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Řešení přechodných dějů na transformátoru v nástroji LTspice

Cvičení PJS

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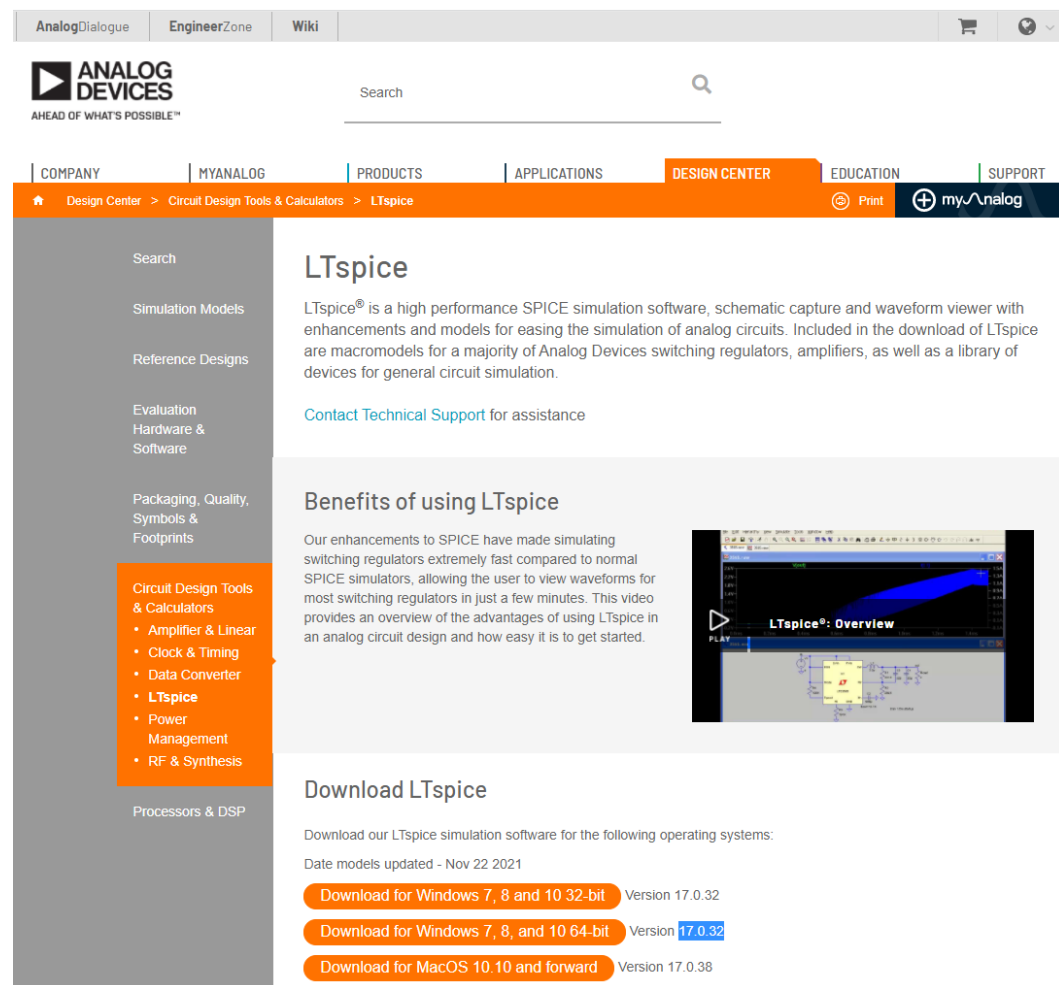
FAKULTA ELEKTROTECHNICKÁ
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KATEDRA
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Výpočet přechodného děje na transformátoru

Pro výpočet ustáleného harmonického stavu nakrátko využít simulační nástroj LTspice:

<https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html>



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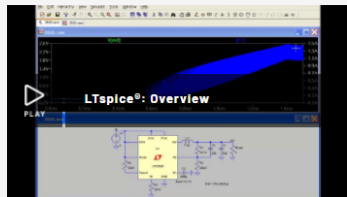
LTspice

LTspice® is a high performance SPICE simulation software, schematic capture and waveform viewer with enhancements and models for easing the simulation of analog circuits. Included in the download of LTspice are macromodels for a majority of Analog Devices switching regulators, amplifiers, as well as a library of devices for general circuit simulation.

