Synchronous Machine Three Phase Fault Example

$pu := 1$ $\quad MVA := MW$ $\quad V_{LL} := 13.8kV$ $\quad S_{rated} := 20MVA$

$X''_d := 0.145pu$ $\quad X_2 := X''_d$ $\quad T''_d := 0.035sec$ $\quad \omega := 2\cdot\pi\cdot 60Hz$

$X'_d := 0.240pu$ $\quad X_{tran} := 0.0pu$ $\quad T'_d := 1sec$

$X_d := 1.10pu$ $\quad V_{term} := 1.0pu$ $\quad T_a := 0.2sec$

$$L_2 := \frac{X_2}{\omega}\cdot\left(\frac{V_{LL}^2}{S_{rated}}\right) \qquad L_2 = 3.66\cdot mH$$

$$R_a := \frac{L_2}{T_a} \qquad R_a = 0.02\,\Omega$$

Since unloaded: $E''_a := V_{term}$ $\quad E'_a := V_{term}$ $\quad E_a := V_{term}$

$$\frac{R_a}{\frac{V_{LL}^2}{S_{rated}}} = 0.00192$$

$$I_{Base} := \frac{S_{rated}}{\sqrt{3}\cdot V_{LL}} \qquad I_{Base} = 836.74\,A$$

- Also I_{rated}

$$I''_a := \frac{E''_a}{j\cdot X''_d + j\cdot X_{tran}} \qquad I''_a = -6.9i\cdot pu \qquad |I''_a|\cdot I_{Base} = 5770.62\,A$$

$$I'_a := \frac{E'_a}{j\cdot X'_d + j\cdot X_{tran}} \qquad I'_a = -4.17i\cdot pu \qquad |I'_a|\cdot I_{Base} = 3486.41\,A$$

$$I_{ss} := \frac{E_a}{j\cdot X_d + j\cdot X_{tran}} \qquad I_{ss} = -0.91i\cdot pu \qquad |I_{ss}|\cdot I_{Base} = 760.67\,A$$

- Less than rated load current

$$I_{dcoffsetmax} := \sqrt{2}\cdot\frac{E''_a}{X''_d + X_{tran}} \qquad I_{dcoffsetmax} = 9.75\cdot pu \qquad I_{dcoffsetmax}\cdot I_{Base} = 8160.89\,A$$

$$t := 0\text{sec}, 1\cdot 10^{-4}\text{sec} .. 2\text{sec}$$

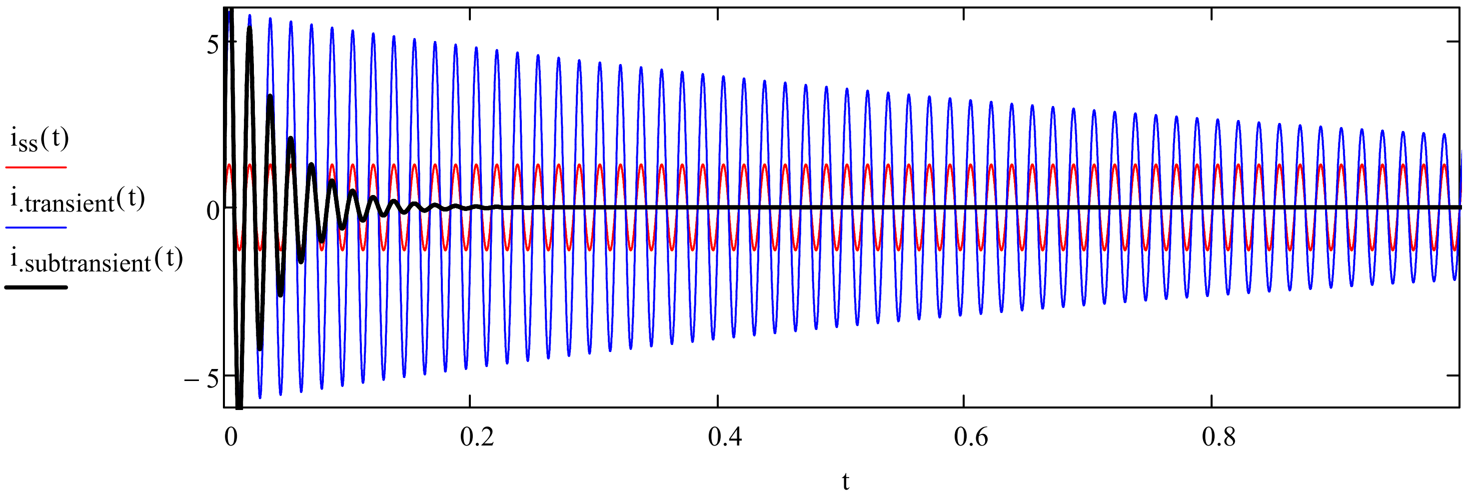
$$i_{ss}(t) := \sqrt{2}\cdot\left|I_{ss}\right|\cdot\cos(\omega\cdot t - 90\text{deg})$$

$$i_{.transient}(t) := e^{\frac{-t}{T'_d}}\cdot\left(\sqrt{2}\cdot\left|I'_a\right|\cdot\cos(\omega\cdot t - 90\text{deg})\right)$$

