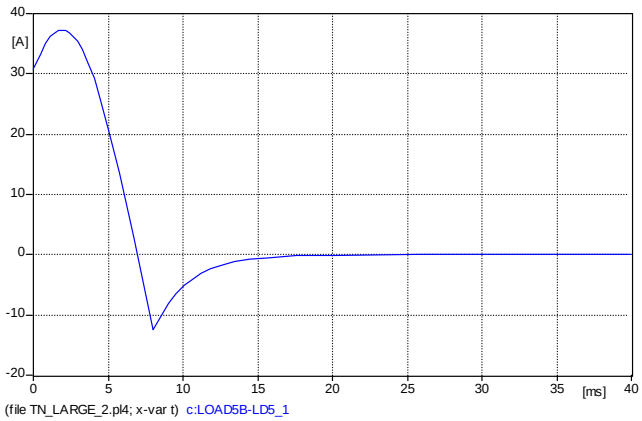



**Figure 19.16: Current along Load 5**

**Figure 19:Branch Currents**

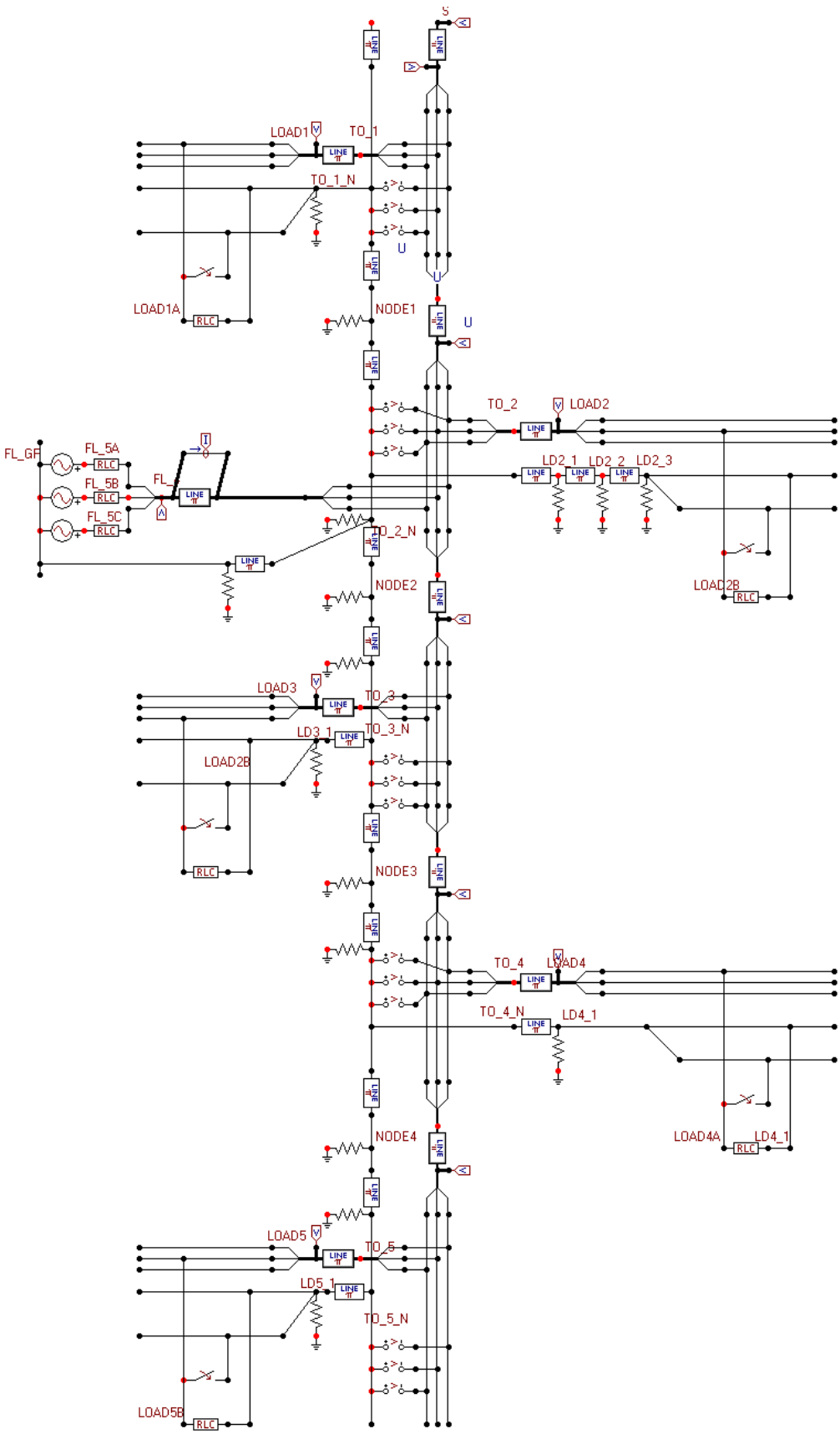



**Figure 20: ATPDraw circuit representation of the LV network that is used to simulate the third examined case.**

## Simulation Results – 3rd Case

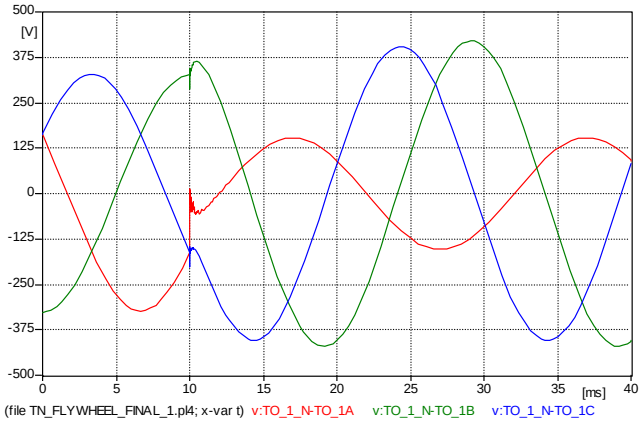



**Figure 21.1: Phase to Neutral Voltages at "TO_1_N"**

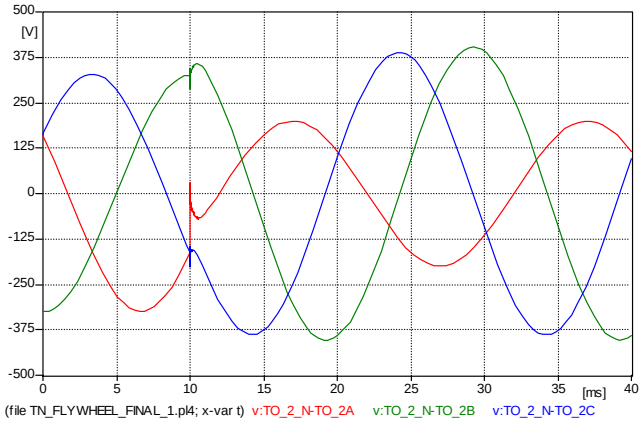



**Figure 21.2: Phase to Neutral Voltages at "TO_2_N"**

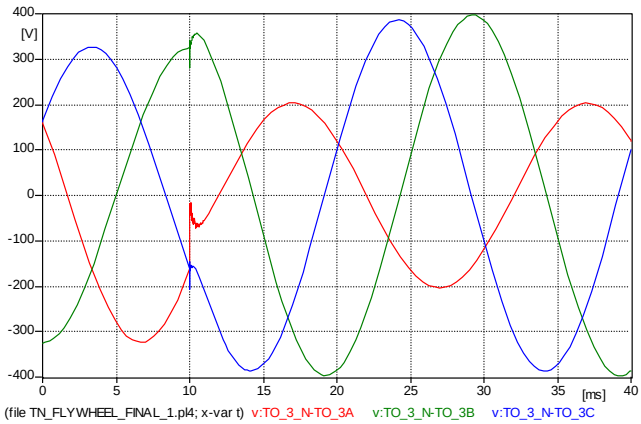



**Figure 21.3: Phase to Neutral Voltages at "TO_3_N"**

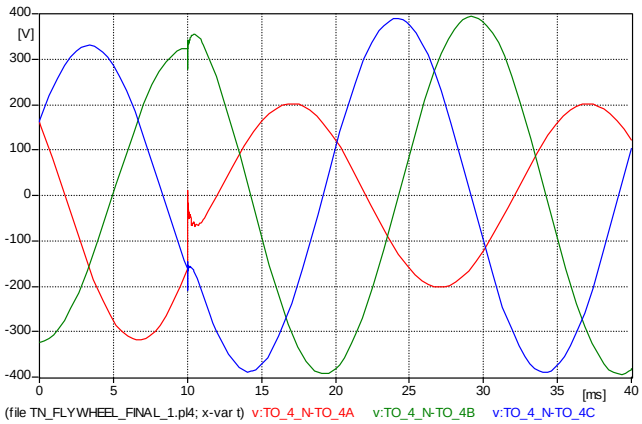



**Figure 21.4: Phase to Neutral Voltages at "TO_4_N"**

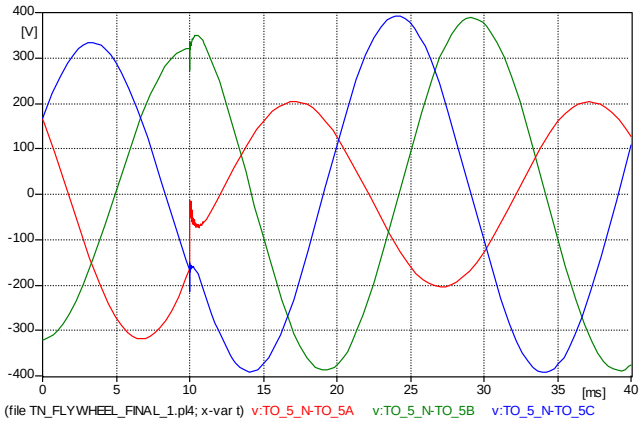



**Figure 21.5: Phase to Neutral Voltages at "TO_5_N"**

**Figure 21: Phase to Neutral Voltages at various nodes of the circuit**

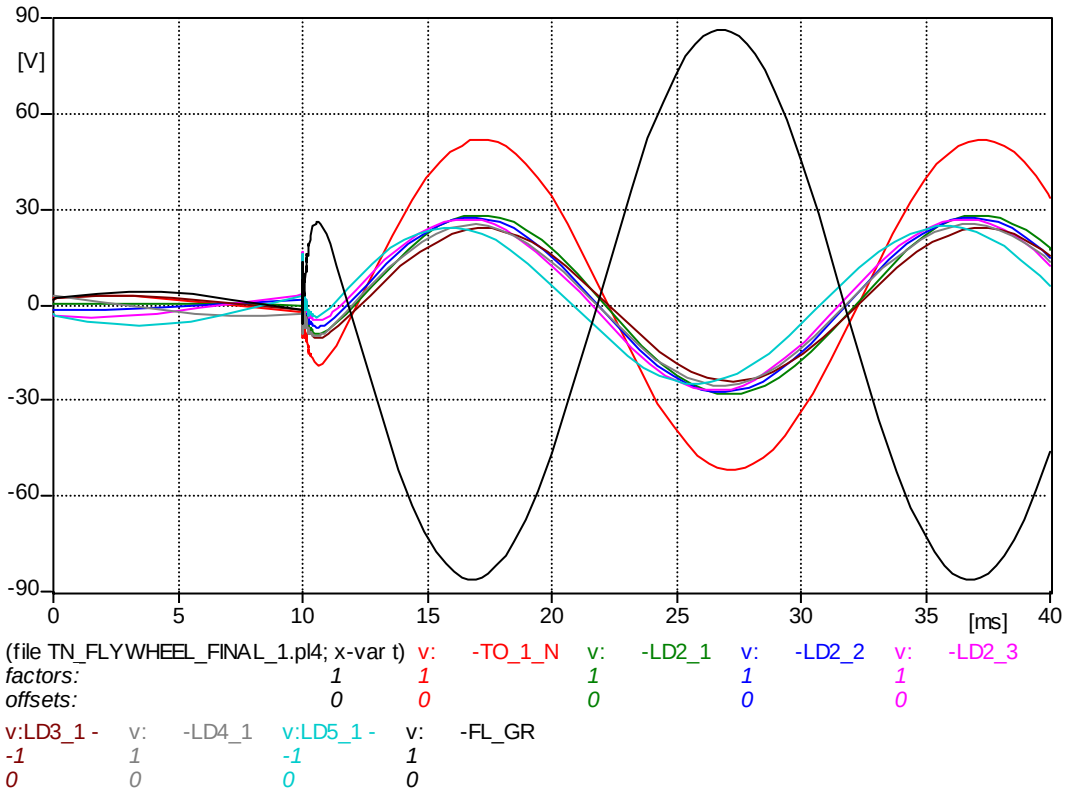



**Figure 22: Neutral and PE to Earth Voltage at 1,2,3,4 and 5**

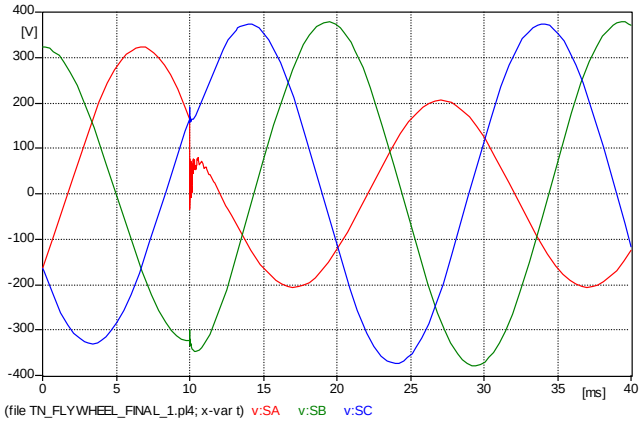



**Figure 23.1: Phase Voltages to Earth at "S"**

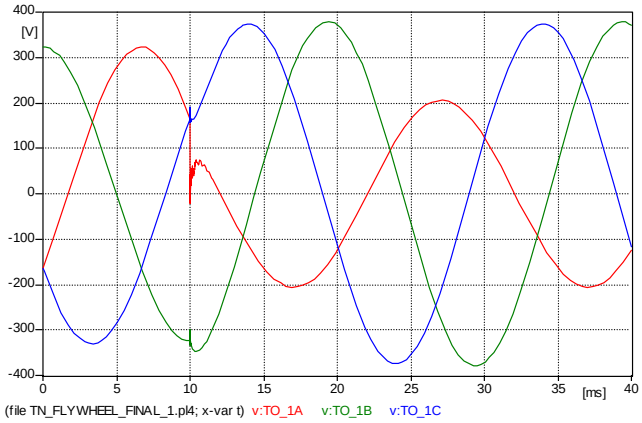



**Figure 23.2: Phase Voltages to Earth at "TO_1"**

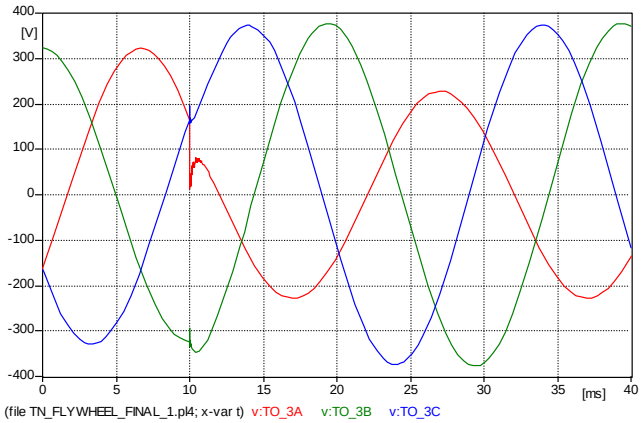



**Figure 23.3: Phase Voltages to Earth at "TO_3"**

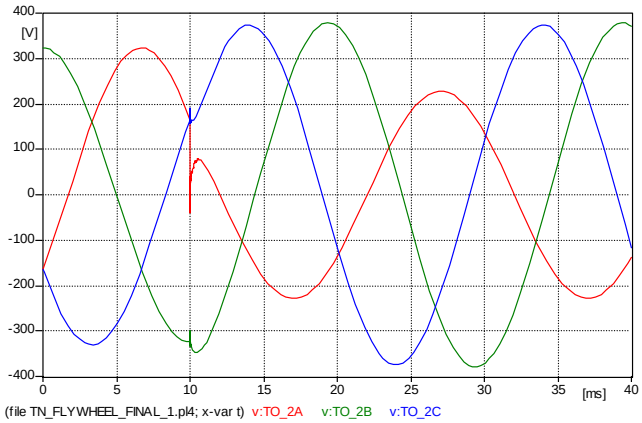



**Figure 23.4: Phase Voltages to Earth at "TO_2"**

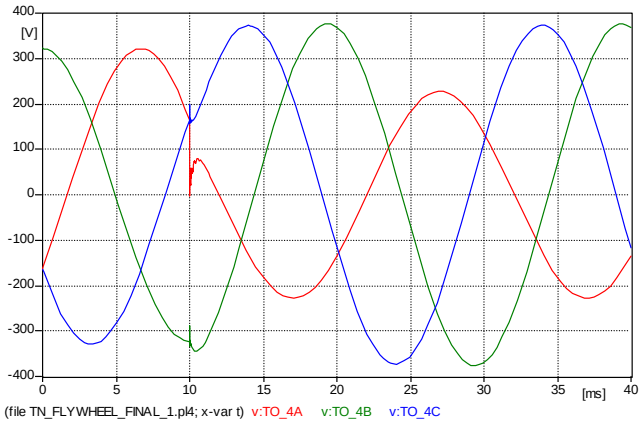



**Figure 23.5: Phase Voltages to Earth at "TO_4"**

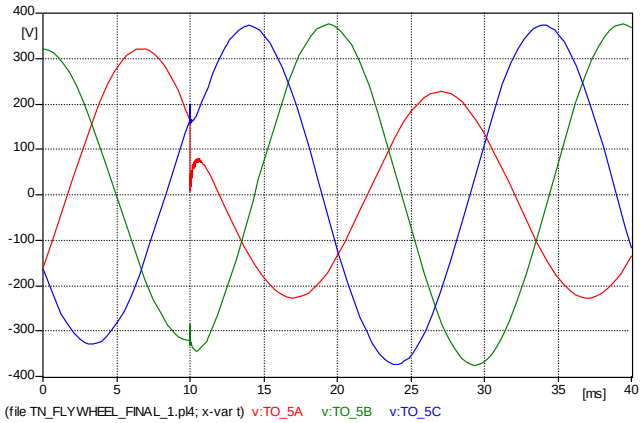



**Figure 23.6: Phase Voltages to Earth at "TO_5"**

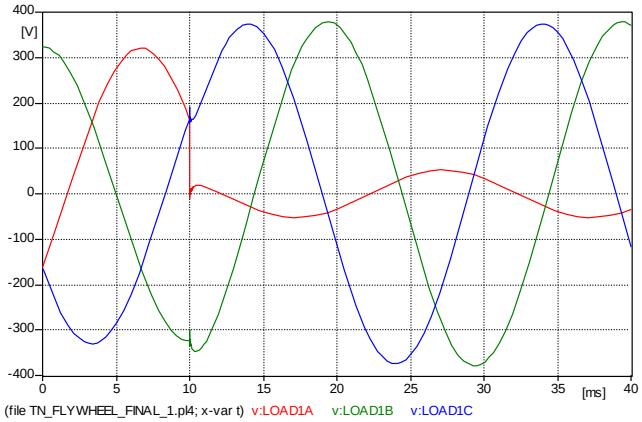