[Contact Technical Support](#) for assistance

Benefits of using LTspice

Our enhancements to SPICE have made simulating switching regulators extremely fast compared to normal SPICE simulators, allowing the user to view waveforms for most switching regulators in just a few minutes. This video provides an overview of the advantages of using LTspice in an analog circuit design and how easy it is to get started.



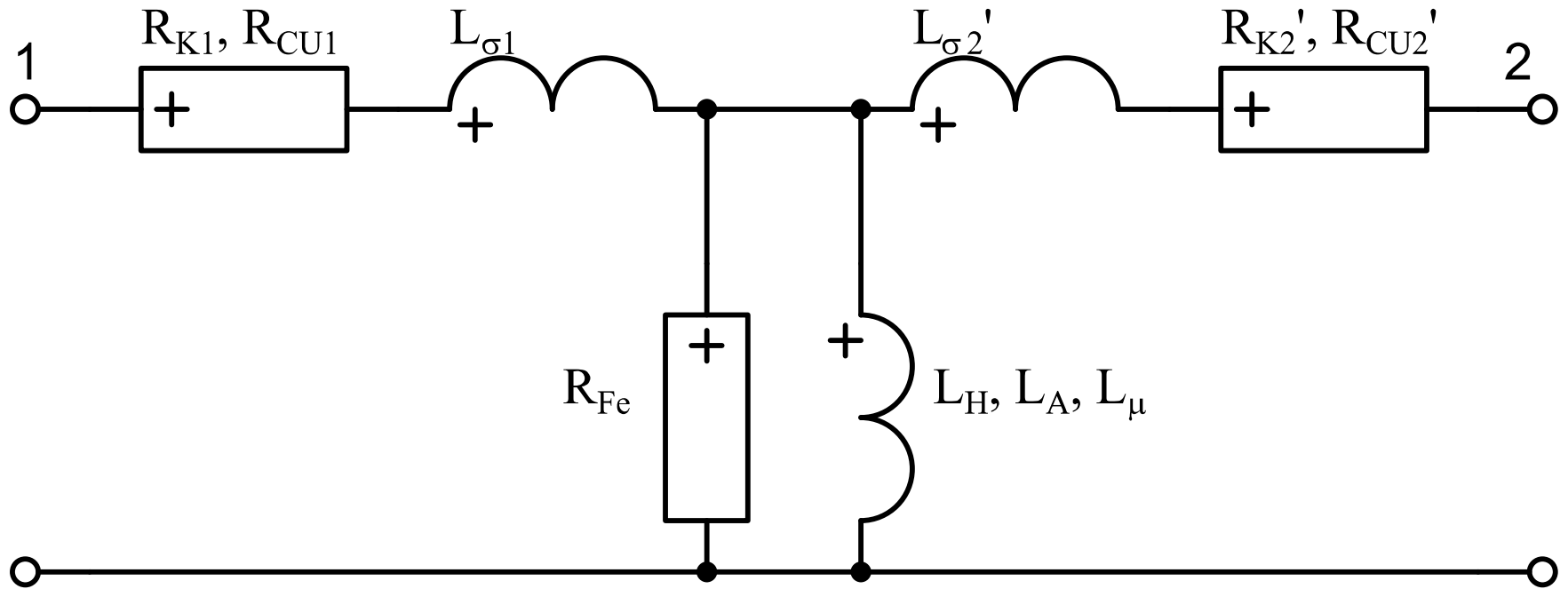
Download LTspice

Download our LTspice simulation software for the following operating systems:

Date models updated - Nov 22 2021

- [Download for Windows 7, 8 and 10 32-bit](#) Version 17.0.32
- [Download for Windows 7, 8, and 10 64-bit](#) Version [17.0.32](#)
- [Download for MacOS 10.10 and forward](#) Version 17.0.38