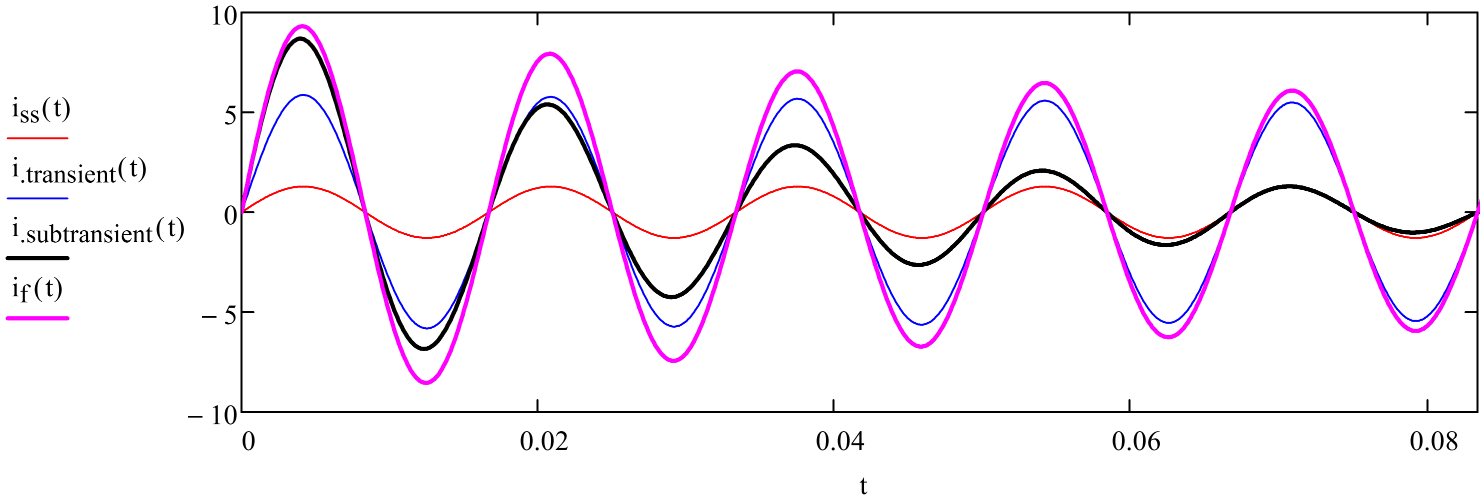
$$i_{.subtransient}(t) := e^{\frac{-t}{T''_d}}\cdot\left(\sqrt{2}\cdot\left|I''_a\right|\cdot\cos(\omega\cdot t - 90\text{deg})\right)$$

- Full symmetrical response:

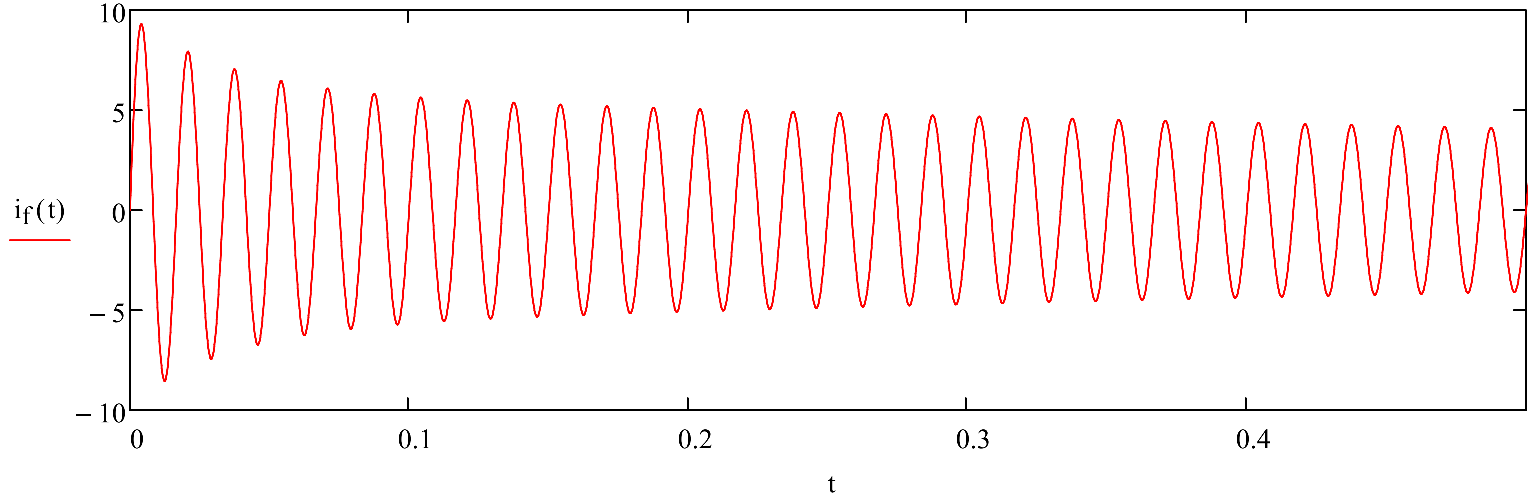
$$i_f(t) := \sqrt{2}\cdot E''_a\cdot\left[\frac{1}{X_d + X_{tran}} + \left(\frac{1}{X'_d + X_{tran}} - \frac{1}{X_d + X_{tran}}\right)\cdot e^{\frac{-t}{T'_d}} + \left(\frac{1}{X''_d + X_{tran}} - \frac{1}{X'_d + X_{tran}}\right)\cdot e^{\frac{-t}{T''_d}}\right]\cdot\cos(\omega\cdot t - 90\text{deg})$$