**Figure 23.7: Phase Voltages to Earth at "LOAD1"**

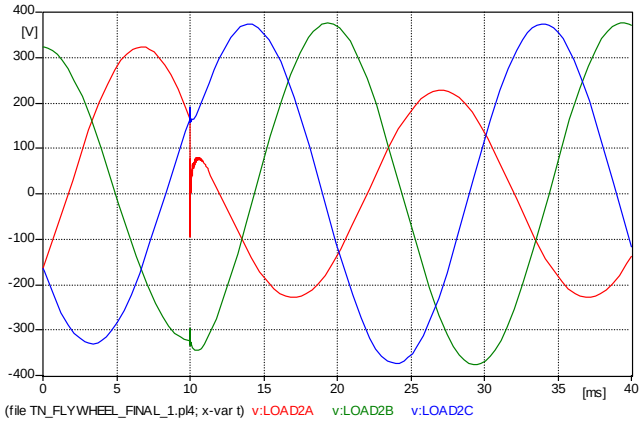



**Figure 23.8: Phase Voltages to Earth at "LOAD2"**

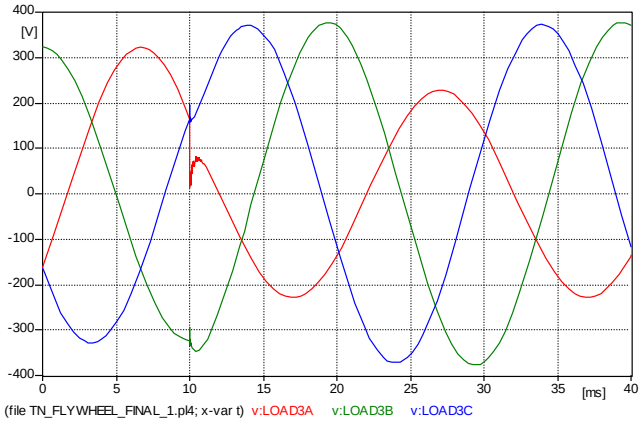



**Figure 23.9: Phase Voltages to Earth at "LOAD3"**

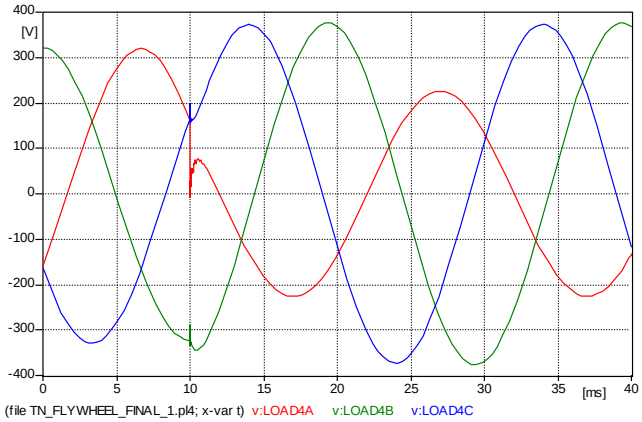



**Figure 23.10: Phase Voltages to Earth at "LOAD4"**

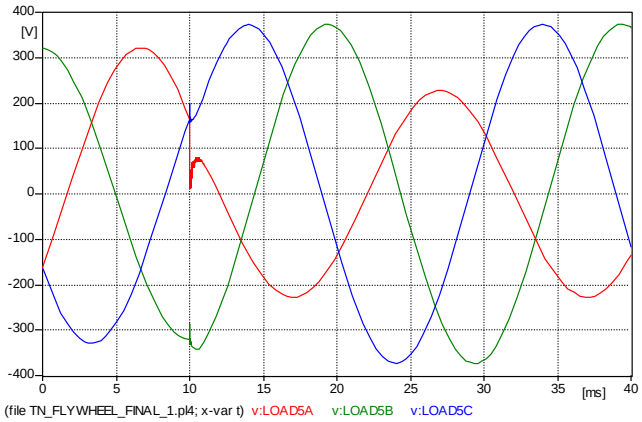



**Figure 23.11: Phase Voltages to Earth at "LOAD5"**

**Figure 23: Phase Voltages to Earth at various nodes of the circuit**

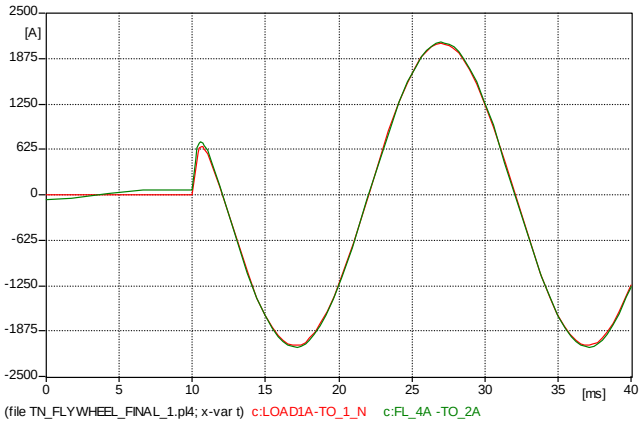



**Figure 24.1: Fault Current**

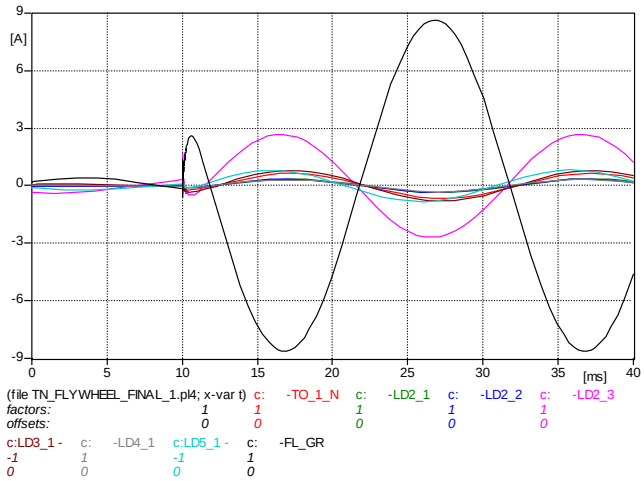



**Figure 24.2: Current Dispersed to Ground**

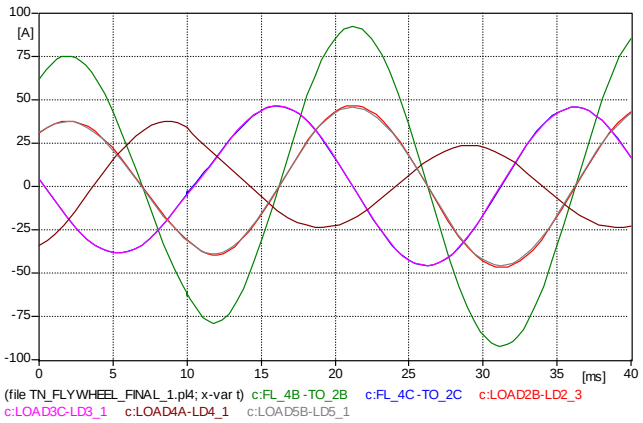



**Figure 24.3: Branch Currents along loads**

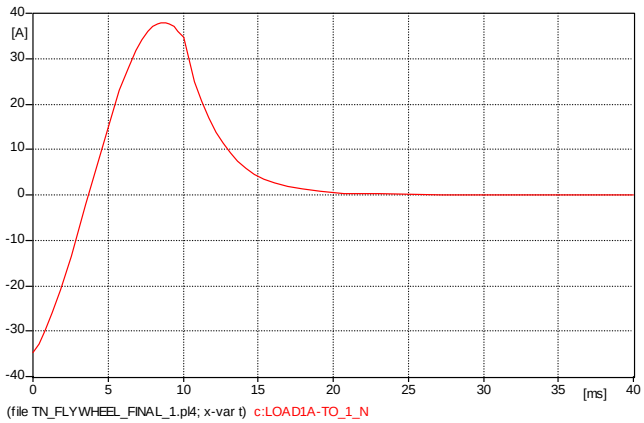



**Figure 24.4: Branch Currents along Load 1**

**Figure 24: Branch Currents**

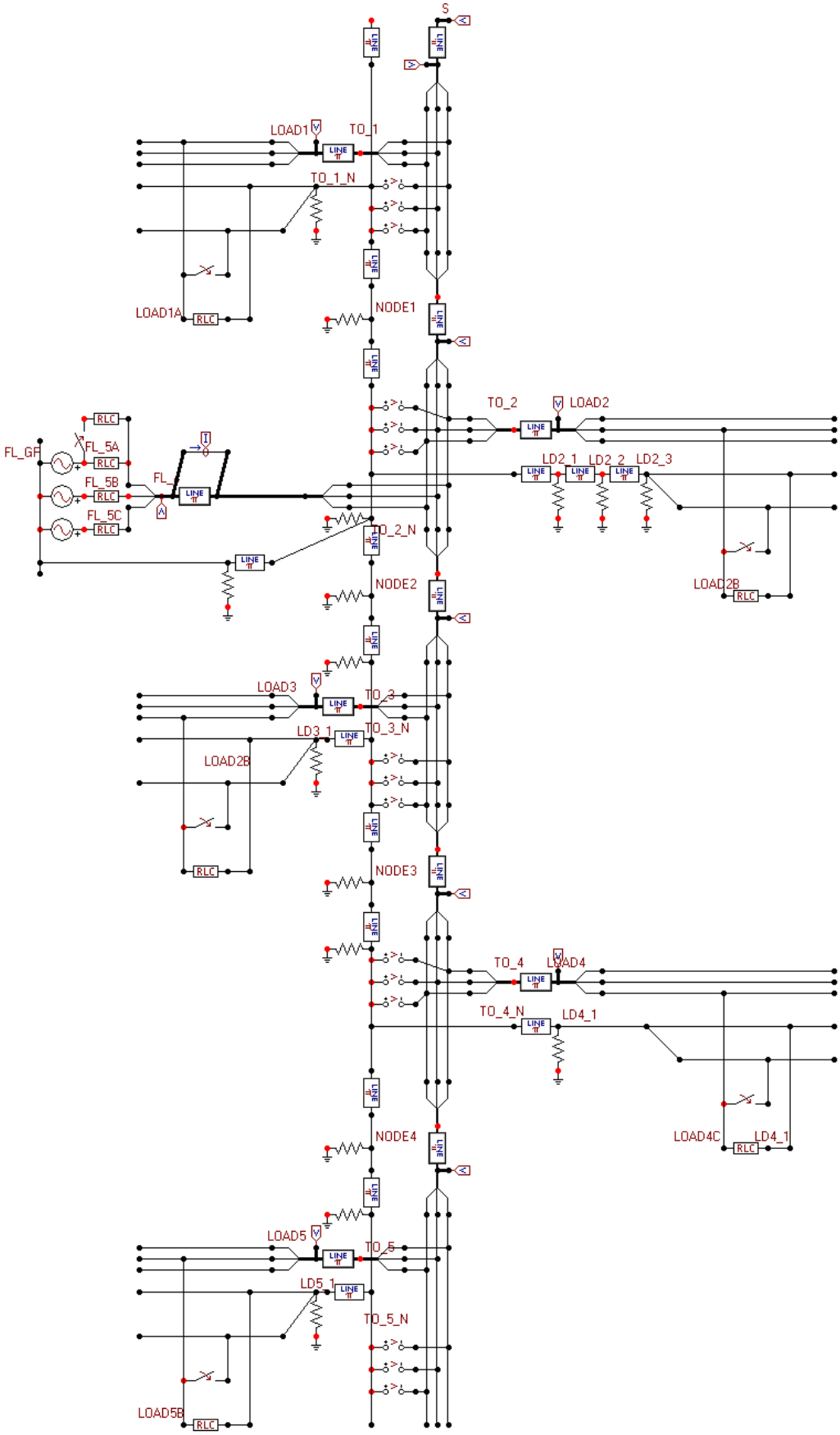



**Figure 25: ATPDraw circuit representation of the LV network that is used to simulate the fourth examined case.**

## Simulation Results – 4th Case

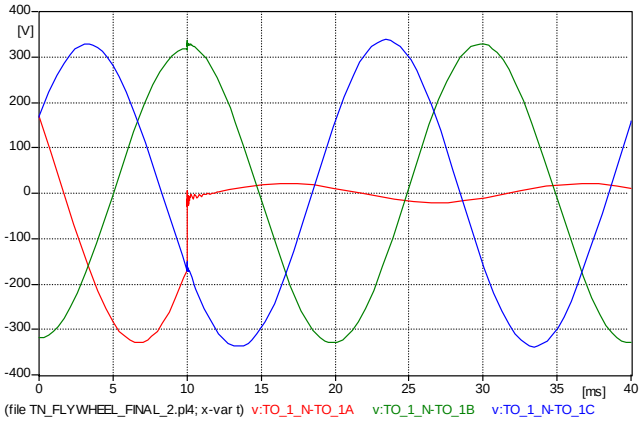



**Figure 26.1: Phase to Neutral Voltages at "TO_1"**

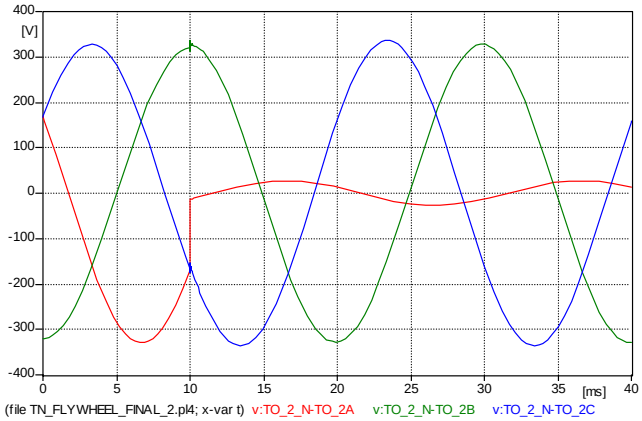



**Figure 26.2: Phase to Neutral Voltages at "TO_2"**

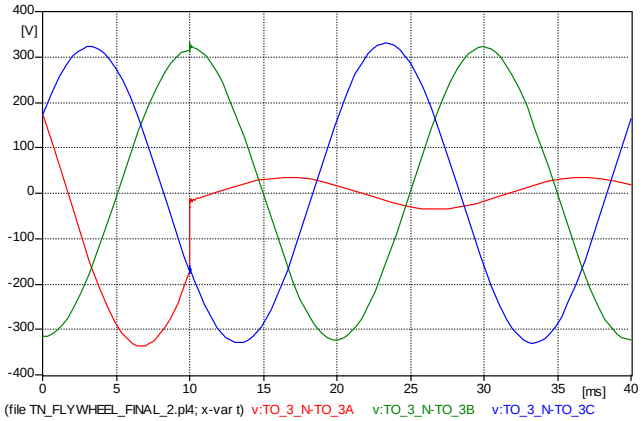



**Figure 26.3: Phase to Neutral Voltages at "TO_3"**

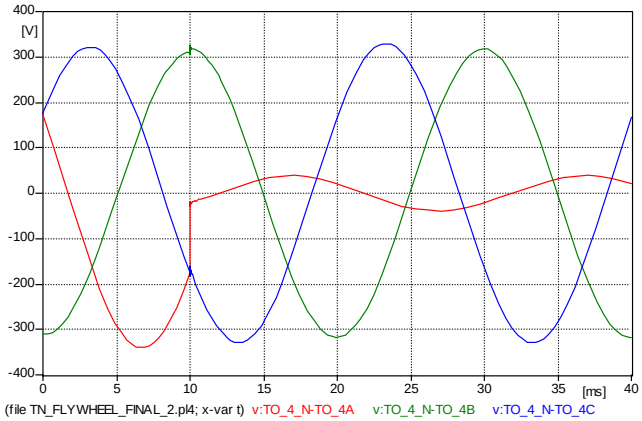



**Figure 26.4: Phase to Neutral Voltages at "TO_4"**

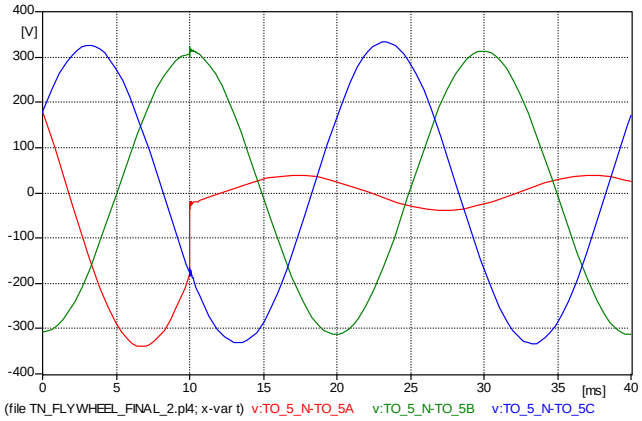



