# Joe Stanley

### ECE 525 - Homework 3

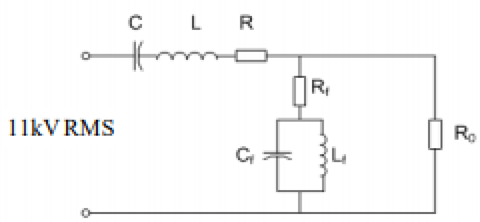
**1.** For the capacitively coupled voltage transformer (CCVT, also known as a capacitive voltage transformer or CVT) circuit below do the following:

A. Determine a Laplace domain transfer function for the relay voltage (the voltage across the load resistance R0) in response to a change in the input voltage. You might find the references linked with the CCVT lectures on the web page very useful.

B. Plot the frequency response of the magnitude of the output voltage from 20Hz to 25th harmonic of 60Hz.

C. Plot the responses for the output voltage versus time for the two sets of CCVT parameters listed below using a circuit simulation program when the primary voltage goes to zero due a fault occuring at a voltage peak with an ideal source. Determine analytical result for extra credit. You are encouraged to use a transient circuit simulation tool

D. Plot the responses for the output voltage versus time for the two sets of CCVT parameters listed below using a circuit simulation program when the primary voltage goes to zero due a fault occuring at  at a voltage zero (again, ideal source). Determine analytical result for extra credit.




CCVT 1 (medium C (energy) CCVT )

$R_0 = 1.03997 \cdot 10^5$ — load resistance, Ω
$L_f = 315.3$ — suppression inductance, H
$C_f = 0.0285 \cdot 10^{-6}$ — suppression capacitance, F
$R_f = 77379$ — suppression resistance, Ω
$R = 3289$ — resistance, Ω
$C = 9.1605 \cdot 10^{-8}$ — sum of dividing capacitances, F
$L = 76.136$ — inductance, H

CCVT 2 (high C (energy) CCVT )

$R_0 = 2.08584 \cdot 10^5$ — load resistance, Ω
$L_f = 616.35$ — suppression inductance, H
$C_f = 0.01134 \cdot 10^{-6}$ — suppression capacitance, F
$R_f = 148519$ — suppression resistance, Ω
$R = 1536$ — resistance, Ω
$C = 0.162442 \cdot 10^{-6}$ — sum of dividing capacitances, F
$L = 48.136$ — inductance, H

In [1]:

```python
# Import Supporting Libraries
import numpy as np
import matplotlib.pyplot as plt
import eepower as eep
import eesignal as ees
from eepower import u,m,k,M # Unit scaling
```

A)

From the GE paper written by B. Kasztenny, D. Sharples, V. Asara and M. Pozzuli, we can see that the transfer function is:

$$H(s) = \frac{A_3 s^3 + A_2 s^2 + A_1 s}{B_4 s^4 + B_3 s^3 + B_2 s^2 + B_1 s + B_0}$$

where the terms are defined as:

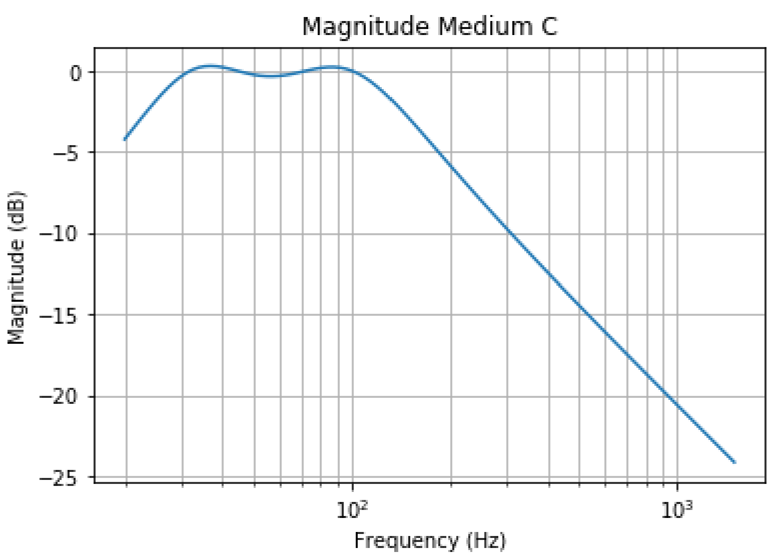
$$A_3 = L_f C_f R_f R_0 C$$
$$A_2 = L_f R_0 C$$
$$A_1 = R_f R_0 C$$
$$B_4 = L_f C_f (R_f + R_0) LC$$
$$B_3 = LCL_f + RCL_f C_f (R_f + R_0) + L_f C_f R_f R_0 C$$
$$B_2 = LC(R_f + R_0) + RCL_f + L_f C_f (R_f + R_0) + L_f R_0 C$$
$$B_1 = RC(R_f + R_0) + L_f + R_f R_0 C$$
$$B_0 = R_f + R_0$$