5
0
– 5
0
0.2
0.4
0.6
0.8
t
$i_{ss}(t)$
$i_{.transient}(t)$
$i_{.subtransient}(t)$



10
5
0
– 5
– 10
0
0.02
0.04
0.06
0.08
t
$i_{ss}(t)$
$i_{.transient}(t)$
$i_{.subtransient}(t)$
$i_f(t)$

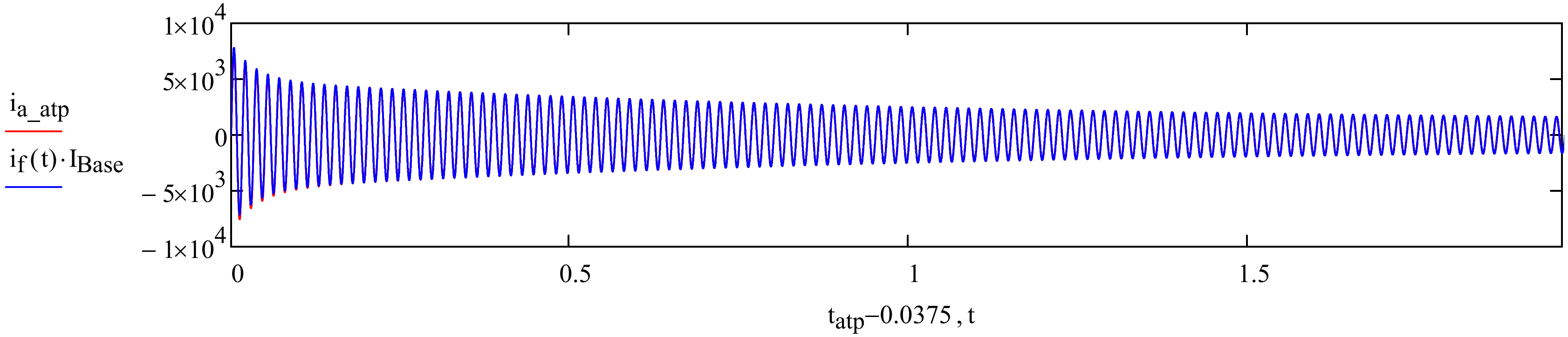


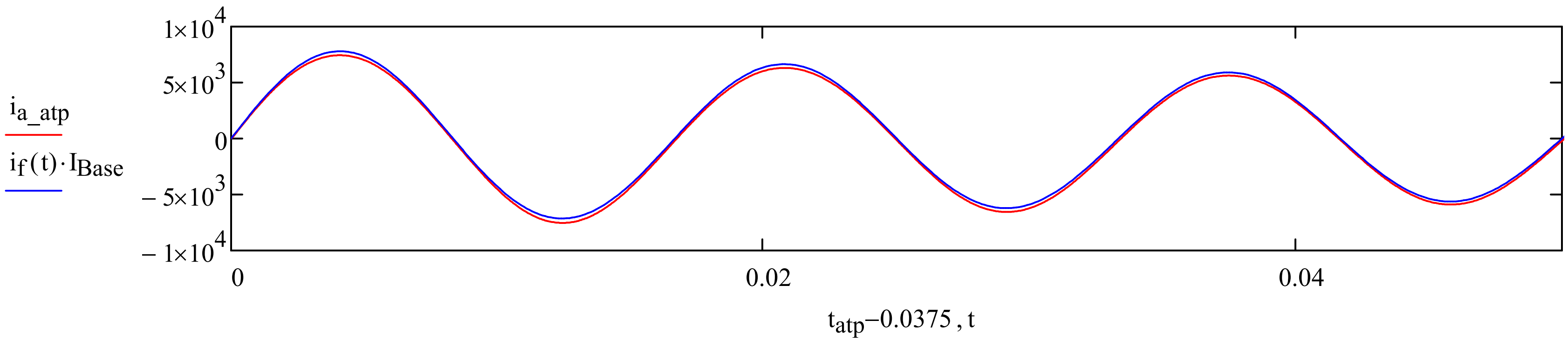
- Compare the equation results with a simulation performed with an detailed generator model in a power systems transients program. First the case with no dc offset.