**Figure 26.5: Phase to Neutral Voltages at "TO_5"**

**Figure 26: Phase to Neutral Voltages at various nodes of the circuit**

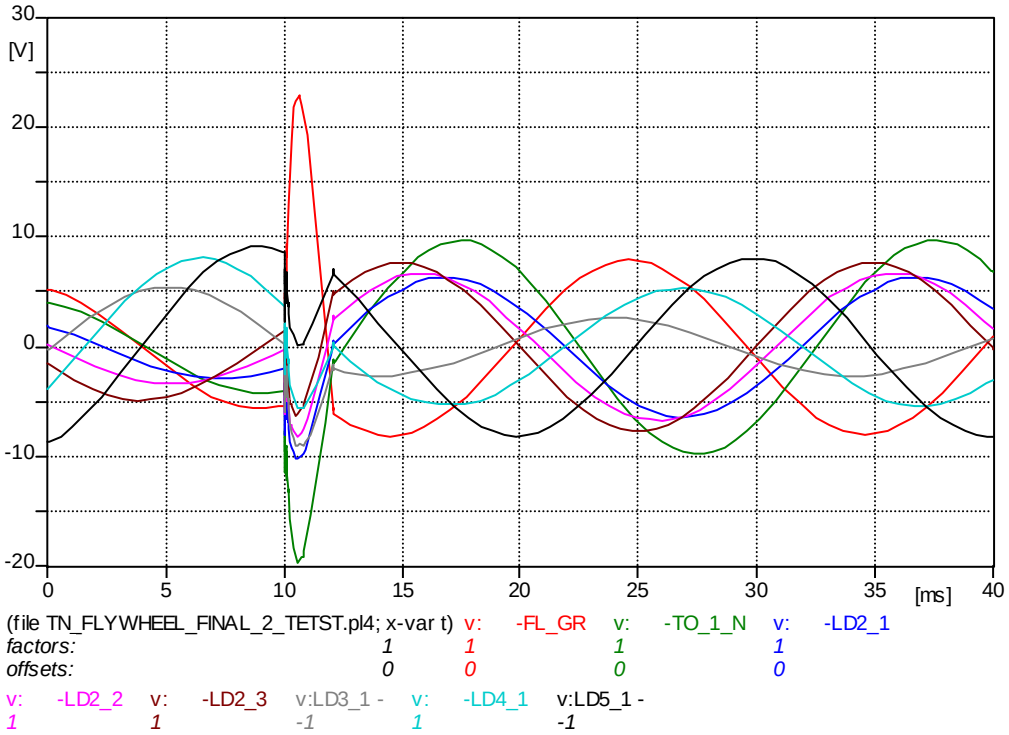



**Figure 27: Neutral and PE to Earth Voltage at 1,2,3,4 and 5**

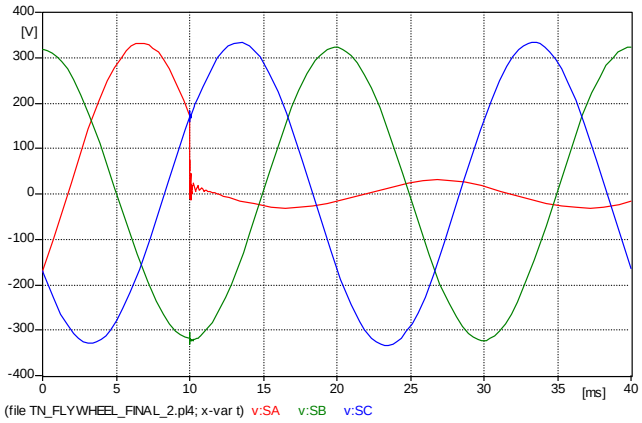



**Figure 28.1: Phase Voltages to Earth at "S"**

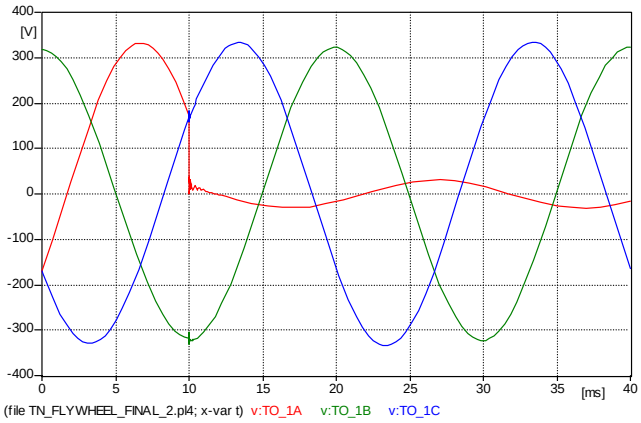



**Figure 28.2: Phase Voltages to Earth at "TO_1"**

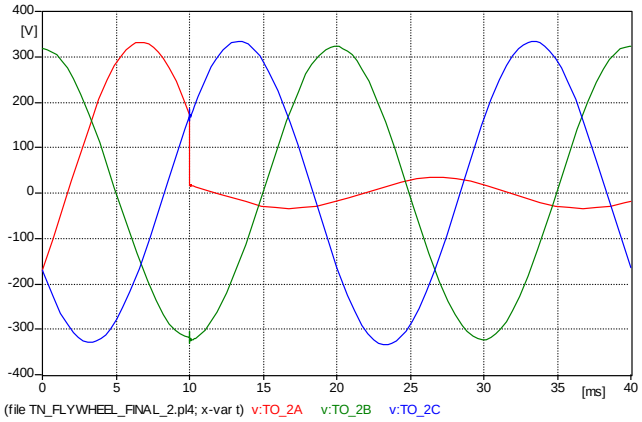



**Figure 28.3: Phase Voltages to Earth at " TO_2"**

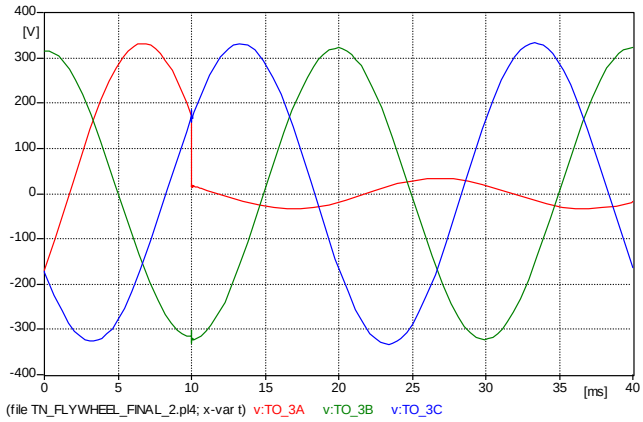



**Figure 28.4: Phase Voltages to Earth at " TO_3"**

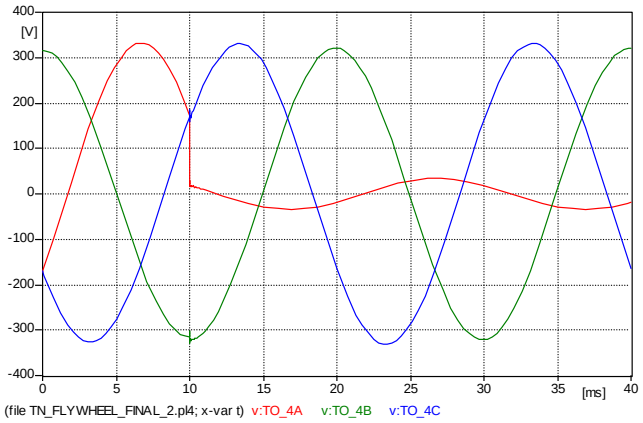



**Figure 28.5: Phase Voltages to Earth at "TO_4"**

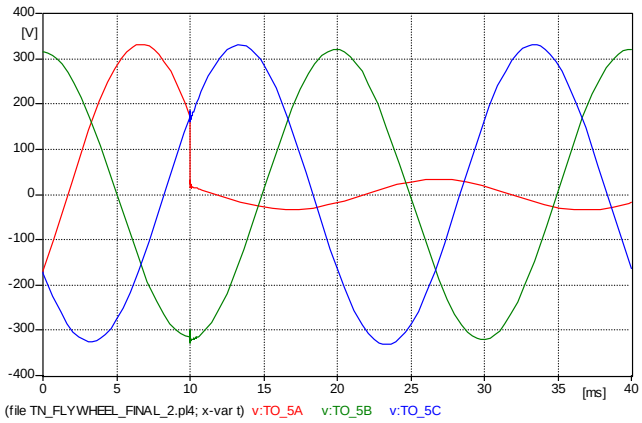



**Figure 28.6: Phase Voltages to Earth at "TO_5"**

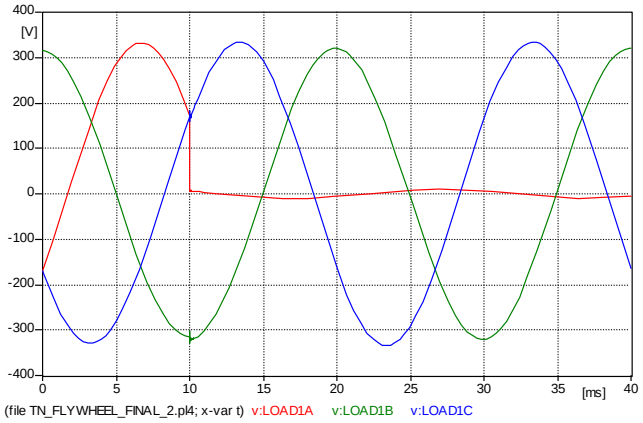



**Figure 28.7: Phase Voltages to Earth at "LOAD1"**

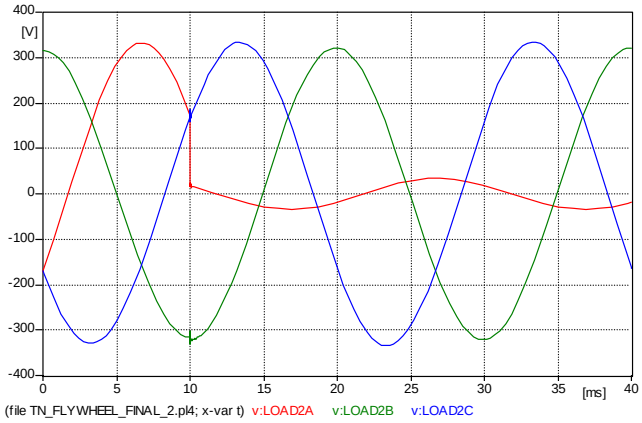



**Figure 28.8: Phase Voltages to Earth at "LOAD2"**

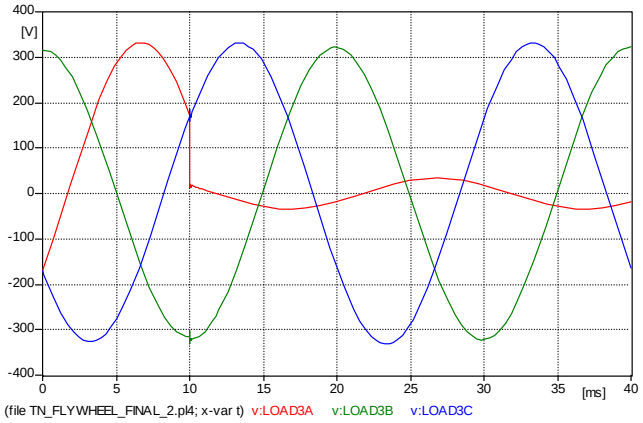



**Figure 28.9: Phase Voltages to Earth at "LOAD3"**

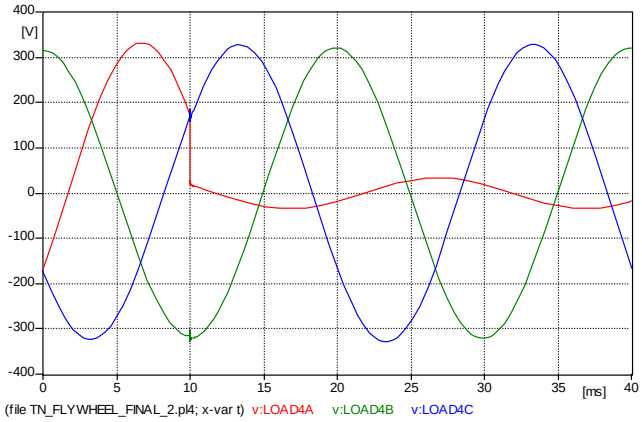



**Figure 28.10: Phase Voltages to Earth at "LOAD4"**

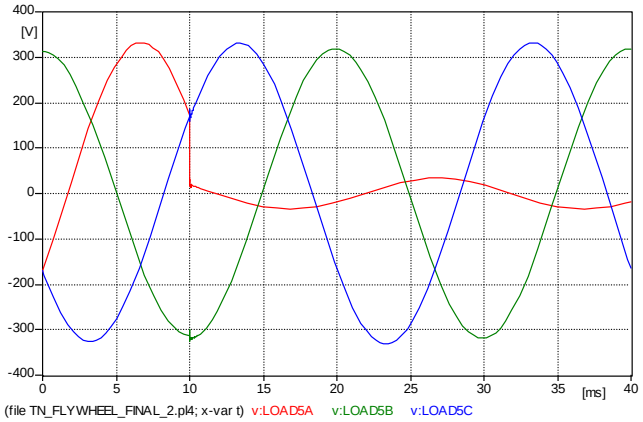



**Figure 28.11: Phase Voltages to Earth at "LOAD5"**

**Figure 28: Phase Voltages to Earth at various nodes of the circuit**

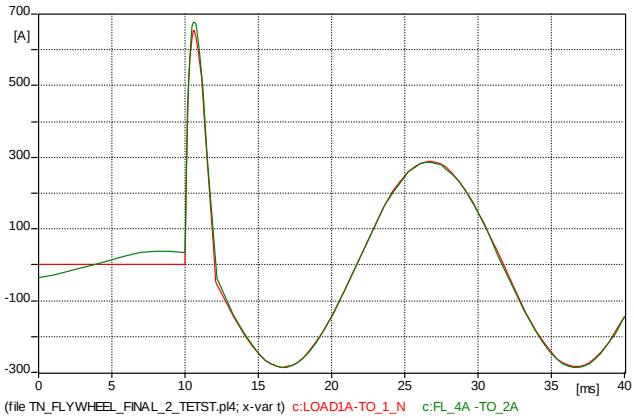



**Figure 29.1: Fault Current**

**Figure 29:Branch Currents**

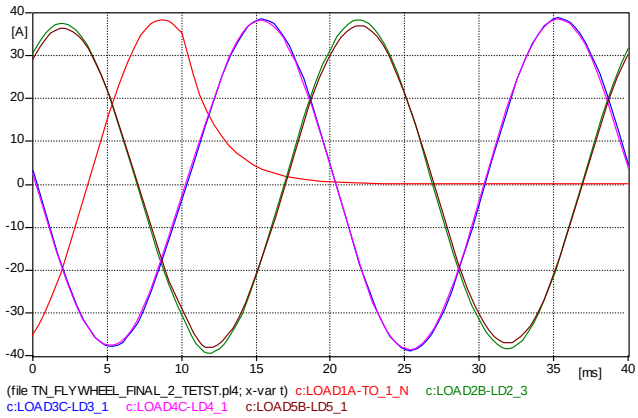



**Figure 29.2: Current along the loads**

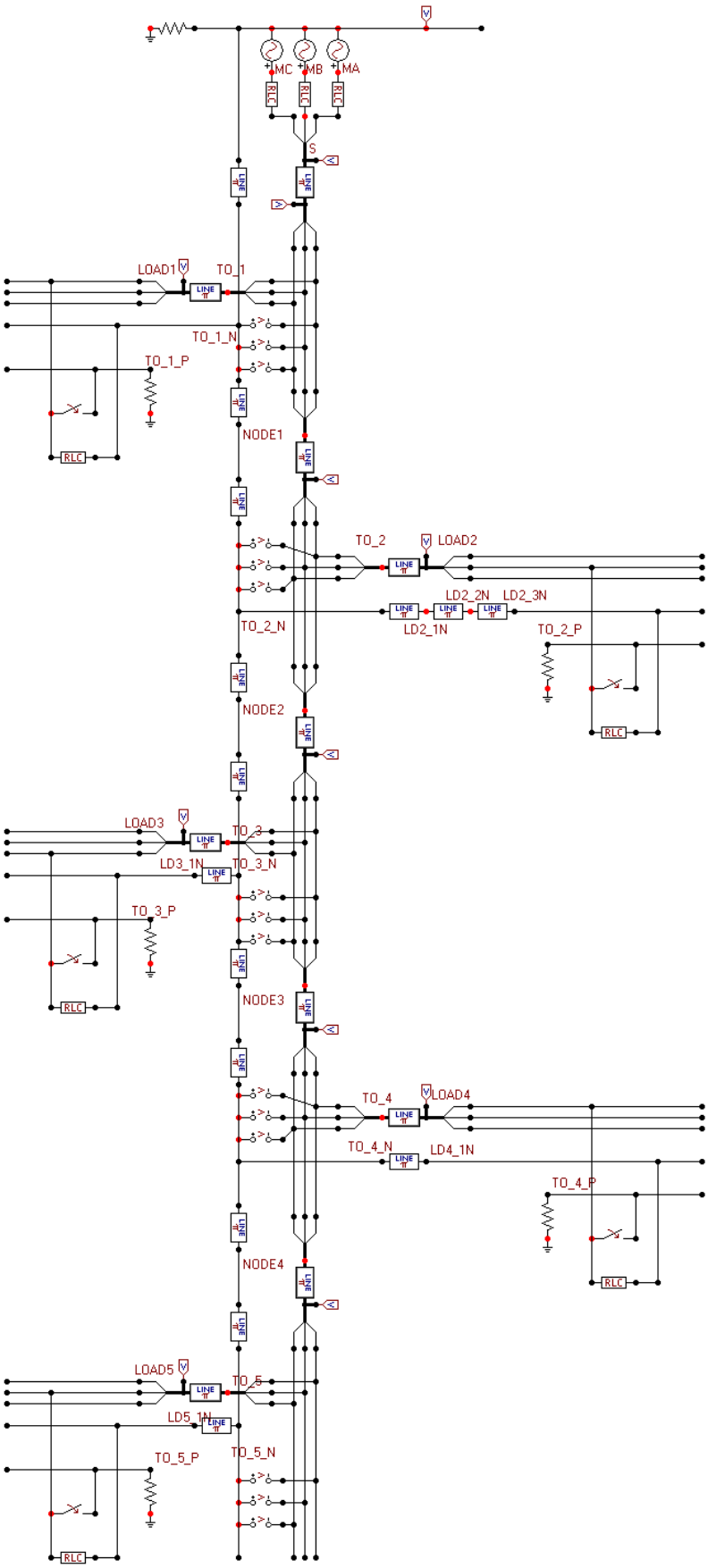



