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# Řešení přechodných dějů na transformátoru v nástroji DYNAST

## Cvičení PJS

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FAKULTA ELEKTROTECHNICKÁ  
ZÁPADOČESKÉ UNIVERZITY  
V PLZNI

KATEDRA  
ELEKTROENERGETIKY

# Výpočet přechodného děje na transformátoru

Pro výpočet přechodného děje zapnutí do stavu nakrátko využít simulační nástroj DYNAST:

<https://home.zcu.cz/~nohac/Dynast/>

## Download DYNAST

The current version of DYNAST for Windows is 4.0.1,  
February 22nd 2015.

Download

### System requirements

- IBM compatible PC computer
- MS Windows 2000/NT/XP/Vista/7/8

### Installation instructions

- Download the installation file to a temporary directory
- Run the downloaded installation file
- Follow the instructions of the setup program

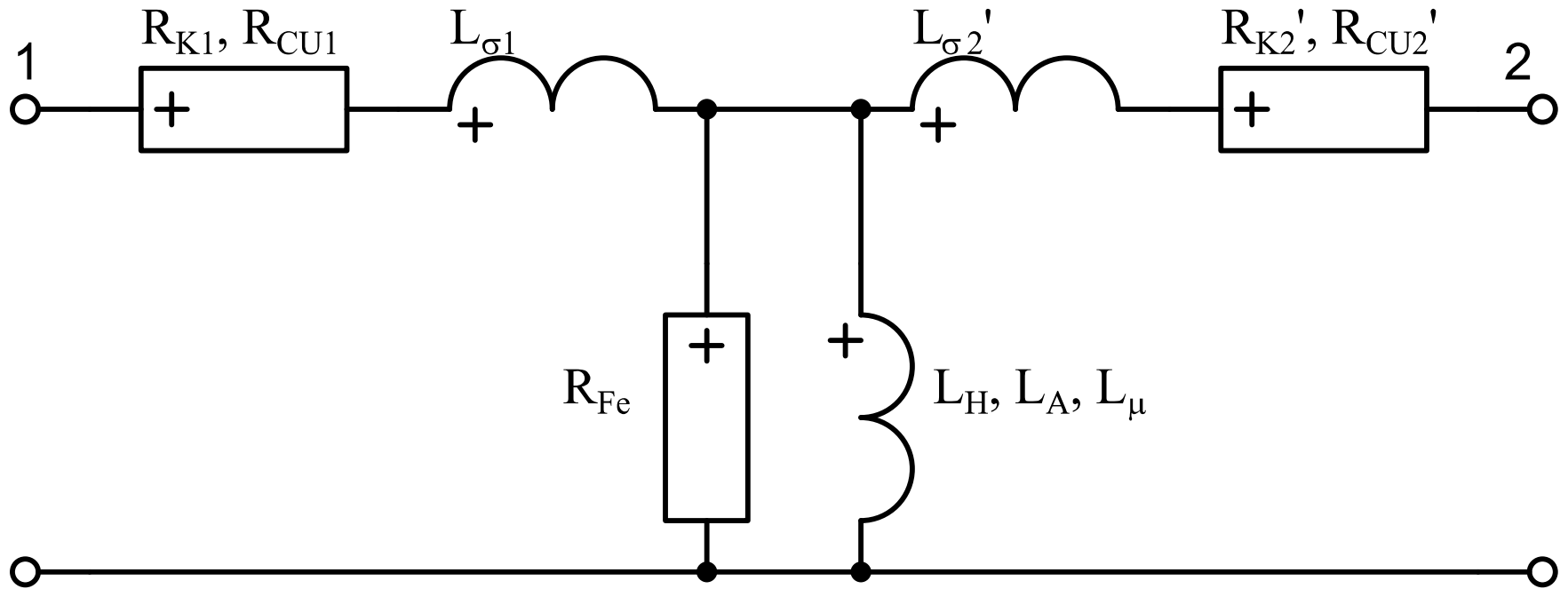
### Documentation

- User's Guide for DYNAST

### Examples

Re-solvable examples of solved equations and simulated real systems that can be modified and re-submitted just by clicking a button