ATPinput :=

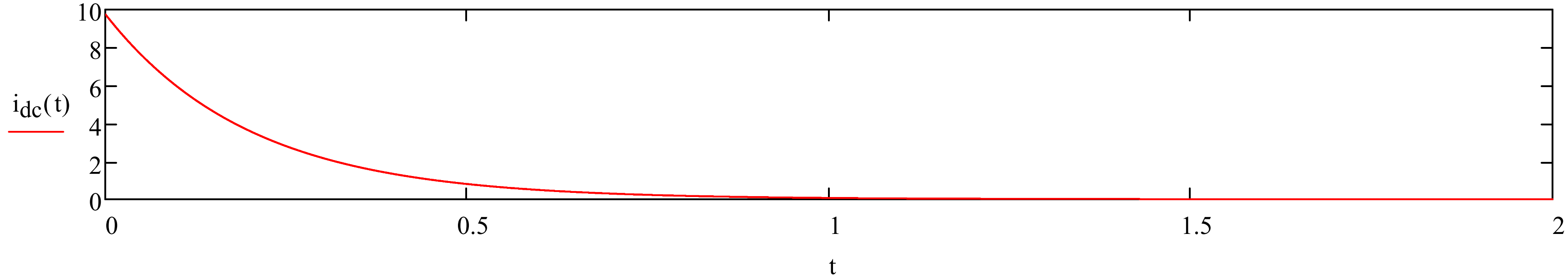
Generator.ADF

$t_{atp} := ATPinput^{\langle 0 \rangle}$ $i_{a\_atp} := ATPinput^{\langle 1 \rangle}$



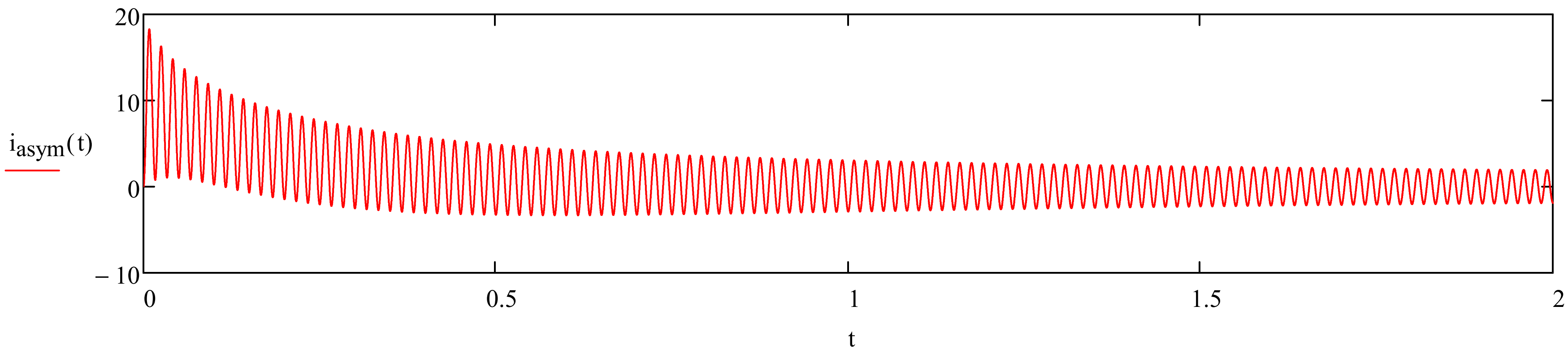


$$i_{dc}(t) := I_{dcoffsetmax}\cdot e^{\frac{-t}{T_a}}$$



$$i_{f2}(t) := \sqrt{2}\cdot E''_a\cdot\left[\frac{1}{X_d + X_{tran}} + \left(\frac{1}{X'_d + X_{tran}} - \frac{1}{X_d + X_{tran}}\right)\cdot e^{\frac{-t}{T'_d}} + \left(\frac{1}{X''_d + X_{tran}} - \frac{1}{X'_d + X_{tran}}\right)\cdot e^{\frac{-t}{T''_d}}\right]\cdot\cos(\omega\cdot t - 180deg)$$