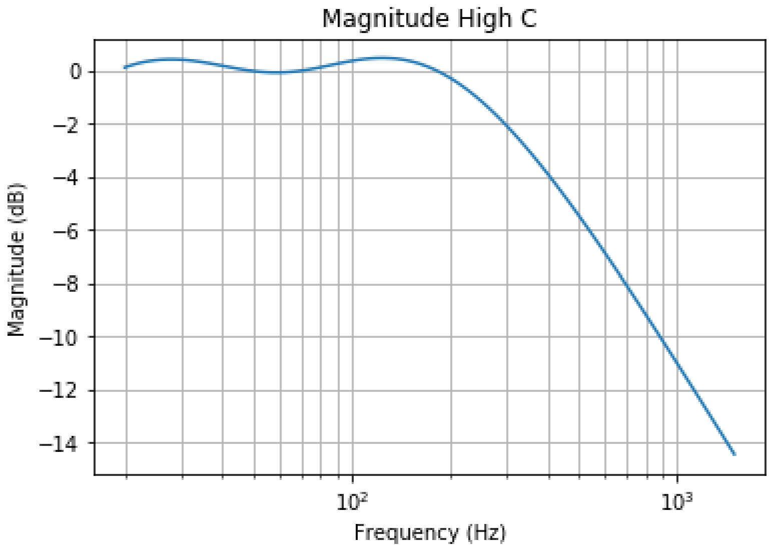
In [2]:

```python
# Define Function to Generate Transfer Function Terms
# Transfer function should be returned as:
# ([NUMERATOR],[DENOMINATOR])
# ie a tuple of lists describing each s-order term
def ccvttransterms(Ro,Lf,Cf,Rf,R,C,L):
    """
    ccvttransterms Function:

    A simple function that accepts the specifying values that
    define a capacitively coupled voltage transformer, and will
    use the arguments to develop a transfer function set (numerator,
    denominator) for use in Bode plot functions and other systems.

    Returns
    -------
    num:    list of float
            List of the numerator terms in traditional polynomial order.
    den:    list of float
            List of the denominator terms in traditional polynomial order.
    """
    # Define Each Term
    A3 = Lf*Cf*Rf*Ro*C
    A2 = Lf*Ro*C
    A1 = Rf*Ro*C
    A0 = 0
    B4 = Lf*Cf*(Rf+Ro)*L*C
    B3 = L*C*Lf+R*C*Lf*Cf*(Rf+Ro)+Lf*Cf*Rf*Ro*C
    B2 = L*C*(Rf+Ro)+R*C*Lf+Lf*Cf*(Rf+Ro)+Lf*Ro*C
    B1 = R*C*(Rf+Ro)+Lf+Rf*Ro*C
    B0 = Rf+Ro
    # Generate Term Lists for Transfer Function
    num = [A3,A2,A1,A0]
    den = [B4,B3,B2,B1,B0]
    return(num,den)
```

In [3]:

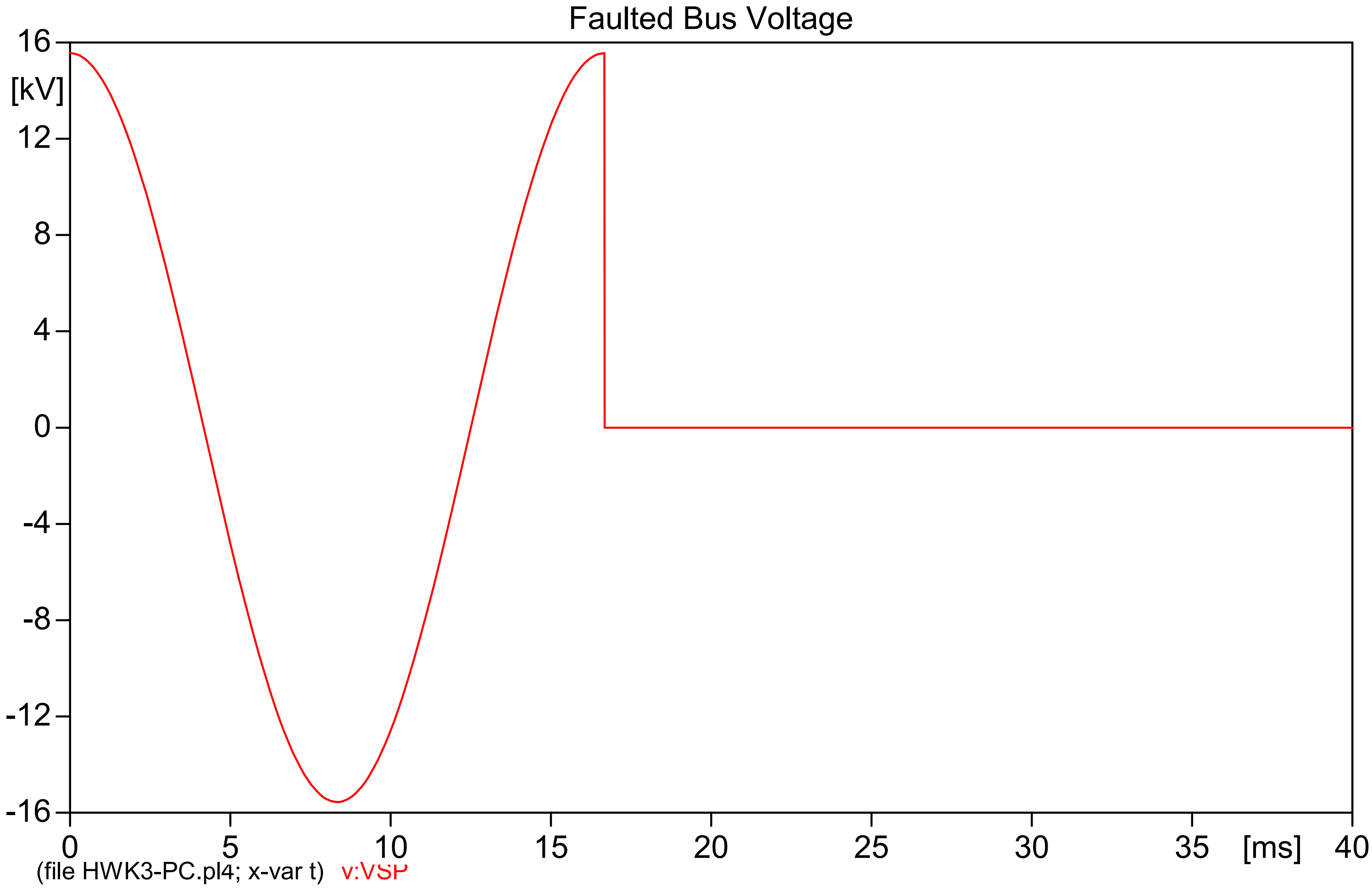
```python
# B) Plot Frequency Response

# Define Givens for CCVT 1
Ro = 1.03997e5   # Ω
Lf = 315.3       # H
Cf = 0.0285e-6   # F
Rf = 77379       # Ω
R = 3289         # Ω
C = 9.1605e-8    # F
L = 76.136       # H

# Generate Transfer Function
system = ccvttransterms(Ro,Lf,Cf,Rf,R,C,L)
# Use Function to generate Bode Plot
ees.bode(system,20,25*60,angle=False,freqaxis='DEG',title="Medium C")

# Define Givens for CCVT 2
Ro = 2.08584e5   # Ω
Lf = 616.35      # H
Cf = 0.01134e-6  # F
Rf = 148519      # Ω
R = 1536         # Ω
C = 0.162442e-6  # F
L = 48.136       # H

# Generate Transfer Function
system = ccvttransterms(Ro,Lf,Cf,Rf,R,C,L)
# Use Function to generate Bode Plot
ees.bode(system,20,25*60,angle=False,freqaxis='deg',title="High C")
```