# 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

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

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

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

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

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

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

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

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

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

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

**frekv=50 ;**

**omega=2pi\*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 ;**

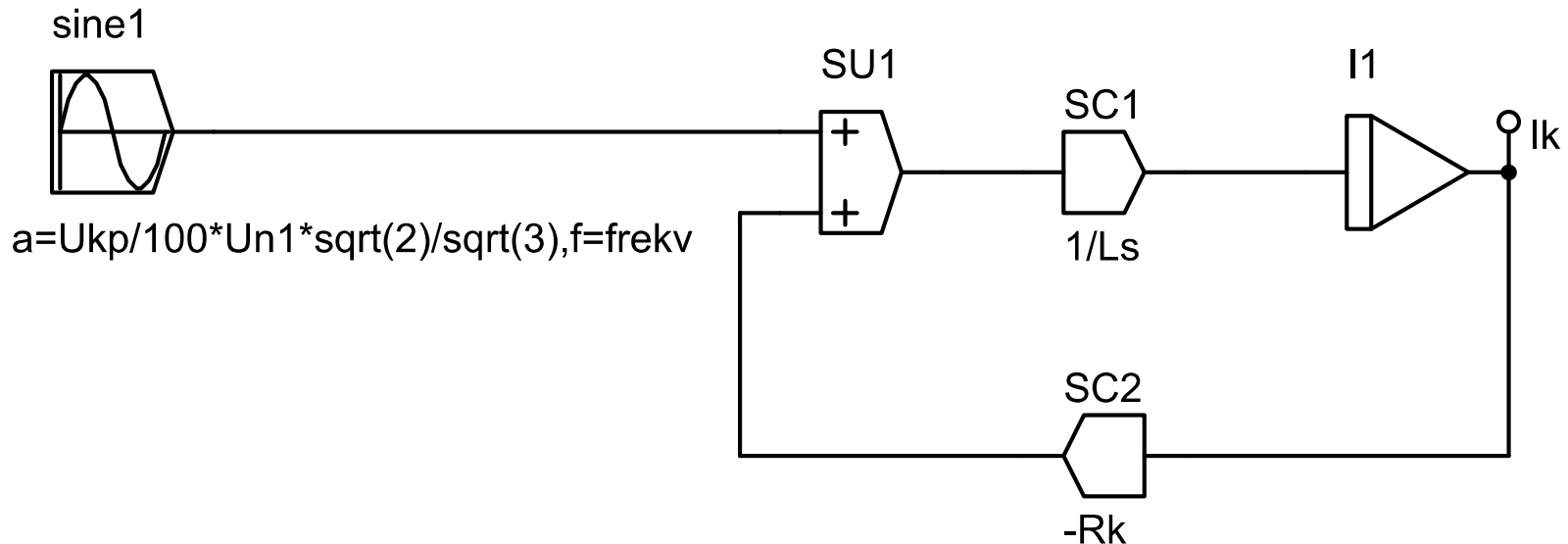
# Transformátor nakrátko

$$L_{\sigma} \frac{di_K}{dt} + i_K \cdot R_K = \frac{u_K [\%]}{100} U_m \sin(\omega \cdot t)$$

$$U_m = \frac{U_n}{\sqrt{3}} \sqrt{2}$$



$$\frac{di_K}{dt} = \frac{\frac{u_K [\%]}{100} U_m \sin(\omega \cdot t) - i_K \cdot R_K}{L_{\sigma}}$$



Zpracování pomocí bloků ala Simulink

# Transformátor nakrátko

The screenshot displays the DYNAST Shell interface for a model named 'Model transformatoru nakratko'. The main window shows a circuit diagram with the following components and connections:

- sine1**: A sine wave source connected to the top input of a summing junction **SU1**.
- SU1**: A summing junction with two inputs. The top input is from **sine1**. The bottom input is from a summing junction **SC2**.
- SC1**: A scalar block labeled  $1/L_s$  connected to the output of **SU1**.
- SC2**: A scalar block labeled  $-R_k$  connected to the output of **SC1** and the bottom input of **SU1**.
- I1**: A current source block connected to the output of **SC1**.
- Ik**: The output current terminal of the circuit.

The left panel contains the model's configuration code:

```
Model transformatoru nakratko
*SYSTEM;

:::DIAGRAM[ ] {}

Un1=110;
Un2=22;
Snt=10;
dP0p=0.3;
dFfep=dP0p;
dPkp=1;
dFcup=dPkp;
Ukp=10;
I0p=1;
frekv=50;
omega=2pi*frekv;

: Vypocty parametru nahraniho schematu
Znt=Un1**2/Snt;

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;

sine1 > @sine 1 / a=Ukp/100*Un1*sqrt(2)/sqrt(3),f=frekv;
SC1 > @Scalar 2,3 / 1/Ls;
SC2 > @Scalar Ik,4 / -Rk;
I1 > @Int 3,Ik;
SU1 > @Summator 1,4,2;
*TR;
TR 0 0.1;
PRINT(1001) Ik;
RUN;
*END;
```