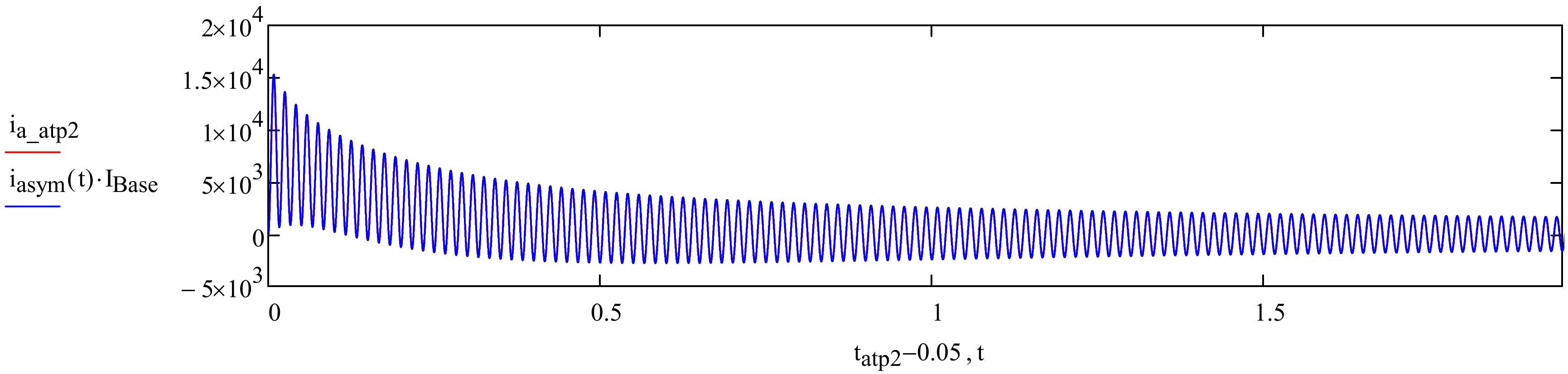
$$i_{asym}(t) := i_{f2}(t) + i_{dc}(t)$$

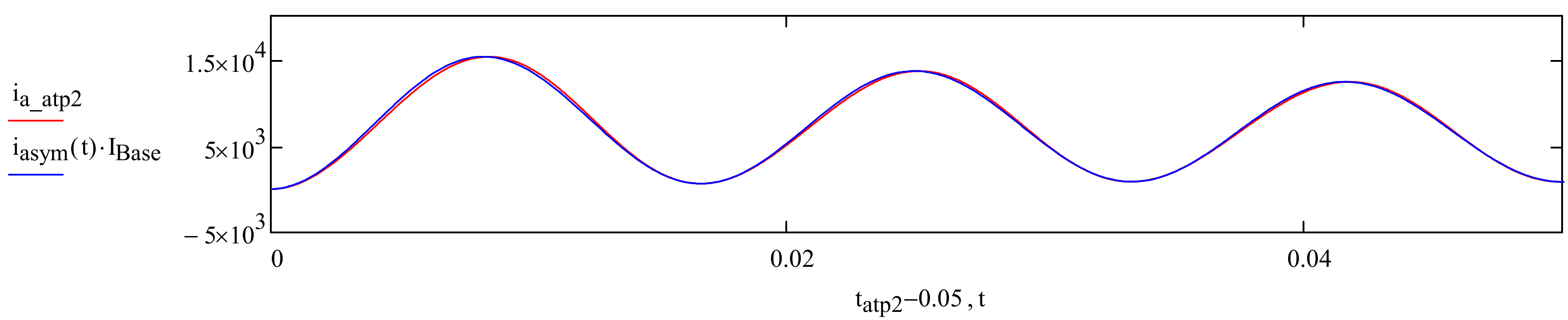


- Now compare with a transient simulation case with a DC offset:

ATPinput :=
GenDConset.ADF

$t_{atp2} := ATPinput^{\langle 0 \rangle}$ $\quad$ $i_{a\_atp2} := ATPinput^{\langle 1 \rangle}$





Generator Example 2: Repeat magnitude calculations with generator operating at rated full load (pf = 0.8 lagging for this machine).

$\phi_{load} := acos(0.8)$ $\phi_{load} = 36.87\cdot deg$

$S_{load} := 1pu\cdot e^{j\cdot\phi_{load}}$

$R_{load} := \left(\frac{1}{0.8}\right)\cdot\frac{V_{LL}^2}{S_{rated}}$ $R_{load} = 11.9\,\Omega$

$I_{load} := \overline{\left(\frac{S_{load}}{V_{term}}\right)}$ $I_{load} = (0.8 - 0.6i)\cdot pu$ $|I_{load}| = 1\cdot pu$

$X_{load} := \left(\frac{1}{0.6}\right)\cdot\frac{V_{LL}^2}{S_{rated}}$

$E''_{a2} := V_{term} + I_{load}\cdot j\cdot X''_d$ $|E''_{a2}| = 1.09\cdot pu$ $arg(E''_{a2}) = 6.09\cdot deg$