**Figure 30: ATPDraw circuit representation of the LV network for the fifth study case.**

## Simulation Results – 5th Case

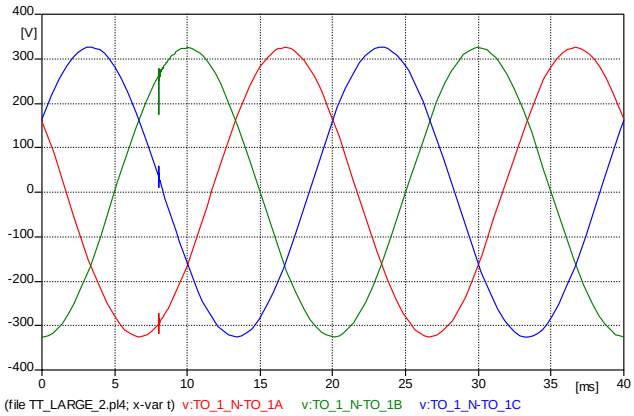



**Figure 31.1: Phase to Neutral Voltages at "TO_1"**

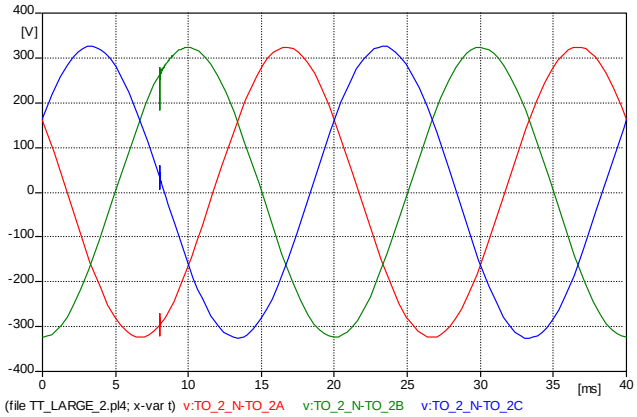



**Figure 31.2: Phase to Neutral Voltages at "TO_2"**

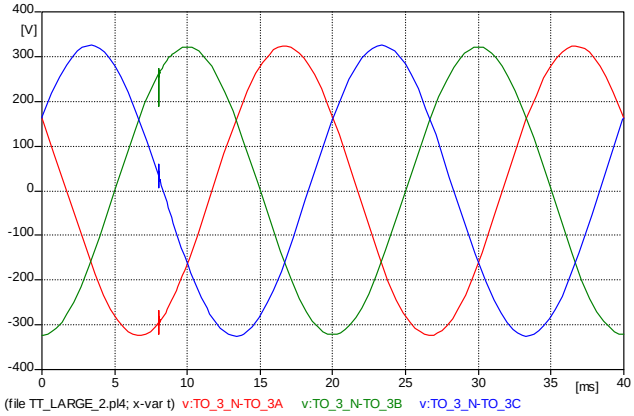



**Figure 31.3: Phase to Neutral Voltages at "TO_3"**

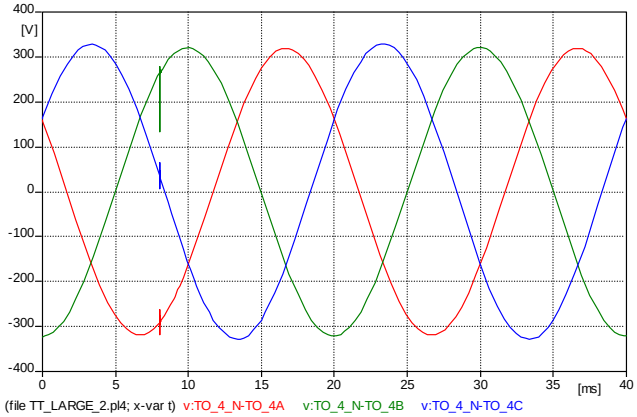



**Figure 31.4: Phase to Neutral Voltages at "TO_4"**

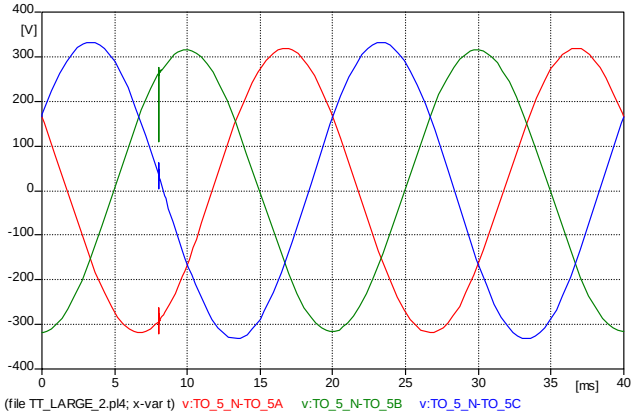



**Figure 31.5: Phase to Neutral Voltages at "TO_5"**

**Figure 31: Phase to Neutral Voltages at various nodes of the circuit**

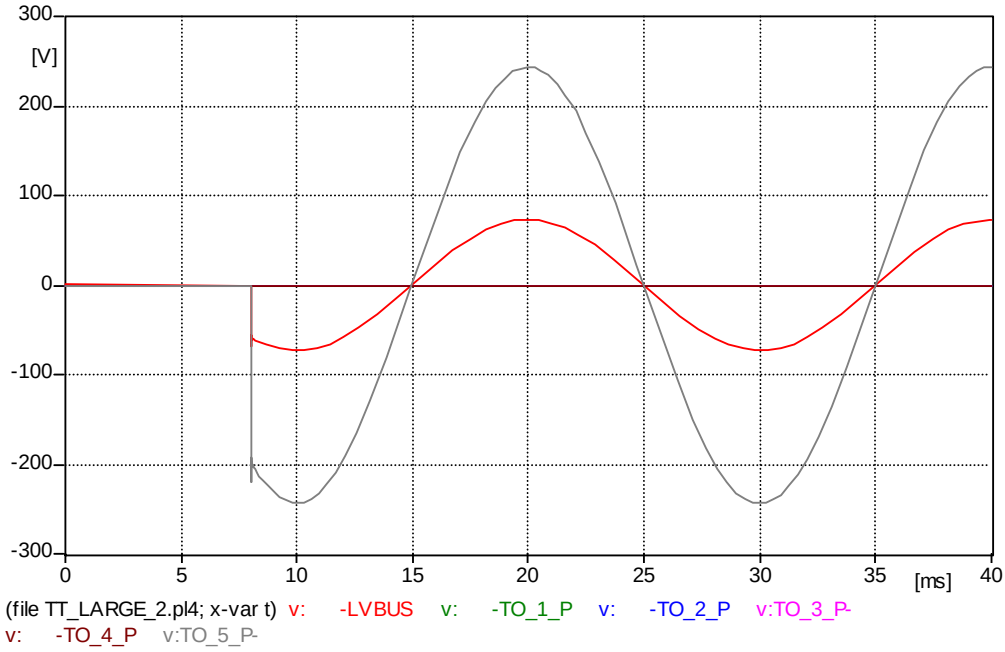



**Figure 32: Neutral and PE to Earth Voltage at 1,2,3,4 and 5**

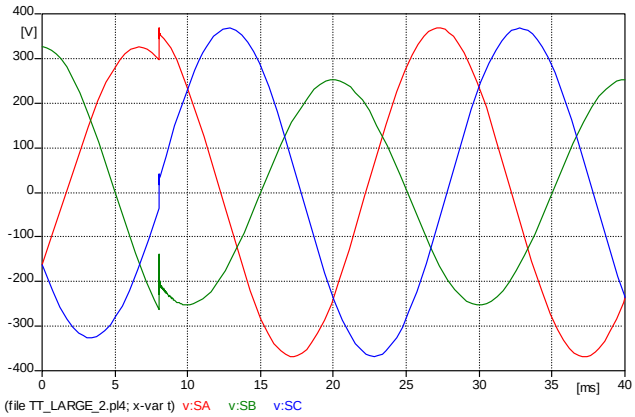



**Figure 33.1: Phase Voltages to Earth at "S"**

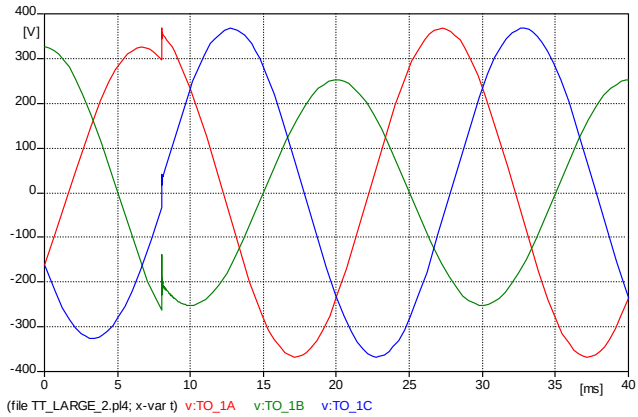



**Figure 33.2: Phase Voltages to Earth at "TO_1"**

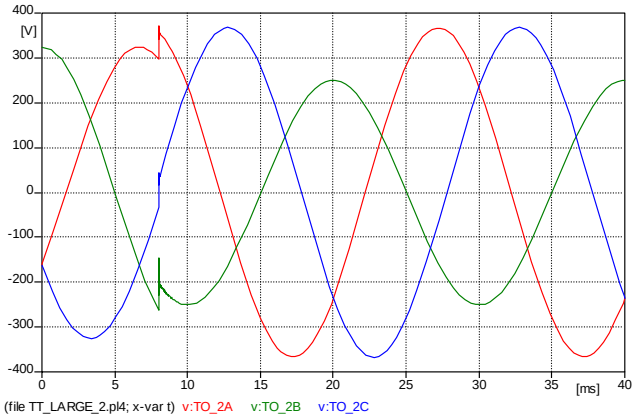



**Figure 33.3: Phase Voltages to Earth at " TO_2"**

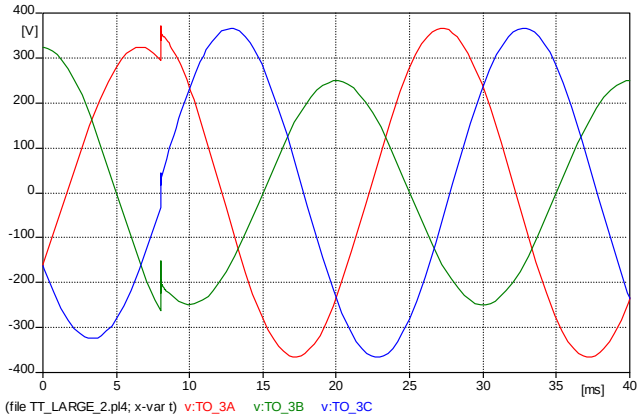



**Figure 33.4: Phase Voltages to Earth at " TO_3"**

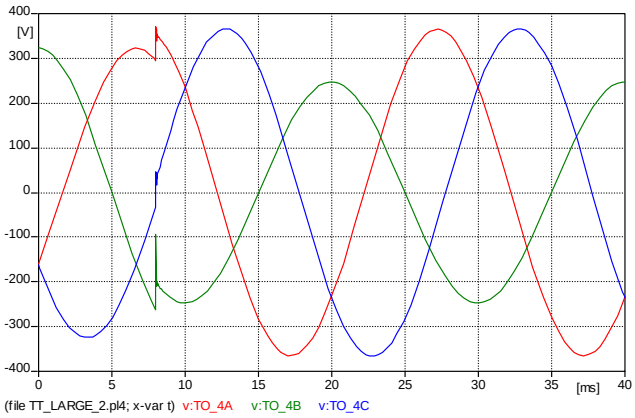



**Figure 33.5: Phase Voltages to Earth at "TO_4"**

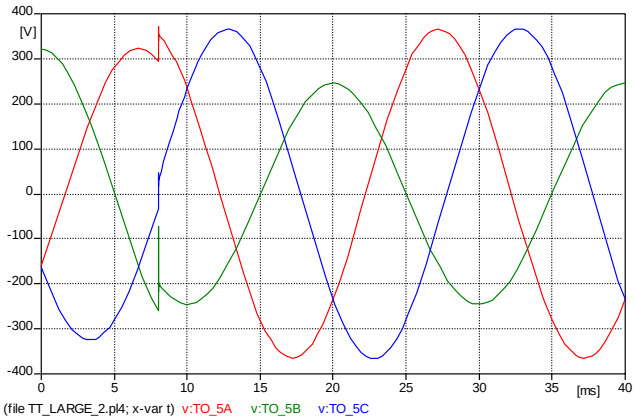



**Figure 33.6: Phase Voltages to Earth at "TO_5"**

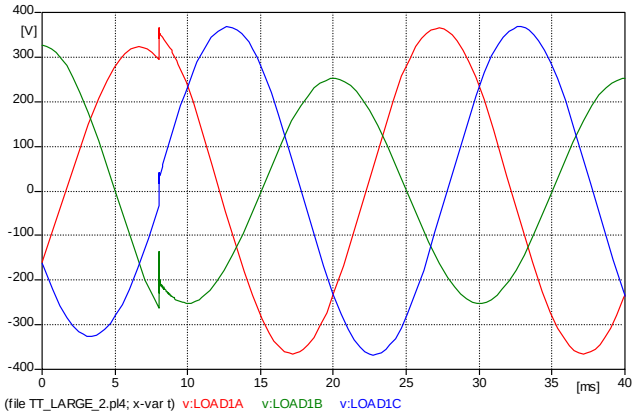



**Figure 33.7: Phase Voltages to Earth at "LOAD1"**

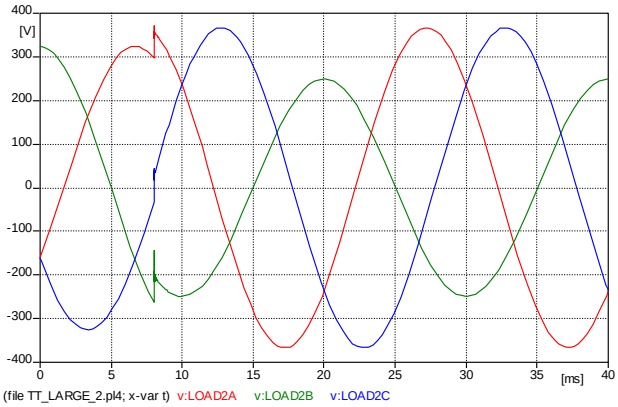



**Figure 33.8: Phase Voltages to Earth at "LOAD2"**

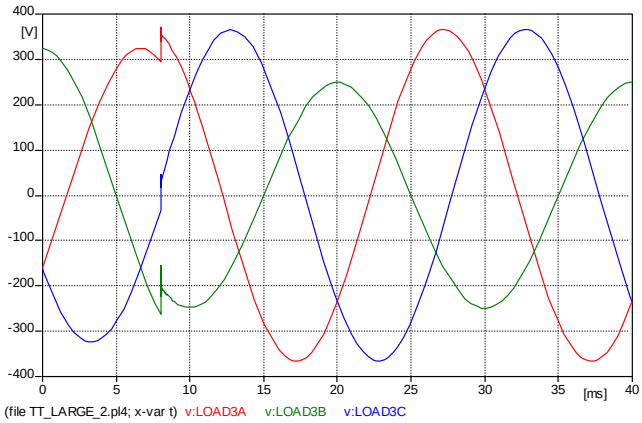



**Figure 33.9: Phase Voltages to Earth at "LOAD3"**

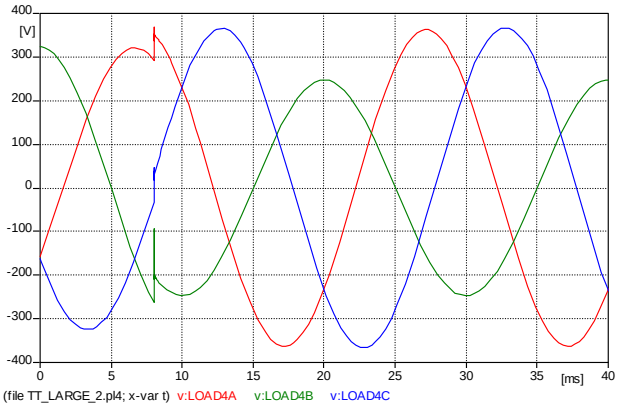