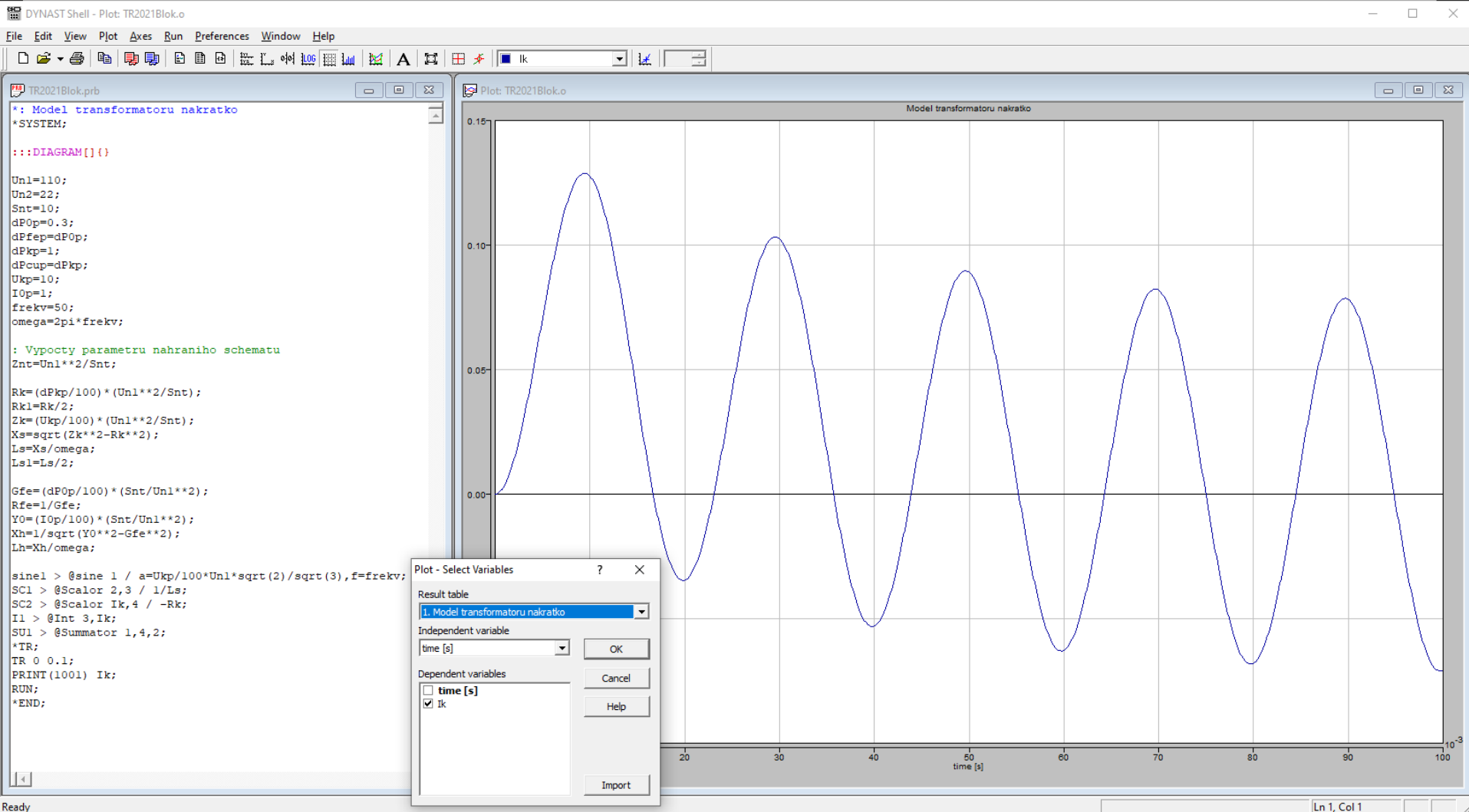
The bottom panel shows the simulation results for the current **Ik**:

X ...	time [s]
0.000000e+000	0.000000e+000
1.000000e-004	3.868751e-005
2.000000e-004	1.475238e-004
3.000000e-004	3.309078e-004

A red arrow points from the circuit diagram to the simulation results table. A yellow circle highlights the text 'Number of nodes: 5' and 'Number of implicit equations: 5' in the bottom panel.