$I''_{a2} := \frac{E''_{a2}}{j\cdot X''_d + j\cdot X_{tran}}$ $|I''_{a2}| = 7.54\cdot pu$ $arg(I''_{a2}) = -83.91\cdot deg$

$\frac{X_{load}}{\omega} = 42.1\cdot mH$

$I_{Base} = 836.74\,A$

$\theta := arg(I_{load})$

$E'_{a2} := V_{term} + I_{load}\cdot j\cdot X'_d$ $|E'_{a2}| = 1.16\cdot pu$ $arg(E'_{a2}) = 9.53\cdot deg$

$\theta = -36.87\cdot deg$

$I'_{a2} := \frac{E'_{a2}}{j\cdot X'_d + j\cdot X_{tran}}$ $|I'_{a2}| = 4.83\cdot pu$ $arg(I'_{a2}) = -80.47\cdot deg$

$E_{a\_2} := V_{term} + I_{load}\cdot j\cdot X_d$ $|E_{a\_2}| = 1.88\cdot pu$ $arg(E_{a\_2}) = 27.93\cdot deg$

$I_{a\_2} := \frac{E_{a\_2}}{j\cdot X_d + j\cdot X_{tran}}$ $|I_{a\_2}| = 1.71\cdot pu$ $arg(I_{a\_2}) = -62.07\cdot deg$

$$I_{dcoffsetmax\_2} := \sqrt{2}\cdot\frac{\left|E''_{a2}\right|}{\left|j\cdot X''_d + j\cdot X_{tran}\right|} \qquad I_{dcoffsetmax\_2} = 10.66\cdot pu$$

$$\frac{\dfrac{1037.6A}{I_{Base}}}{\left[\dfrac{\sqrt{2}\cdot\left|E''_{a2}\right|}{\left(X''_d + X_{tran}\right)}\right]} = 0.1163 \qquad acos(0.1163) = 83.32\cdot deg$$

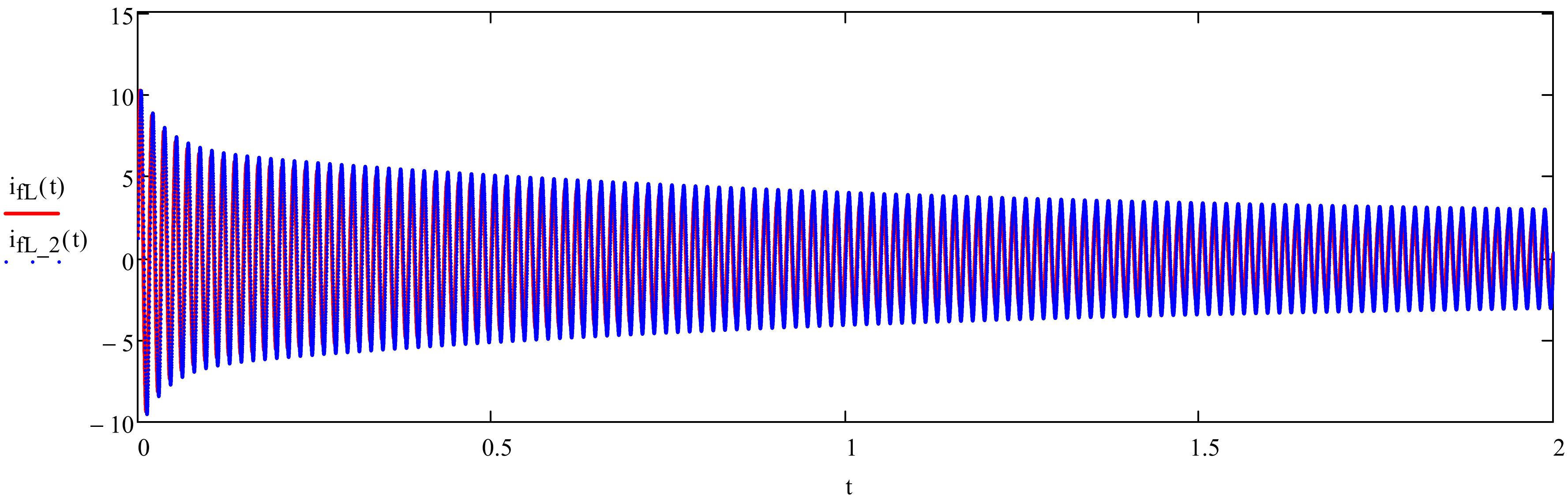
Now look at the impact of the loading on the decay exponential response:

$$i_{fL}(t) := \sqrt{2}\cdot\left|E''_{a2}\right|\cdot\left[\left[\frac{1}{\left(X''_d + X_{tran}\right)} - \frac{1}{\left(X'_d + X_{tran}\right)}\right]\cdot e^{\frac{-t}{T''_d}} + \left[\frac{1}{\left(X'_d + X_{tran}\right)} - \frac{1}{\left(X_d + X_{tran}\right)}\right]\cdot e^{\frac{-t}{T'_d}} + \left[\frac{1}{\left(X_d + X_{tran}\right)}\right]\right]\cdot\cos(\omega\cdot t - 83.32deg)$$