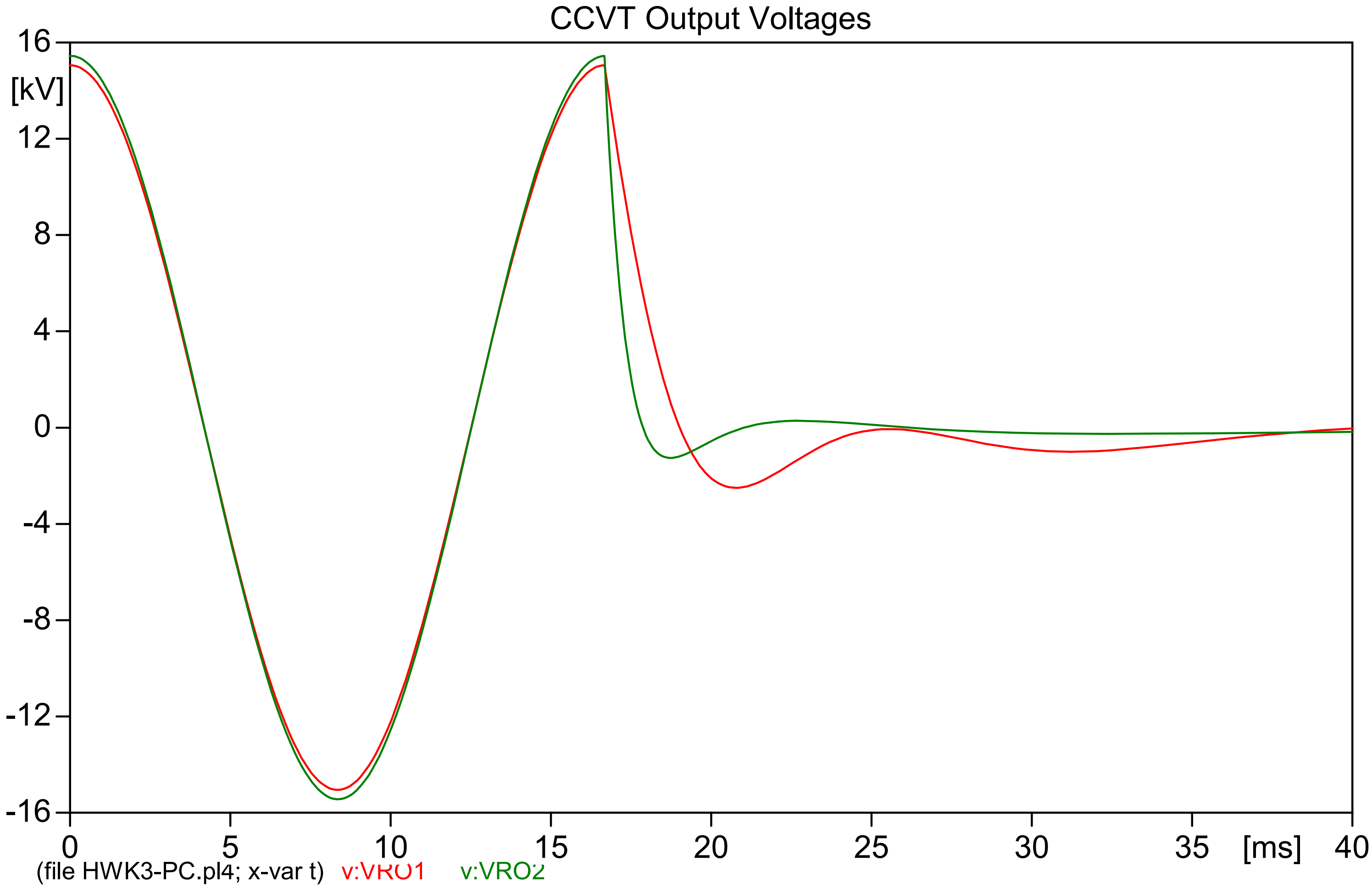



Magnitude High C
Magnitude (dB)
0
−2
−4
−6
−8
−10
−12
−14
$10^2$
$10^3$
Frequency (Hz)