Náhradní schéma transformátoru



Parametry transformátoru

$$u_K = 10 \%$$

$$i_0 = 1 \%$$

$$U_{N1} = 110 \text{ kV}$$

$$U_{N2} = 22 \text{ kV}$$

$$S_{NT} = 10 \text{ MVA}$$

$$\Delta P_0 = 0.3 \%$$

$$\Delta P_K = 1.0 \%$$

$$U_{kp} = 10 ;$$

$$I_0p = 1 ;$$

$$U_{n1} = 110 ;$$

$$U_{n2} = 22 ;$$

$$S_{nt} = 10 ;$$

$$dP_0p = 0.3 ;$$

$$dP_{kp} = 1 ;$$

Parametry transformátoru

$$\omega = 2 \cdot \pi \cdot f$$

$$R_K = r_K Z_{NT} = \frac{\Delta p_{K\%}}{100} \cdot \frac{U_{N1}^2}{S_{NT}}$$

$$R_{K1} = \frac{R_K}{2}$$

$$Z_K = z_K Z_{NT} = \frac{u_{K\%}}{100} \cdot \frac{U_{N1}^2}{S_{NT}}$$

$$X_\sigma = \sqrt{Z_K^2 - R_K^2}$$

$$L_\sigma = \frac{X_\sigma}{\omega} \quad L_{\sigma 1} = \frac{L_\sigma}{2}$$

$$G_{Fe} = g_{Fe} Y_{NT} = \frac{\Delta p_{0\%}}{100} \cdot \frac{S_{NT}}{U_{N1}^2}$$

$$R_{Fe} = G_{Fe}^{-1}$$

$$Y_0 = y_0 Y_{NT} = \frac{i_{0\%}}{100} \cdot \frac{S_{NT}}{U_{N1}^2}$$

$$X_H = \left(\sqrt{Y_0^2 - G_{Fe}^2} \right)^{-1} \quad L_H = \frac{X_H}{\omega}$$

frekv=50;

omega=2*pi*frekv;

Rk= (dPkp/100) * (Un1^2/Snt) ;

Rk1=Rk/2 ;

Zk= (Ukp/100) * (Un1^2/Snt) ;

Xs=sqrt (Zk^2-Rk^2) ;

Ls=Xs/omega ;

Ls1=Ls/2 ;

Gfe= (dP0p/100) * (Snt/Un1^2) ;

Rfe=1/Gfe ;

Y0= (I0p/100) * (Snt/Un1^2) ;

Xh=1/sqrt (Y0^2-Gfe^2) ;

Lh=Xh/omega ;

Parametry transformátoru

$$\omega = 2 \cdot \pi \cdot f$$

$$R_K = r_K Z_{NT} = \frac{\Delta p_{K\%}}{100} \cdot \frac{U_{N1}^2}{S_{NT}}$$

$$R_{K1} = \frac{R_K}{2}$$

$$Z_K = z_K Z_{NT} = \frac{u_{K\%}}{100} \cdot \frac{U_{N1}^2}{S_{NT}}$$

$$X_\sigma = \sqrt{Z_K^2 - R_K^2}$$

$$L_\sigma = \frac{X_\sigma}{\omega} \quad L_{\sigma 1} = \frac{L_\sigma}{2}$$

$$G_{Fe} = g_{Fe} Y_{NT} = \frac{\Delta p_{0\%}}{100} \cdot \frac{S_{NT}}{U_{N1}^2}$$

$$R_{Fe} = G_{Fe}^{-1}$$

$$Y_0 = y_0 Y_{NT} = \frac{i_{0\%}}{100} \cdot \frac{S_{NT}}{U_{N1}^2}$$

$$X_H = \left(\sqrt{Y_0^2 - G_{Fe}^2} \right)^{-1} \quad L_H = \frac{X_H}{\omega}$$