The more accurate formula for the loaded generator case is:

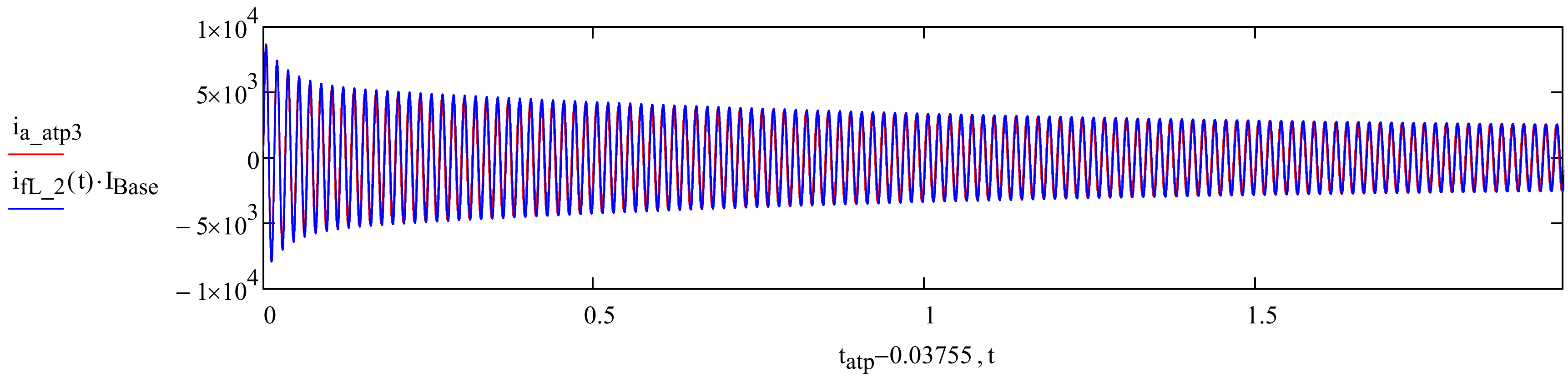
$$i_{fL\_2}(t) := \sqrt{2}\cdot\left[\left[\frac{\left|E''_{a2}\right|}{\left(X''_d + X_{tran}\right)} - \frac{\left|E'_{a2}\right|}{\left(X'_d + X_{tran}\right)}\right]\cdot e^{\frac{-t}{T''_d}} + \left[\frac{\left|E'_{a2}\right|}{\left(X'_d + X_{tran}\right)} - \frac{\left|E_{a\_2}\right|}{\left(X_d + X_{tran}\right)}\right]\cdot e^{\frac{-t}{T'_d}} + \left[\frac{\left|E_{a\_2}\right|}{\left(X_d + X_{tran}\right)}\right]\right]\cdot\cos((\omega\cdot t - 83.32deg))$$

Note that the case with a single voltage value decays more quickly.