In [ ]:
```
1
```

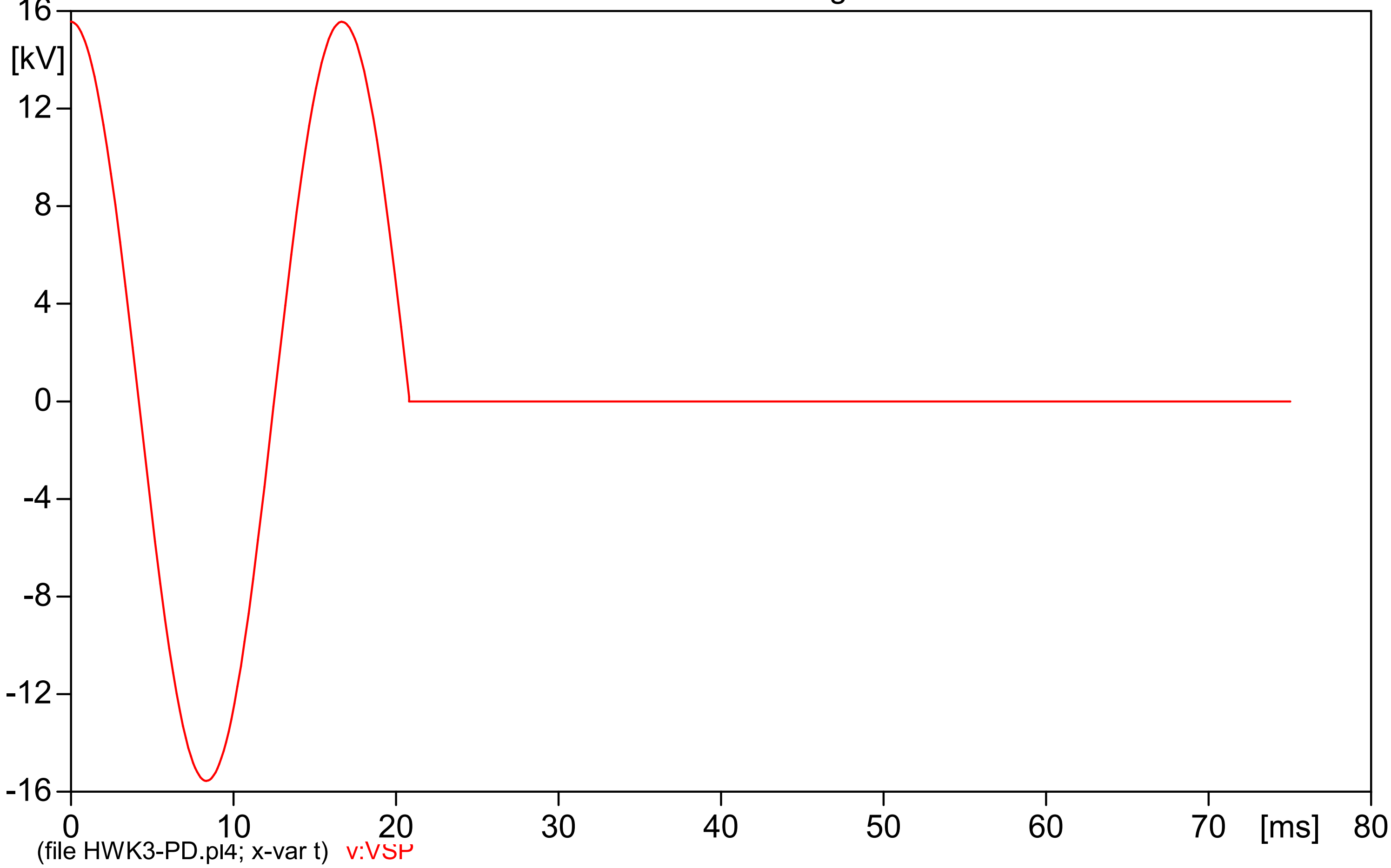
In [ ]:
```
1
```

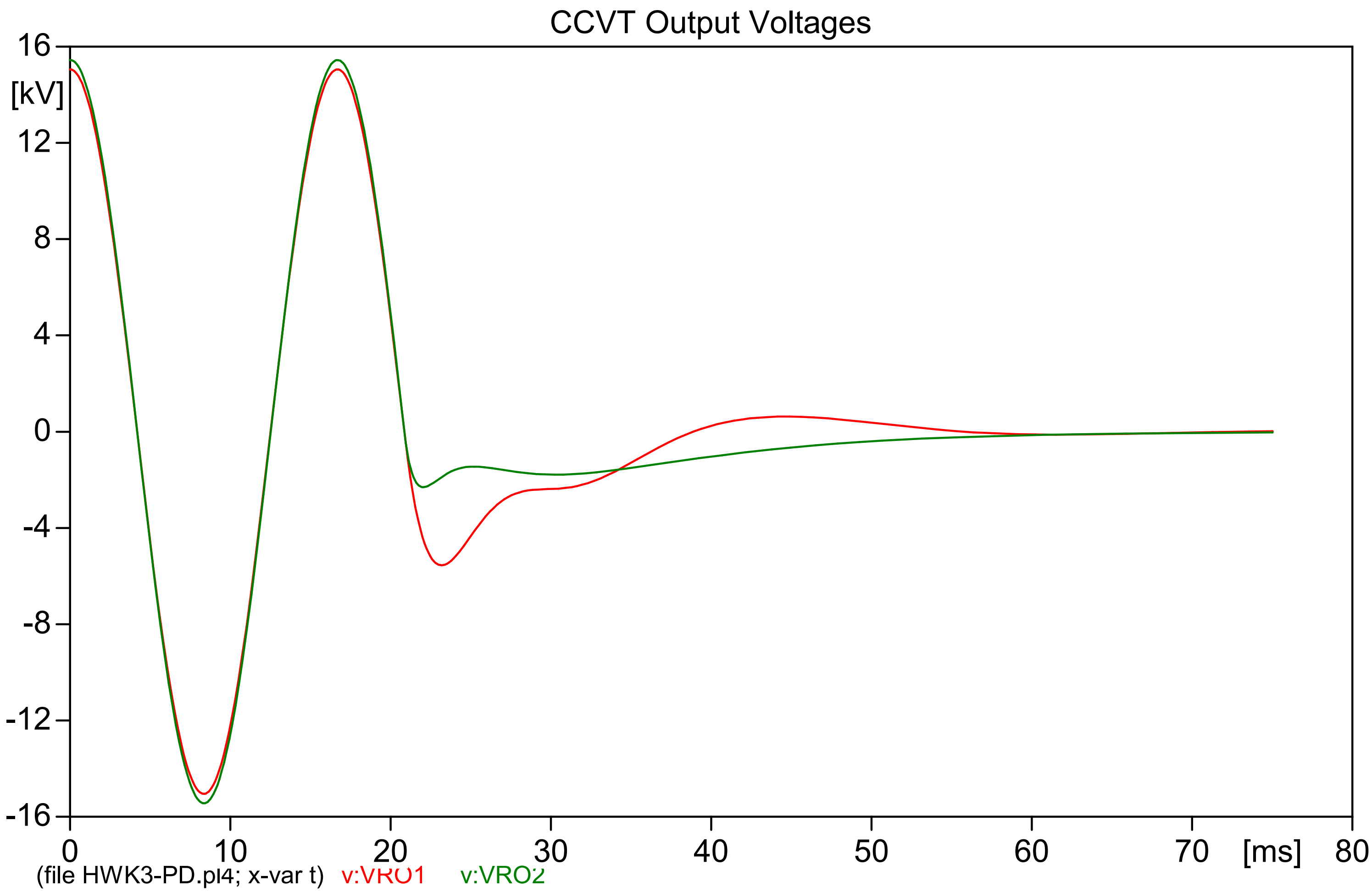

Faulted Bus Voltage
16
[kV]
12
8
4
0
-4
-8
-12
-16
0
5
10
15
20
25
30
35
[ms]
40
(file HWK3-PC.pl4; x-var t)
v:VSP



CCVT Output Voltages
[kV]
16
12
8
4
0
-4
-8
-12
-16
0
5
10
15
20
25
30
35
[ms]
40
(file HWK3-PC.pl4; x-var t)
v:VRO1
v:VRO2

Faulted Bus Voltage





CCVT Output Voltages
16
[kV]
12
8
4
0
-4
-8
-12
-16
0
10
20
30
40
50
60
70
[ms]
80
(file HWK3-PD.pl4; x-var t)
v:VRO1
v:VRO2