Zpracování pomocí bloků ala Simulink

# Transformátor nakrátko



Zpracování pomocí bloků ala Simulink





# Transformátor nakrátko

Řešení implicitní numerickou metodou bez zanedbání  $L_H$ :

$$\frac{L_\sigma}{2} \frac{di_1}{dt} + i_1 \cdot \frac{R_K}{2} + L_h \frac{di_1}{dt} - L_h \frac{di_2}{dt} = \frac{u_K [\%]}{100} U_m \sin(\omega \cdot t)$$
$$-L_h \frac{di_1}{dt} + L_h \frac{di_2}{dt} + \frac{L_\sigma}{2} \frac{di_2}{dt} + i_2 \cdot \frac{R_K}{2} = 0 \quad \rightarrow$$

---

$$U_t = U_k / 100 * U_m * \sin(\Omega * TIME) ;$$

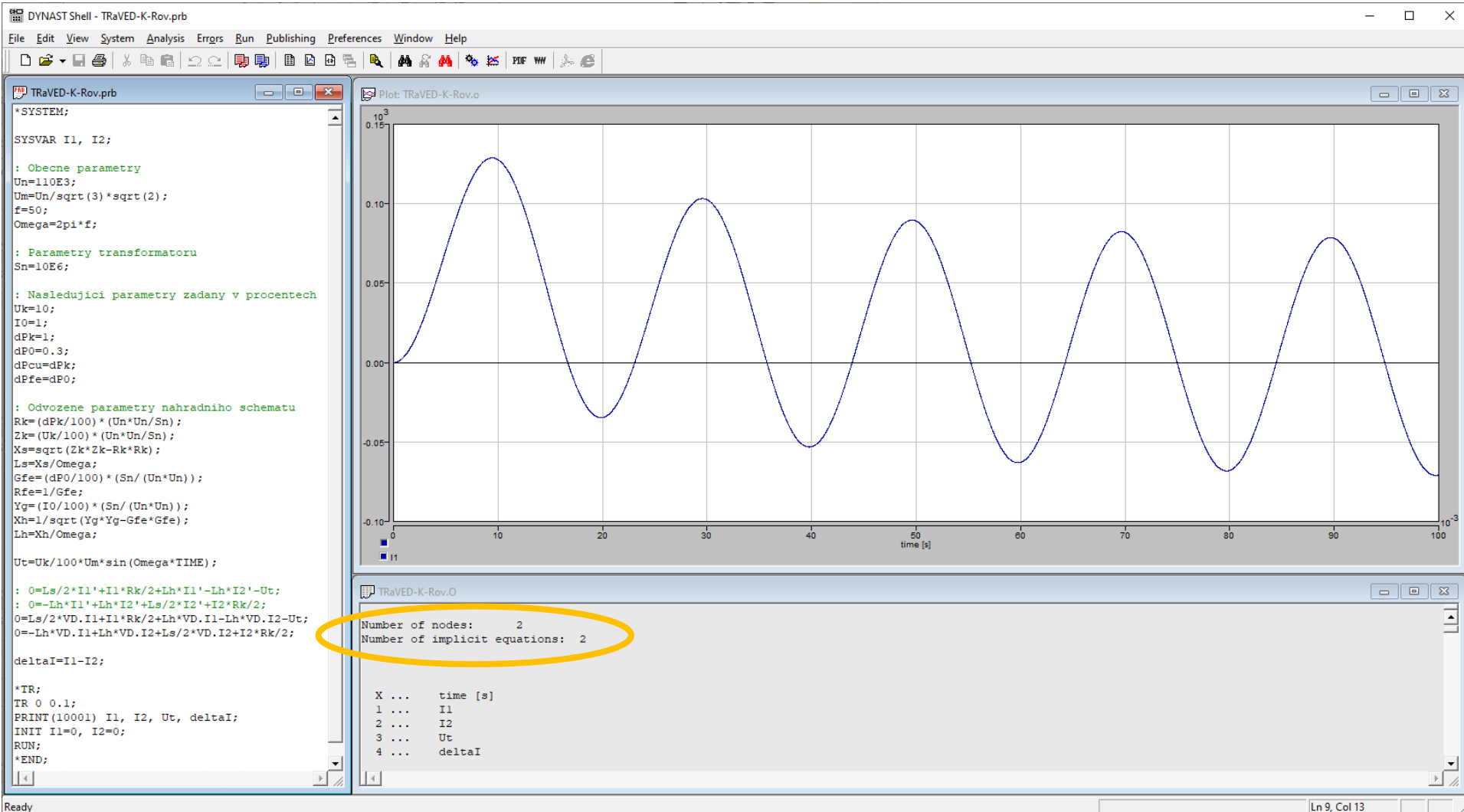
$$0 = L_s / 2 * V_D . I_1 + I_1 * R_k / 2 + L_h * V_D . I_1 - L_h * V_D . I_2 - U_t ;$$

$$0 = -L_h * V_D . I_1 + L_h * V_D . I_2 + L_s / 2 * V_D . I_2 + I_2 * R_k / 2 ;$$