**Figure 33.10: Phase Voltages to Earth at "LOAD4"**

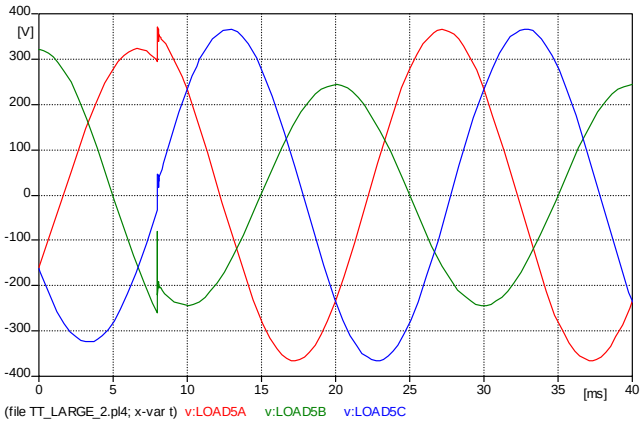



**Figure 33.11: Phase Voltages to Earth at "LOAD5"**

**Figure 33: Phase Voltages to Earth at various nodes of the circuit**

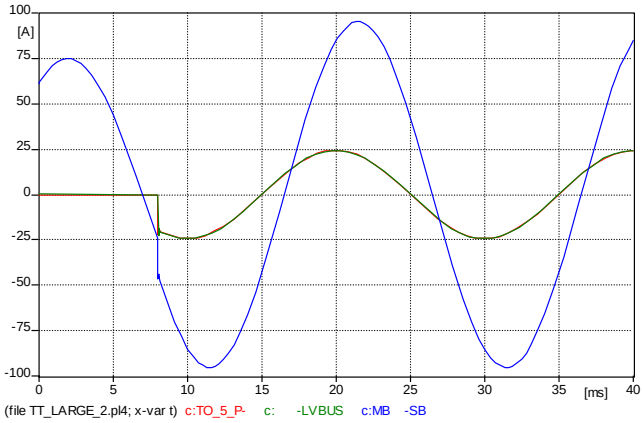



**Figure 34.1: Fault currents**

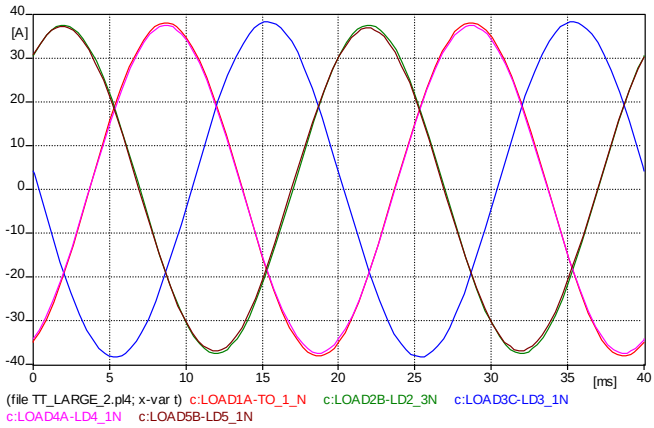



**Figure 34.2: Currents along the loads**

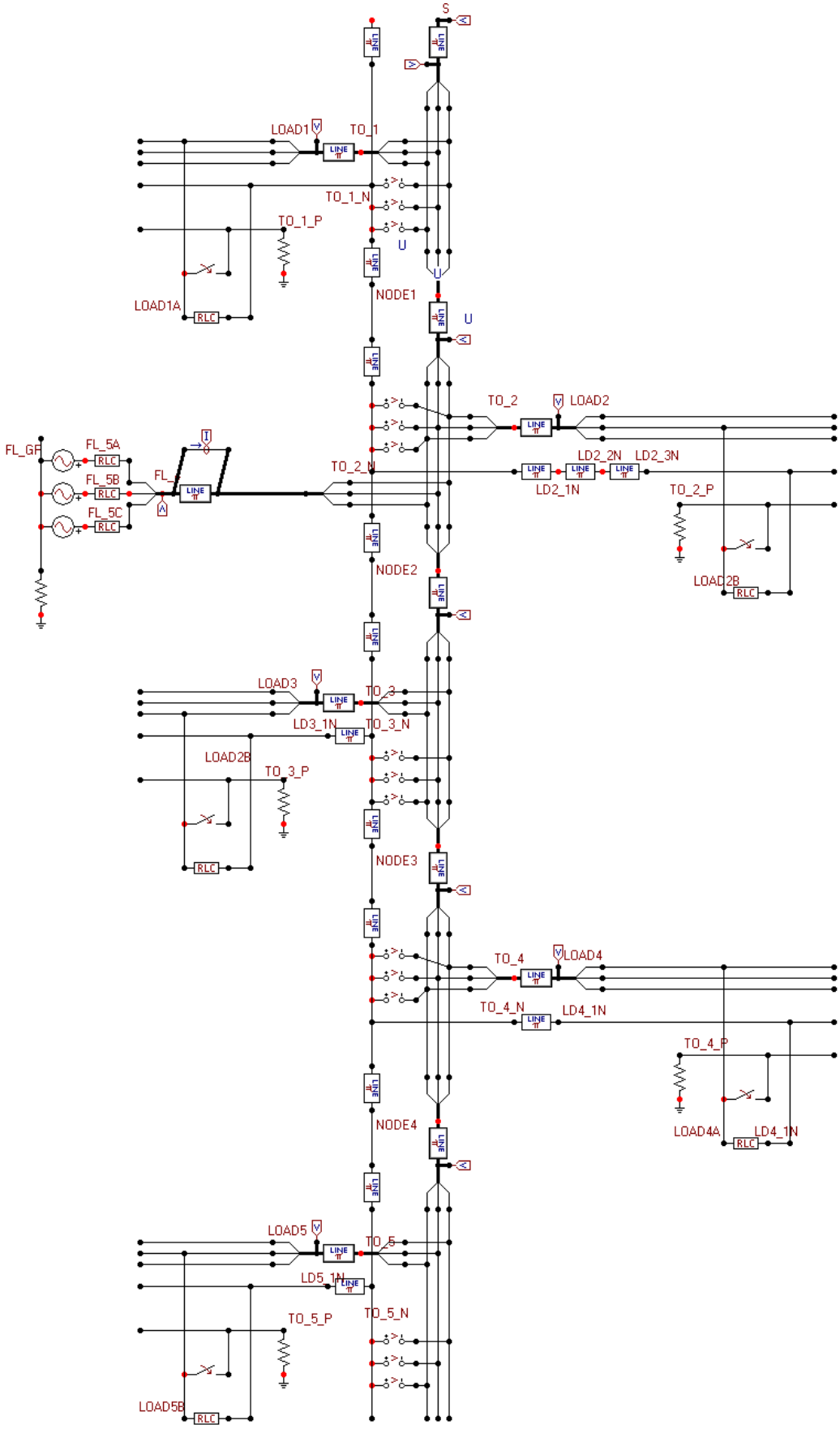



**Figure 35: ATPDraw circuit representation of the LV network for the sixth study case.**

## Simulation Results – 6th Case

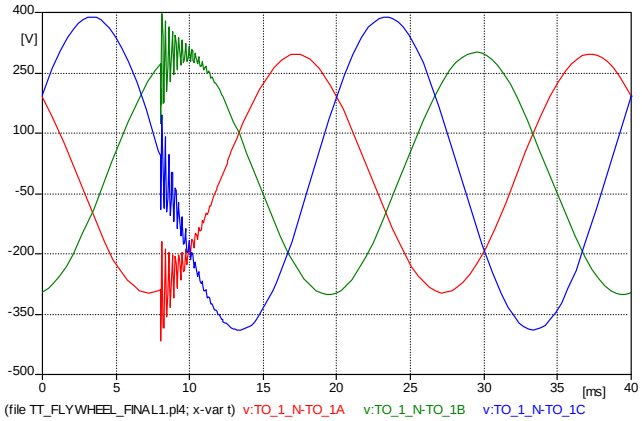



**Figure 36.1: Phase to Neutral Voltages at "TO_1"**

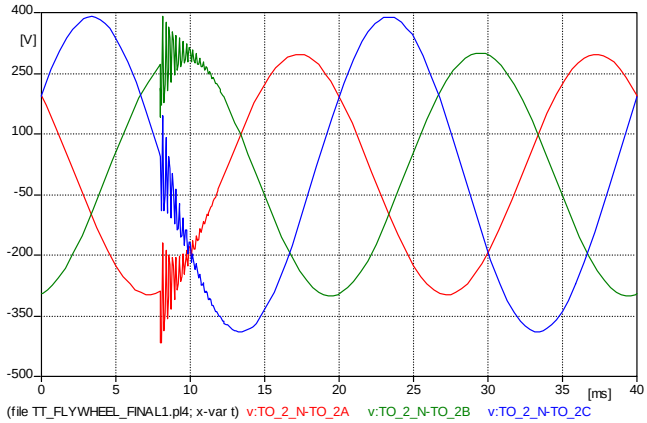



**Figure 36.2: Phase to Neutral Voltages at "TO_2"**

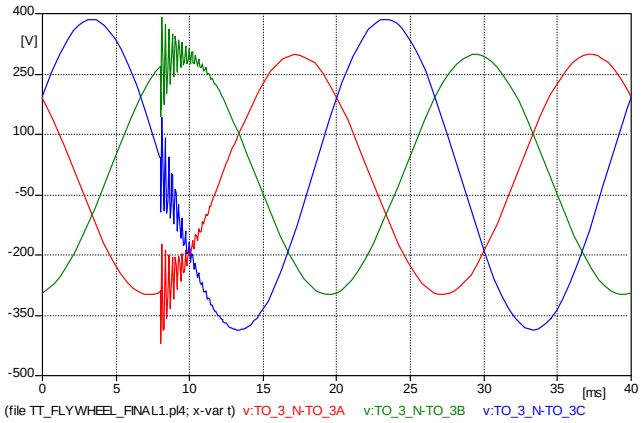



**Figure 36.3: Phase to Neutral Voltages at "TO_3"**

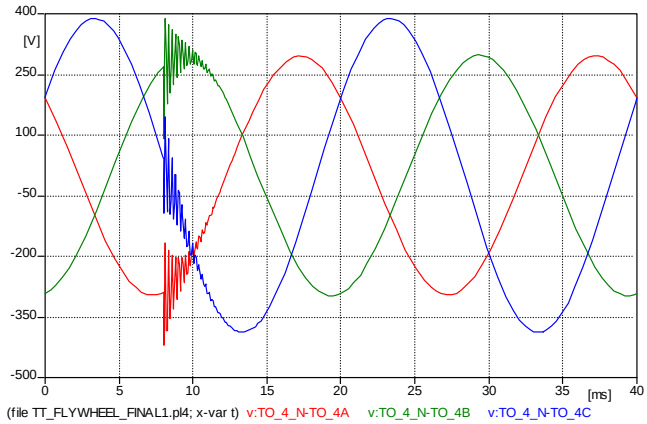



**Figure 36.4: Phase to Neutral Voltages at "TO_4"**

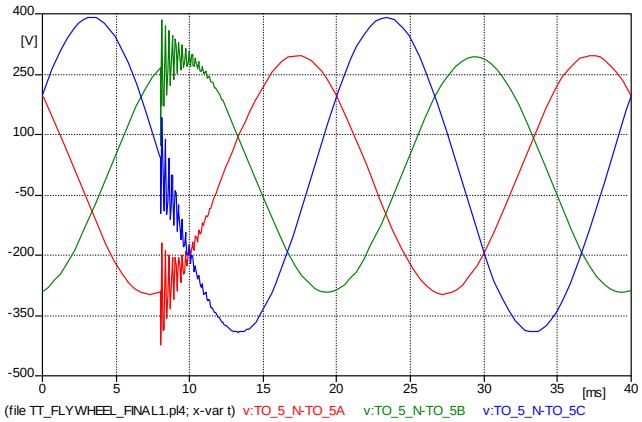



**Figure 36.5: Phase to Neutral Voltages at "TO_5"**

**Figure 36: Phase to Neutral Voltages at various nodes of the circuit**

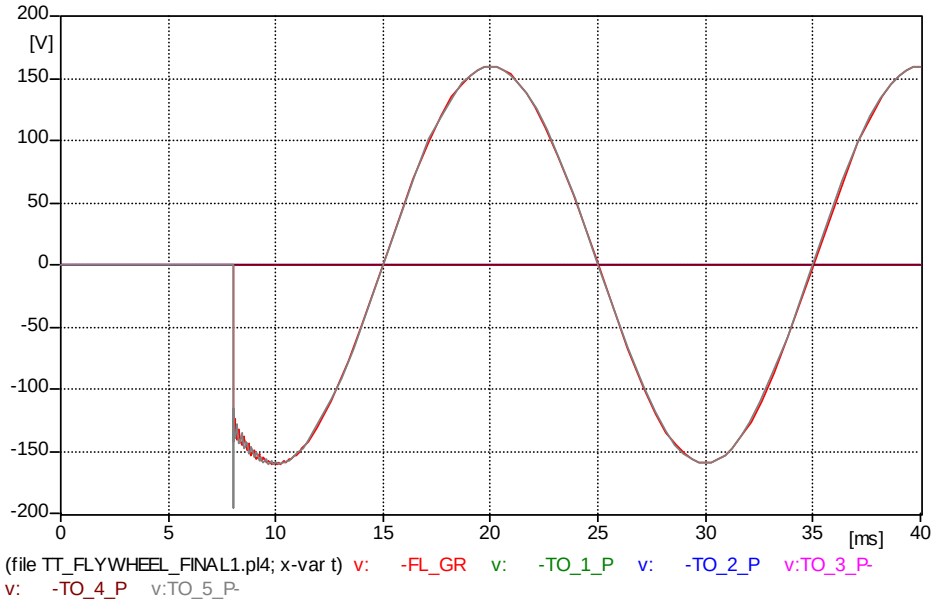



**Figure 37: Neutral and PE to Earth Voltage at 1,2,3,4 and 5**

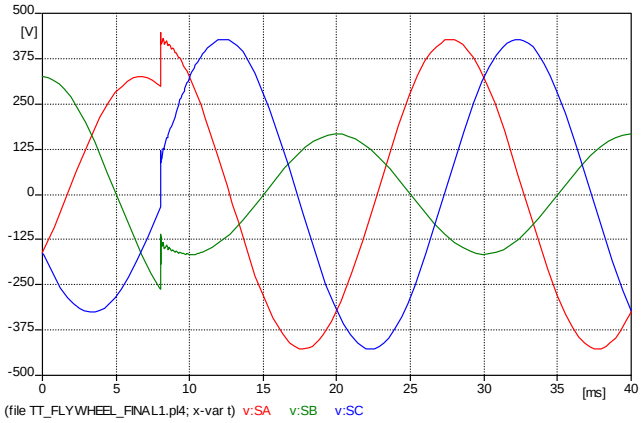



**Figure 38.1: Phase Voltages to Earth at "S"**

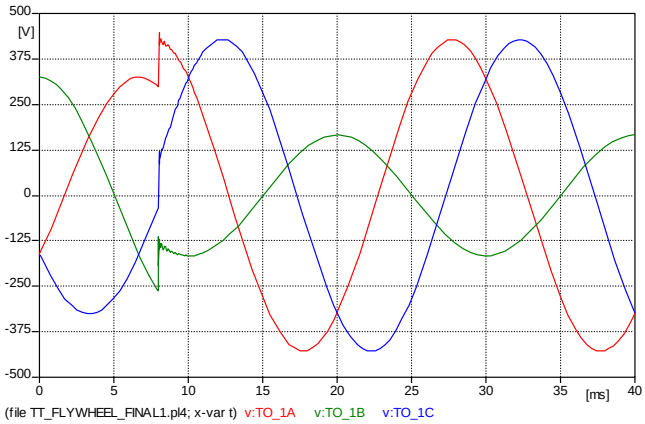



**Figure 38.2: Phase Voltages to Earth at "TO_1"**

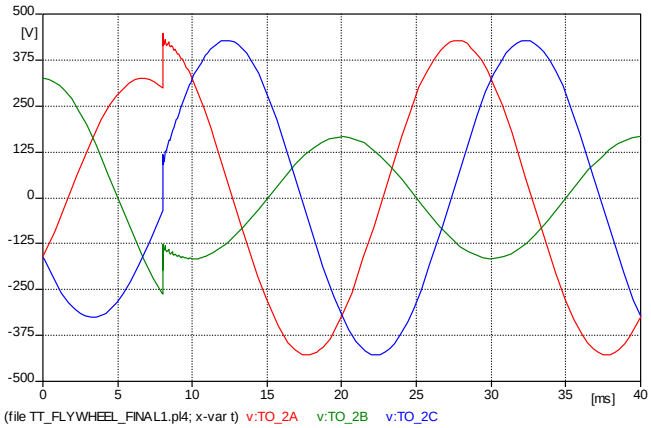



**Figure 38.3: Phase Voltages to Earth at " TO_2"**

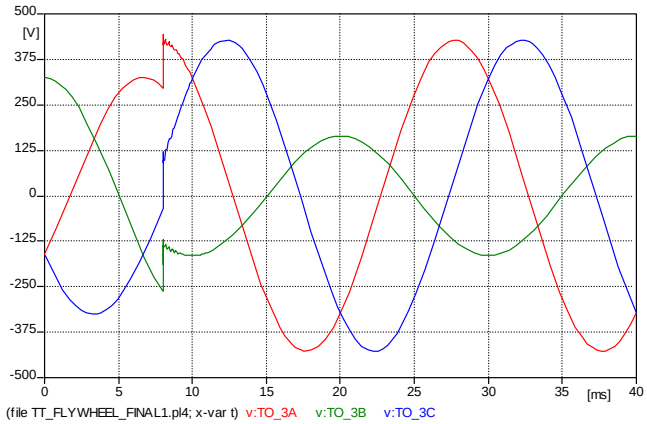