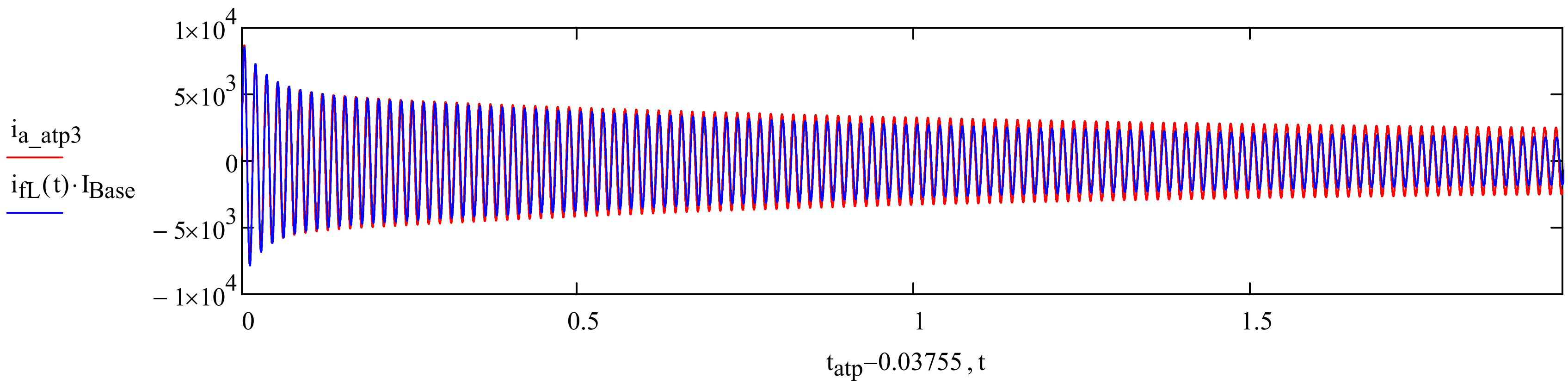


ATPinput :=
LoadedGen.ADF

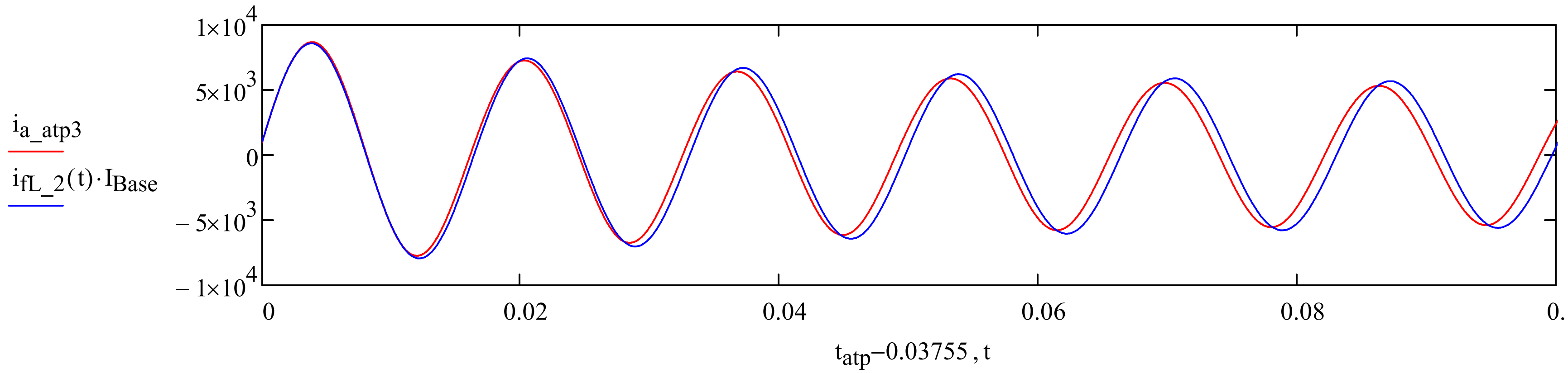
$t_{atp3} := ATPinput^{\langle 0 \rangle}$ $i_{a\_atp3} := ATPinput^{\langle 1 \rangle}$



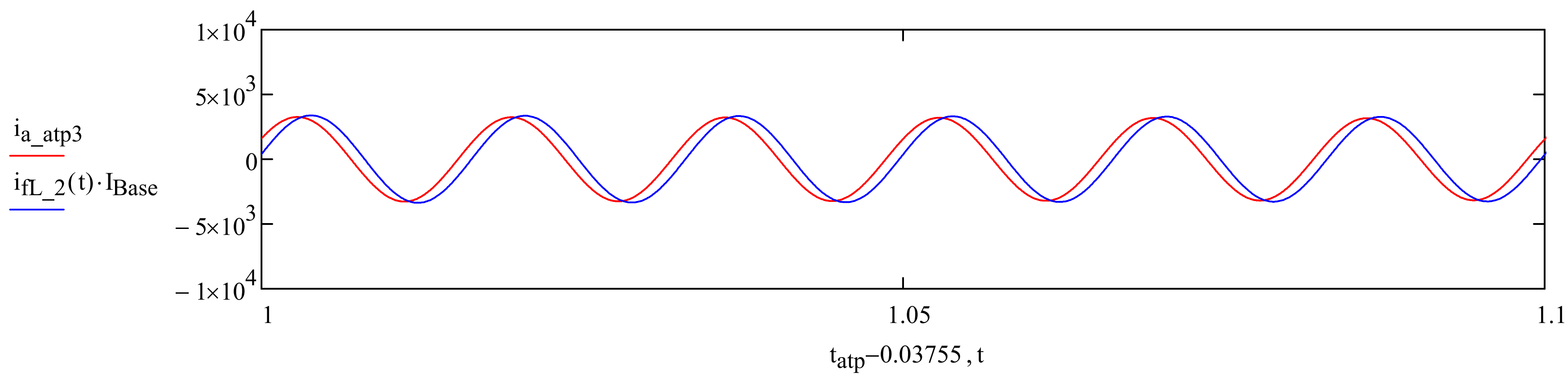
The case with the voltage values matching the impedances matches the ATP results better than the first case, which is below.



The second case with the different voltages is more accurate for amplitude



- Machine rotor is accelerating causing the phase error, which would normally occur
- Not accounted for in analytical calculations.



Notice that amplitudes line up