Zpracování pomocí soustavy implicitních diferenciálních rovnic

# Transformátor nakrátko

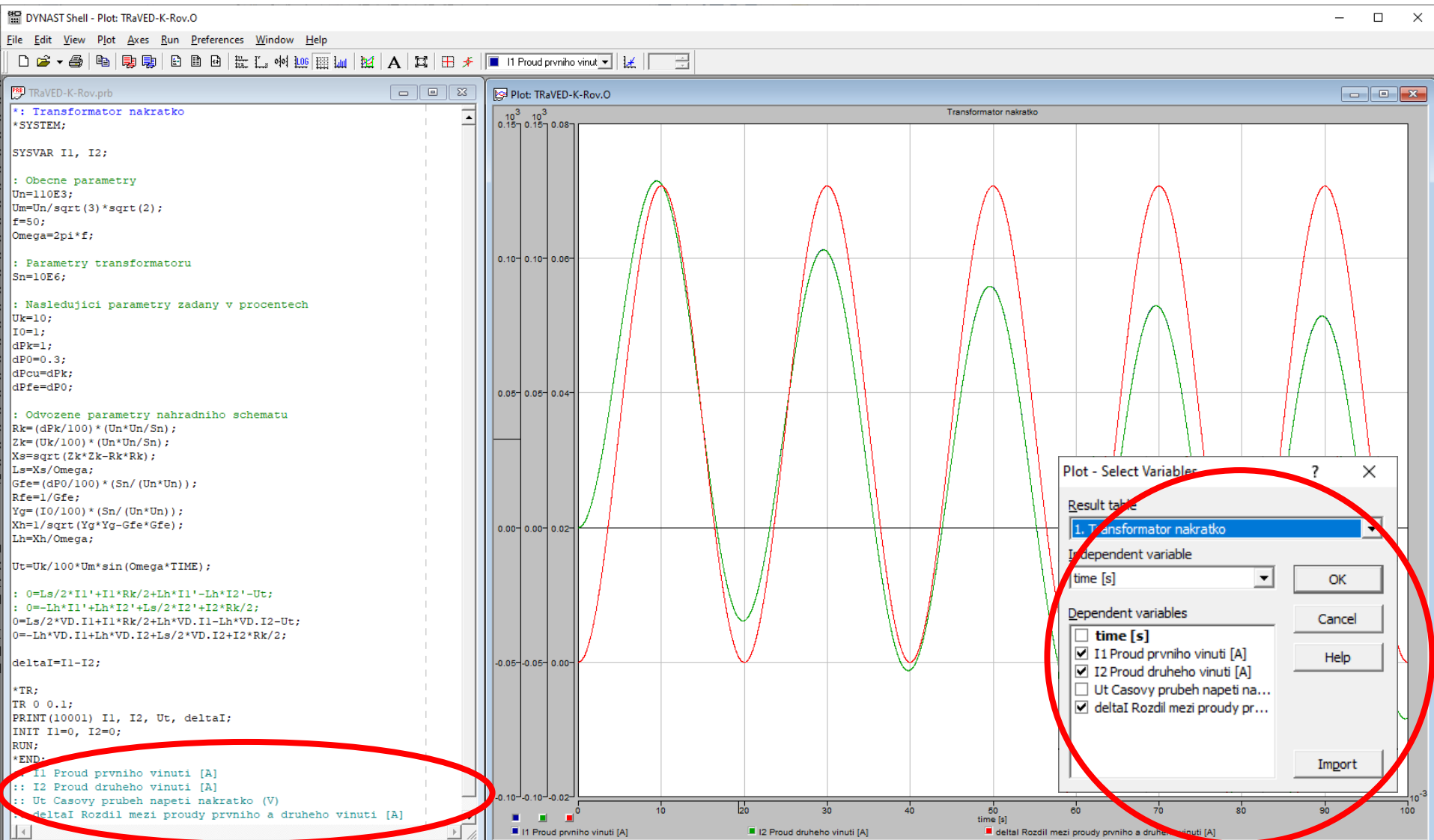
Řešení implicitní numerickou metodou bez zanedbání  $L_H$ :