**Figure 38.4: Phase Voltages to Earth at " TO_3"**

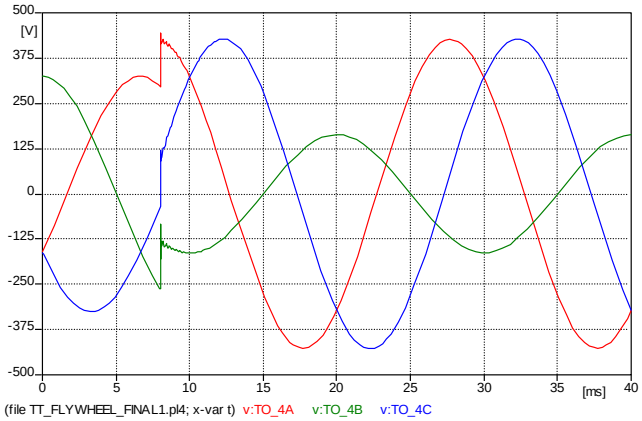



**Figure 38.5: Phase Voltages to Earth at "TO_4"**

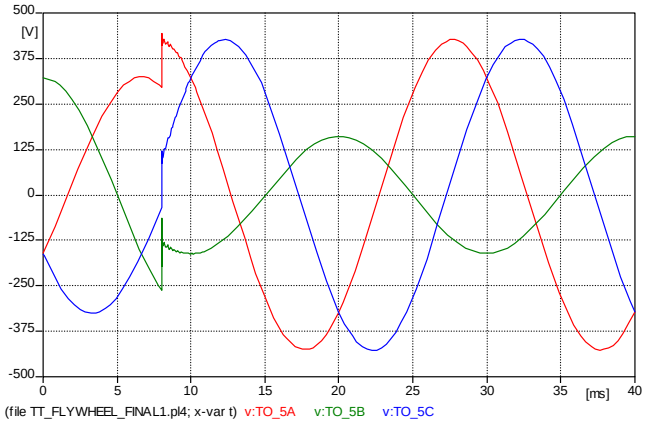



**Figure 38.6: Phase Voltages to Earth at "TO_5"**

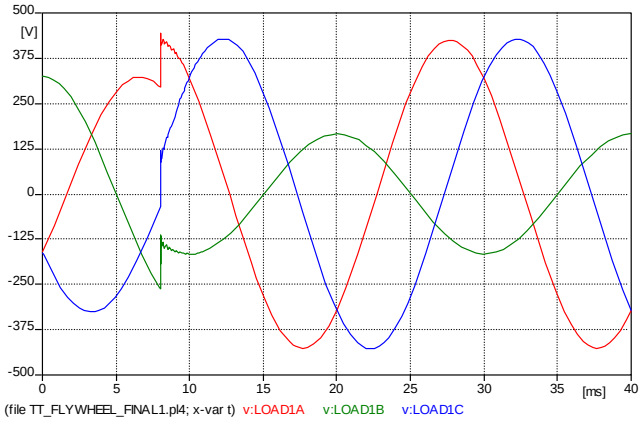



**Figure 38.7: Phase Voltages to Earth at "LOAD1"**

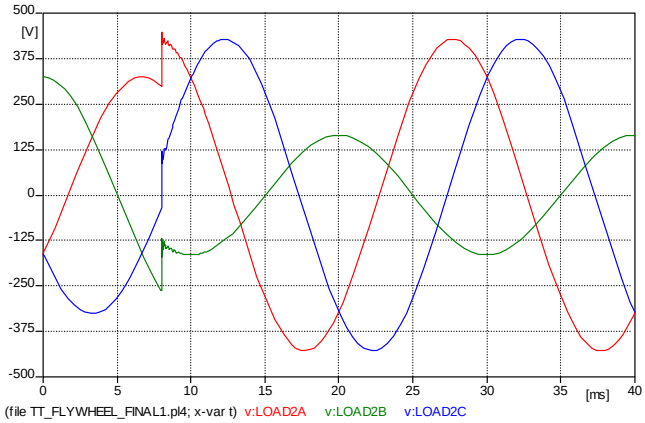



**Figure 38.8: Phase Voltages to Earth at "LOAD2"**

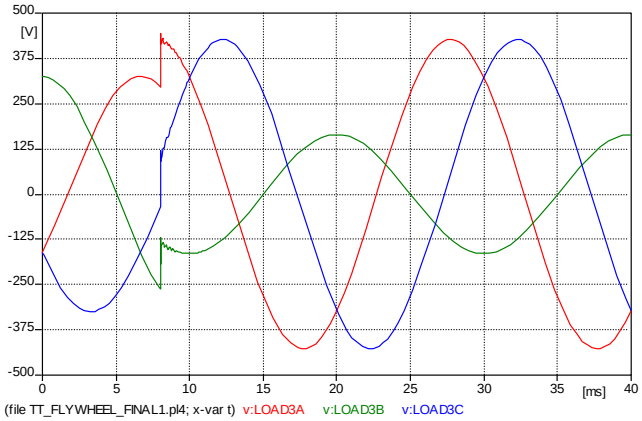



**Figure 38.9: Phase Voltages to Earth at "LOAD3"**

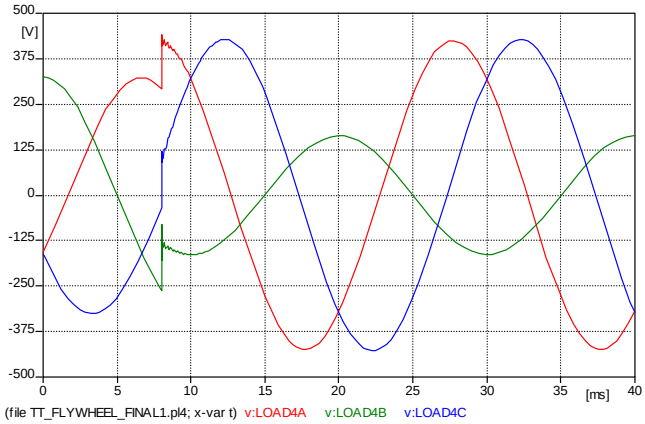



**Figure 38.10: Phase Voltages to Earth at "LOAD4"**

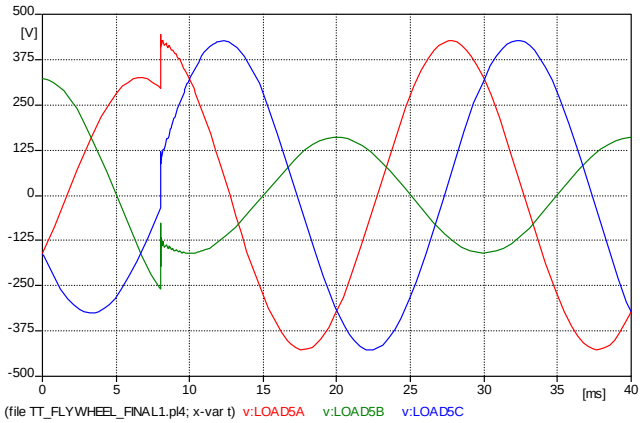



**Figure 38.11: Phase Voltages to Earth at "LOAD5"**

**Figure 38: Phase Voltages to Earth at various nodes of the circuit**

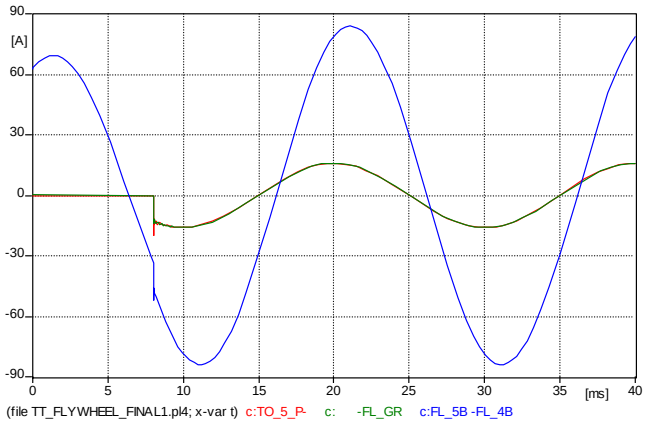



**Figure 39.1: Fault currents.**

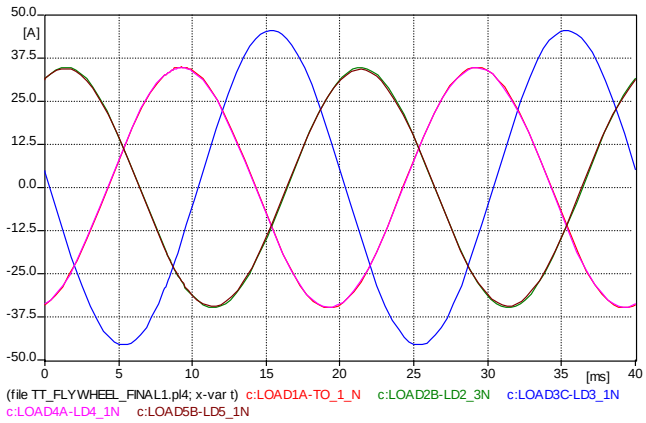



**Figure 39.2.: Currents along the loads.**

## 4. Short discussion

**Case 1 simulation results**

Phase A to neutral voltages are reduced, while the voltages of phases B and C are not influenced by the short-circuit. Voltages to earth of the neutral and PE conductors at all nodes of the network do not exceed 20 V and therefore do not present any threat. The short circuit current is of the order of 2 kA, ensuring thus the fast operation of the overcurrent protection.