$$\text{frekv} = 50$$

$$\text{omega} = 314.16$$

$$\text{Rk} = 12.100$$

$$\text{Rk1} = 6.0500$$

$$\text{Zk} = 121$$

$$\text{Xs} = 120.39$$

$$\text{Ls} = 0.38322$$

$$\text{Ls1} = 0.19161$$

$$\text{Gfe} = 0.0000024793$$

$$\text{Rfe} = 403333.33333$$

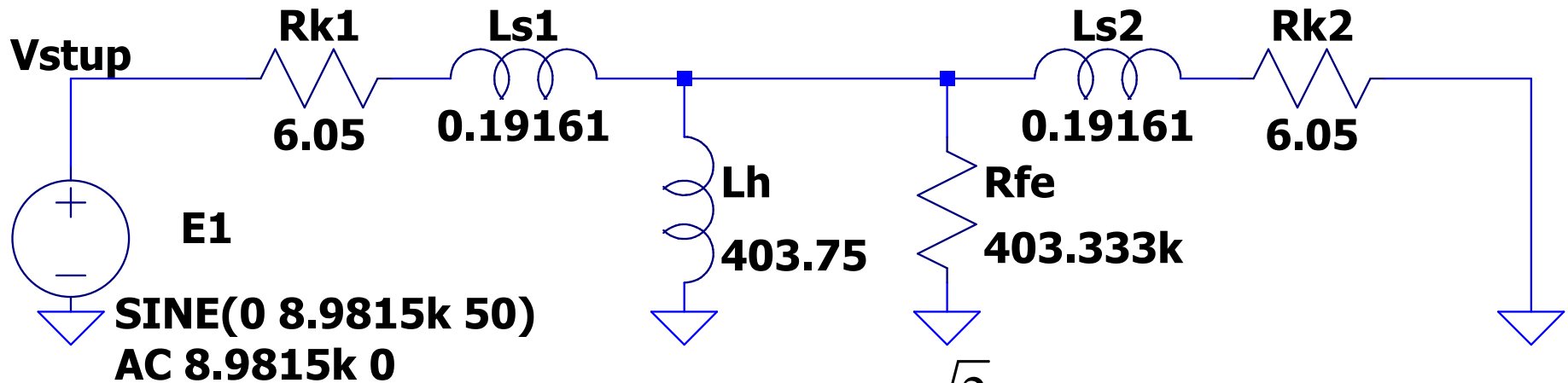
$$\text{Y0} = 0.0000082645$$

$$\text{Xh} = 126842.46524$$

$$\text{Lh} = 403.75$$

Transformátor nakrátko

Řešení s kompletní topologií:



$$U_{KM} = U_{N1} \frac{u_K}{100} \cdot \frac{\sqrt{2}}{\sqrt{3}}$$

$$U_{km} = U_{n1} * U_{kp} / 100 / \text{sqrt}(3) * \text{sqrt}(2)$$

$$R_{k1} = 6.0500$$

$$L_{s1} = 0.19161$$

$$G_{fe} = 0.0000024793$$

$$R_{fe} = 403333.33333$$

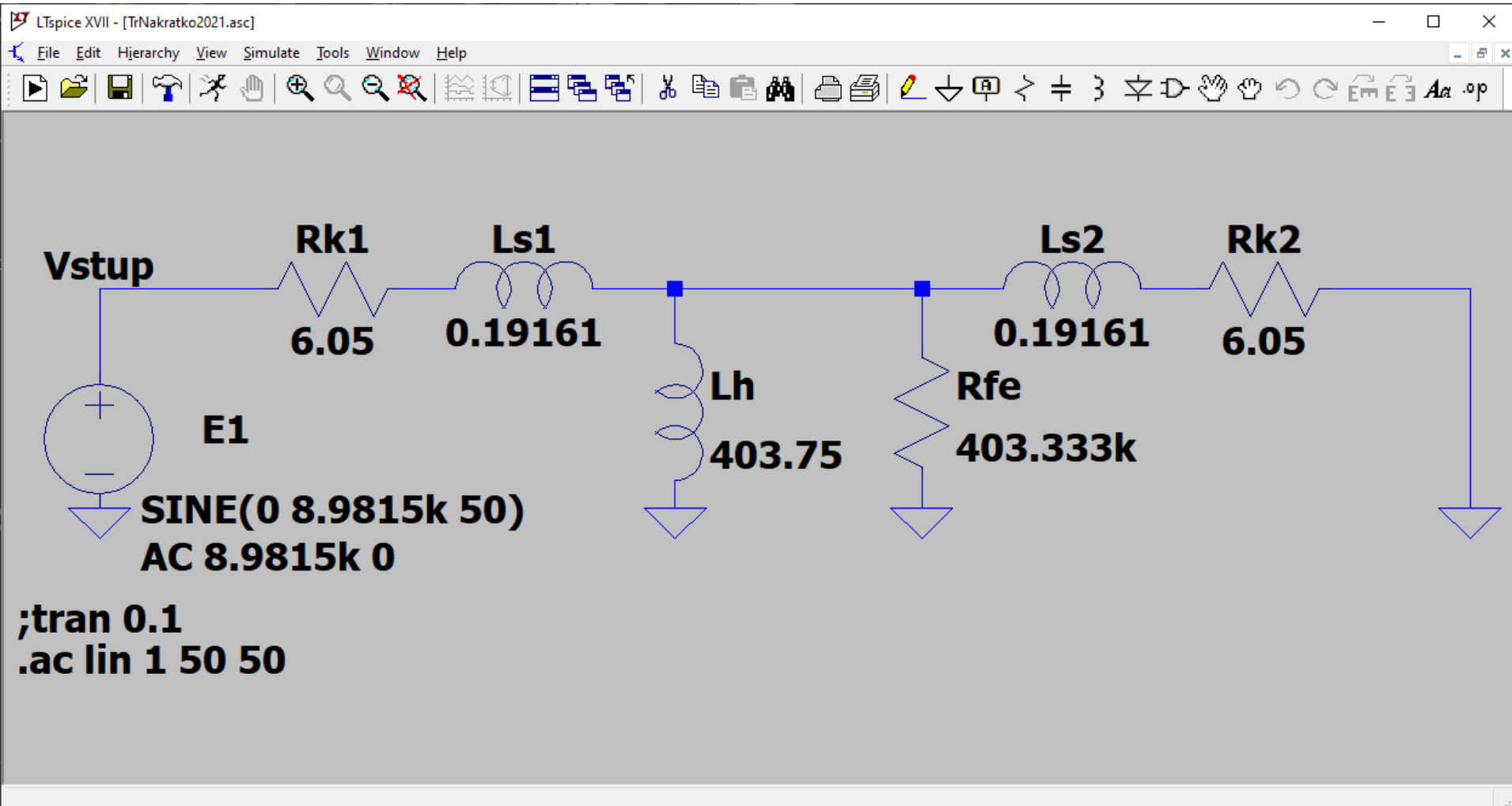
$$L_h = 403.75$$

$$U_{km} = 8.9815$$

Zpracování pomocí obvodového schéma

Transformátor nakrátko

Řešení s kompletní topologií:



Zpracování pomocí obvodového schéma

Transformátor nakrátko

Řešení s kompletní topologií:

The image displays the LTspice XVII interface with three dialog boxes open over a schematic diagram of a transformer short-circuit model. The schematic shows an independent voltage source $E1$ connected to a resistor R_{fe} , an inductor $Ls2$ with an inductance of 0.19161 H, and a resistor $Rk2$ with a resistance of 6.05 Ω .

Resistor - Rk1 Dialog:

- Manufacturer: -----
- Part Number: -----
- Select Resistor
- Resistor Properties:
 - Resistance[Ω]:
 - Tolerance[%]:
 - Power Rating[W]:
- Buttons: OK, Cancel

Independent Voltage Source - E1 Dialog:

- Functions:
 - (none)
 - PULSE(V1 V2 Tdelay Trise Tfall Ton Period Ncycles)
 - SINE(Voffset Vamp Freq Td Theta Phi Ncycles)
 - EXP(V1 V2 Td1 Tau1 Td2 Tau2)
 - SFFM(Voff Vamp Fcar MDI Fsig)
 - PWL(t1 v1 t2 v2...)
 - PWL FILE: Browse
- DC Value:
 - DC value:
 - Make this information visible on schematic:
- Small signal AC analysis(AC):
 - AC Amplitude:
 - AC Phase:
 - Make this information visible on schematic:
- Parasitic Properties:
 - Series Resistance[Ω]:
 - Parallel Capacitance[F]:
 - Make this information visible on schematic:
- Parameters:
 - DC offset[V]:
 - Amplitude[V]:
 - Freq[Hz]:
 - Tdelay[s]:
 - Theta[1/s]:
 - Phi[deg]:
 - Ncycles:
- Buttons: Cancel, OK
- Additional PWL Points
- Make this information visible on schematic:

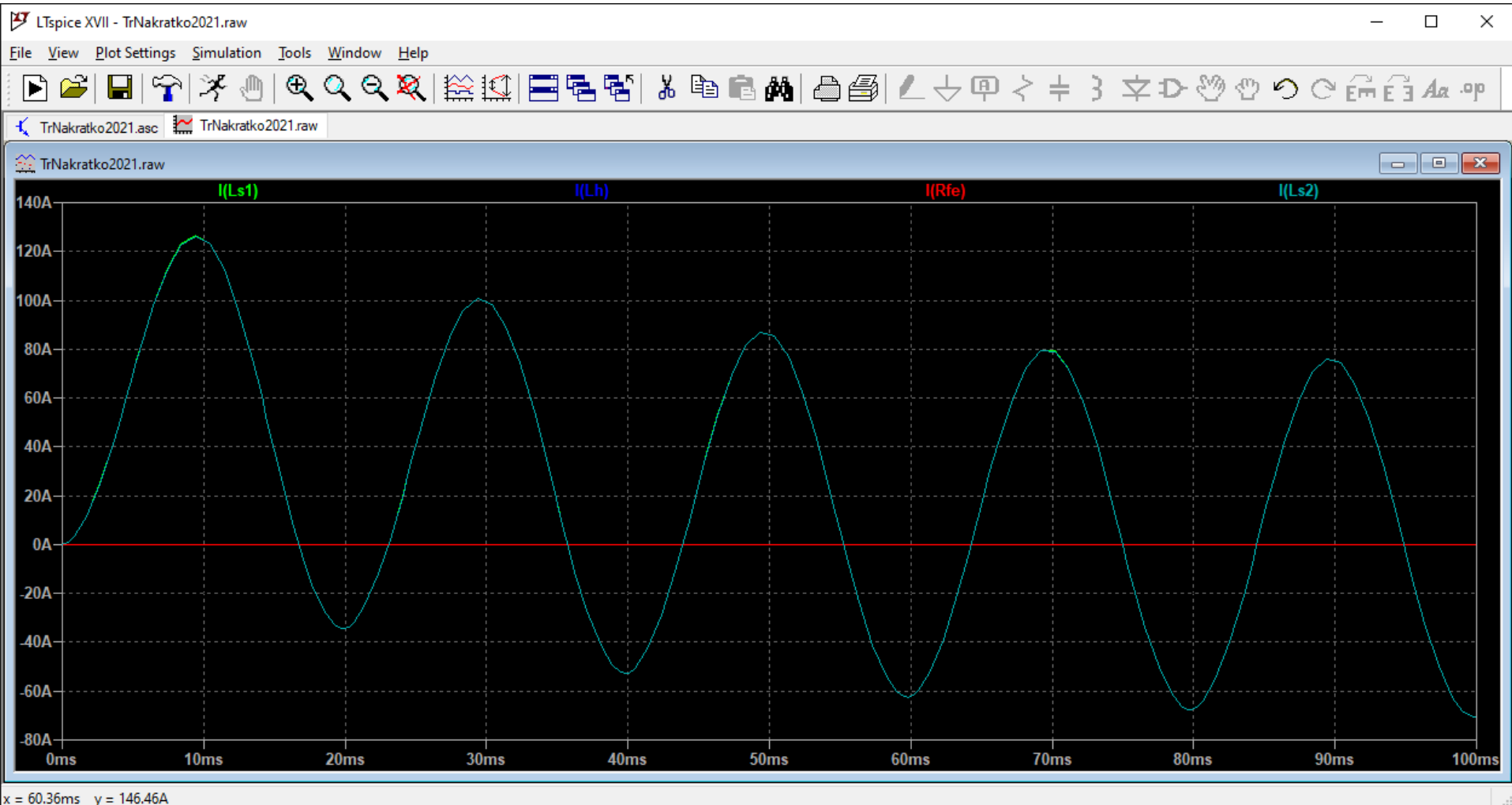
Inductor - Ls1 Dialog:

- Manufacturer: -----
- Part Number: -----
- Select Inductor
- Inductor Properties:
 - Inductance[H]:
 - Peak Current[A]:
 - Series Resistance[Ω]:
 - Parallel Resistance[Ω]:
 - Parallel Capacitance[F]:
- Show Phase Dot:
- (Series resistance defaults to $1m\Omega$)
- Buttons: OK, Cancel

Zpracování pomocí obvodového schéma

Transformátor nakrátko

Řešení s kompletní topologií:



Zpracování pomocí obvodového schéma

Transformátor nakrátko

Řešení ustáleného stavu nakrátko s kompletní topologií:

The screenshot displays the LTspice XVII interface for a transformer circuit simulation. The circuit diagram shows an AC voltage source labeled **E1** connected to a resistor **Rk1** (6.05), followed by an inductor **Ls1** (0.19161). A transformer core is represented by two coupled inductors, **Ls2** (0.19161) and **Rfe** (403.333k), which are connected to another resistor **Rk2** (6.05). The output terminals are short-circuited. A simulation command window is open, showing the **AC Analysis** tab. The window contains the following text:

Compute the small signal AC behavior of the circuit linearized about its DC operating point.

Type of sweep: Linear

Number of points: 1

Start frequency: 50

Stop frequency: 50

Syntax: `.ac <oct, dec, lin> <Npoints> <StartFreq> <EndFreq>`

`.ac lin 1 50 50`

Zpracování pomocí obvodového schéma a frekvenční analýzy

Transformátor nakrátko

Řešení ustáleného stavu nakrátko s kompletní topologií:

$$I_N = \frac{S_{NT}}{\sqrt{3} \cdot U_{N1}}$$

$$I_{KM} = I_N \cdot \sqrt{2}$$

$$\Psi_K = \arctan\left(\frac{X_\sigma}{R_K}\right)$$

$$\Psi_{K \text{ rad}} = -\frac{\Psi_K}{\pi} 180$$

$$I_n = S_{nt} / U_{n1} / \text{sqrt}(3)$$

$$I_n = 0.052486$$

$$I_{km} = I_n * \text{sqrt}(2)$$

$$I_{km} = 0.074227$$

$$\Psi_{iK} = \text{atan}(X_s / R_k)$$

$$\Psi_{iK} = 1.4706$$

$$\Psi_{iK \text{ rad}} = -\Psi_{iK} / \pi * 180$$

$$\Psi_{iK \text{ rad}} = -84.261$$

Transformátor nakrátko

Řešení ustáleného stavu nakrátko s kompletní topologií:

The screenshot displays the LTspice XVII interface. On the left, a circuit diagram shows an AC voltage source **E1** connected in series with a resistor **Rk1** (value 6.05) and an inductor **Ls1** (value 0.19161). The source is configured as **SINE(0 8.9815k 50)** and **AC 8.9815k 0**. Below the circuit, the simulation commands are **;tran 0.1** and **.ac lin 1 50 50**.

On the right, the **AC Analysis** window shows the following results for a frequency of 50 Hz:

Variable	mag	phase	unit
V(n001):	8947.72	2.86309°	voltage
V(vstup):	8981.5	0°	voltage
V(n002):	4489.65	-0.00290824°	voltage
V(n003):	4489.65	-0.00290824°	voltage
I(Ls2):	74.2098	-84.2627°	device_current
I(Ls1):	74.2461	-84.2569°	device_current
I(Lh):	0.0333257	90.8825°	device_current
I(Rk2):	74.2098	95.7373°	device_current
I(Rfe):	0.0111314	-0.00290824°	device_current
I(Rk1):	74.2461	95.7431°	device_current
I(E1):	74.2461	95.7431°	device_current

Zpracování pomocí obvodového schéma a frekvenční analýzy