Zpracování pomocí soustavy implicitních diferenciálních rovnic

# Transformátor nakrátko

Řešení implicitní numerickou metodou bez zanedbání  $L_H$ :



Zpracování pomocí soustavy implicitních diferenciálních rovnic

# Transformátor nakrátko

Řešení numerickou metodou s kompletní topologií:

The screenshot displays the DYNAST Shell interface for a transformer short-circuit analysis. The main window shows a circuit diagram with the following components:

- Node 1: AC voltage source  $U_k$  with  $V_{ef} = U_{kp} / 100 \cdot U_{n1} / \sqrt{3}$ ,  $R = 0$ .
- Series branch: Resistor  $R_{k1}$  (value  $R_k/2$ ) and inductor  $L_{s1}$  (value  $L_s/2$ ).
- Node S: Short-circuit point.
- Series branch: Inductor  $L_{s2c}$  (value  $L_s/2$ ) and resistor  $R_{k2c}$  (value  $R_k/2$ ).
- Node 2: Output terminal.
- Shunt branches: Resistor  $R_{fe1}$  (value  $R_{fe}$ ) and inductor  $L_{h1}$  (value  $L_h$ ) connected to ground.
- Switch  $S1$  is shown in the closed position.

The bottom window displays the numerical solution results:

```
Number of nodes: 5
Number of implicit equations: 13

X ... time [s]
1 ... V.1
2 ... V.2
3 ... S
4 ... I.Ls1
5 ... I.Ls2c
6 ... I.Lh1
7 ... I.Rfe1
```

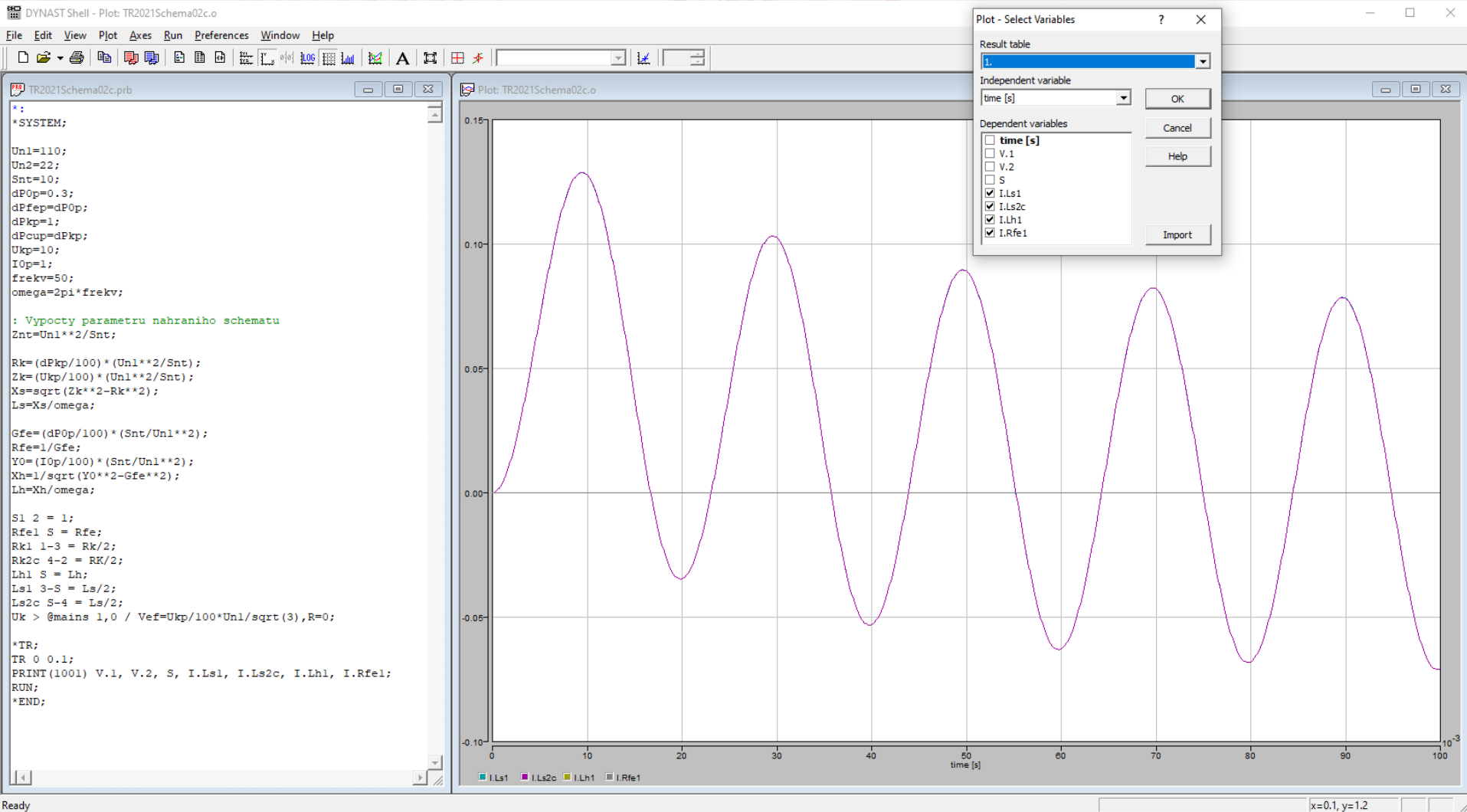
X	1	2	3	4
	5	6	7	
0.000000e+000	0.000000e+000	0.000000e+000	0.000000e+000	0.000000e+000
1.000000e-004	0.000000e+000	0.000000e+000	0.000000e+000	0.000000e+000
	2.821081e-001	0.000000e+000	1.406847e-001	3.861267e-005
	3.824569e-005	1.817184e-008	3.488050e-007	