**Case 2 simulation results**

The voltages of the healthy phases are slightly increased, particularly near the end of the feeder. Voltages to earth of the neutral and PE conductors at all nodes of the network will rise to maximum values of the order of 140V, necessitating the fast operation of protections, which is possible, but not guaranteed with fault currents of approximately 400 A (a known issue in TN networks, when faults occur far from the source).

**Case 3 simulation results**

The apparent reduction of the total earthing impedance of the network, due to the loss of the substation neutral earth, results in the voltages of the healthy phases increasing by 25-30%, which is quite significant. Voltages to earth of the neutral and PE conductors at all nodes of the network do not exceed 60V, while the fault current of 1.5 kA ensures the fast operation of the overcurrent protection.

**Case 4 simulation results**

The limitation of the inverter fault current contribution to approximately 200 A (three times its rated current) results in small overvoltages for the healthy phases, as well as between the N/PE conductors and earth. However, the selective operation of overcurrent protections along the network has to be further examined.

**Case 5 simulation results**

It is observed that the application of the TT system results in very low fault currents, which would hardly lead to the operation of any overcurrent protection device. This is due to the non-negligible earthing resistances (primarily at the consumer premises and secondarily at the source), leading also to the appearance of high touch voltages. This is a well-known characteristic of the TT earthing system, which is recommended only with good earthing provisions. In addition, the use of Residual Current Breakers (RCBs) is always stipulated by the standards.

**Case 6 simulation results**

Remarks similar to those for Case 5 apply here as well. In the isolated mode of the TT grounded network, very low fault currents and high touch voltages are observed, along with large voltage increases in the healthy phases. Nevertheless, the operating and safety problems are not aggravated compared to the grid-tied mode. It is not that the inverter current limitation is irrelevant here, because very small fault currents are expected.

## 5. Conclusions

Hence, from the study cases presented in the previous sections it is deduced that EMTP can be easily applied to the study of the microgrid earthing systems. It can easily represent the complexity of actual networks with sufficient detail and accuracy, while the simulation times required are not prohibitive at all.

Regarding the earthing arrangements of the network, it appears that the TN system with a multi-grounded neutral is rather preferable to the TT system. Most significant though is the observation that the isolated operation of a microgrid does not pose any exceptional requirements on the earthing arrangements of microsources and consumer premises. Situations with potentially dangerous touch voltages may indeed appear, but the same would happen if the network operated in the grid-tied mode, i.e. the problem is not associated with the islanded operation and the microsources. Hence, the main issue remains the design of suitable protection systems, to effectively deal with the reduced fault level and the non-radial feed of faults in the islanded mode of operation.