A red arrow points from the circuit diagram to the numerical results window, highlighting the relationship between the physical model and its numerical representation.

Zpracování pomocí obvodového schéma

# Transformátor nakrátko

Řešení numerickou metodou s kompletní topologií:



Zpracování pomocí obvodového schéma

# Transformátor nakrátko

Řešení ustáleného stavu nakrátko s kompletní topologií:

The screenshot displays the DYNAST Shell software interface. On the left is a code editor window titled 'TR2021Schema03c-Dok.prb' containing the following code:

```
Zk=(Ukp/100)*(Un1**2/Snt);  
Xs=sqrt(Zk**2-Rk**2);  
Ls=Xs/omega;  
  
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;  
  
Rfe1 S = Rfe;  
Rk1 1-2 = Rk/2;  
Rk2c 3 = RK/2;  
Lh1 S = Lh;  
Ls1 2-S = Ls/2;  
Ls2c S-3 = Ls/2;  
  
Esine1 > @esine 1,0 / Em=Ukp/100*Un1/sqrt(3)*sqrt(2),f=50;  
  
*TR;  
TR 0 0.1;  
PRINT(1001) V.1, S, I.Ls1, I.Ls2c, I.Lh1, I.Rfe1;  
RUN;  
  
*AC;  
FREQ = 50;  
PRINT MOD.1, MOD.I.Ls1, RAD.I.Ls1, DEG.I.Ls1, MOD.I.Ls2c,  
RAD.I.Ls2c, DEG.I.Ls2c;  
RUN;  
*END;
```

On the right is a circuit diagram window titled 'Problem TR2021Schema03c-Dok'. The diagram shows a transformer model with a primary winding (resistor  $R_{k1}$ , inductor  $L_{s1}$ ) and a secondary winding (resistor  $R_{k2c}$ , inductor  $L_{s2c}$ ). A short-circuit switch  $S$  is connected between the primary and secondary terminals. A voltage source  $Esine1$  is connected to the primary terminal 1. The source is defined as  $Em = U_{kp}/100 \cdot U_{n1} / \sqrt{3} \cdot \sqrt{2}$  at  $f = 50$  Hz. Other components include a core loss resistor  $R_{fe1}$  and a magnetizing inductor  $L_{h1}$ . A red arrow points from the code editor to the voltage source in the circuit diagram.

Zpracování pomocí obvodového schéma a frekvenční analýzy

# Transformátor nakrátko

Řešení ustáleného stavu nakrátko s kompletní topologií:

The image displays a software interface for circuit simulation, specifically DYNAST Shell. The main window shows a circuit diagram with components labeled  $Ls2c$ ,  $Rk2c$ , and  $RK/2$ . The circuit is connected to a voltage source  $s/2$ . The diagram is overlaid on a grid.

Below the diagram is a code editor window titled "TR2021Schema03c-Dok.prb" containing the following code:

```
Zk=(Ukp/100)*(Un1**2/Snt);  
Xs=sqrt(Zk**2-Rk**2);  
Ls=Xs/omega;  
  
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;  
  
Rfe1 S = Rfe;  
Rk1 1-2 = Rk/2;  
Rk2c 3 = RK/2;  
Lh1 S = Lh;  
Ls1 2-S = Ls/2;  
Ls2c S-3 = Ls/2;  
  
Esine1 > @esine 1,0 / Em=Ukp/100*Un1/omega**2)*sqrt(2),f=50;  
  
*TR;  
TR 0 0.1;  
PRINT(1001) V.1, S, I.Ls1, I.Ls2c, I.Lh1, I.Rfe1;  
RUN;  
  
*AC;  
FREQ = 50;  
PRINT MOD.1, MOD.I.Ls1, RAD.I.Ls1, DEG.I.Ls1, MOD.I.Ls2c,  
RAD.I.Ls2c, DEG.I.Ls2c;  
RUN;  
*END;
```

Two "Numerical Frequency Analysis" dialog boxes are overlaid on the interface. The top dialog box shows the "Frequency" tab with the following settings:

- Frequency range: from  $1E-1$  to  $1E1$  [Hz]
- Logarithmic or Linear scale:  Logarithmic
- Equidistant results at: 501 points
- Individual frequency points in Hz (comma-separated):
- Points: 50

The bottom dialog box shows the "Frequency" tab with the following settings:

- Select desired variable: 

Variable	Description
Element through variables:	
I.Rfe1	
I.Rk1	
I.Rk2c	
I.Lh1	
I.Ls1	
I.Ls2c	
Submodels:	
Esine1	
Element through variables:	
I.E	
I.FE	
- Components:  Magnitude,  Magnitude in dB,  Phase in radians,  Phase in degrees,  Real part,  Imaginary part

Red arrows point from the dialog boxes to the code editor, indicating the configuration of the simulation parameters.

Zpracování pomocí obvodového schéma a frekvenční analýzy



# Transformátor nakrátko

Řešení ustáleného stavu nakrátko s kompletní topologií:

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

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

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

$$\Psi_K' = 2\pi - \Psi_K$$

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

$$I_n = 0.052486$$

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

$$I_{km} = 0.074227$$

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

$$\Psi_{iK} = 1.4706$$

$$\Psi_{iKc} = 2 * \text{pi} - \Psi_{iK}$$

$$\Psi_{iKc} = 4.8126$$

Zpracování pomocí obvodového schéma a frekvenční analýzy

# Transformátor nakrátko

Řešení ustáleného stavu nakrátko s kompletní topologií:

```
DYNAST Shell - TR2021Schema03c-Dok.o
File Edit View Errrs Run Preferences Window Help
TR2021Schema03c-Dok.prb
Zk=(Ukp/100)*(Un1**2/Snt);
Xs=sqrt(Zk**2-Rk**2);
Ls=Xs/omega;

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;

Rfel S = Rfe;
Rk1 1-2 = Rk/2;
Rk2c 3 = RK/2;
Lh1 S = Lh;
Ls1 2-S = Ls/2;
Ls2c S-3 = Ls/2;

Esinel > @esine 1,0 / Em=Ukp/100*Un1/sqrt(3)*sqrt(2),f=50;

*TR;
TR 0 0.1;
PRINT(1001) V.1, S, I.Ls1, I.Ls2c, I.Lh1, I.Rfel;
RUN;

*AC;
FREQ = 50;
PRINT MOD.1, MOD.I.Ls1, RAD.I.Ls1, DEG.I.Ls1, MOD.I.Ls2c,
      RAD.I.Ls2c, DEG.I.Ls2c;
RUN;
*END;
```

```
Number of nodes: 4
Number of implicit equations: 11

X ...      freq [Hz]
1 ...      MOD.V.1
2 ...      MOD.I.Ls1
3 ...      RAD.I.Ls1
4 ...      DEG.I.Ls1
5 ...      MOD.I.Ls2c
6 ...      RAD.I.Ls2c
7 ...      DEG.I.Ls2c

X          1          2          3          4
          5          6          7
5.000000e+001 8.981462e+000 7.424513e-002 4.812607e+000 2.757421e+002
              7.420880e-002 4.812506e+000 2.757363e+002

MAX         8.981462e+000 7.424513e-002 4.812607e+000 2.757421e+002
              7.420880e-002 4.812506e+000 2.757363e+002
MIN         8.981462e+000 7.424513e-002 4.812607e+000 2.757421e+002
              7.420880e-002 4.812506e+000 2.757363e+002

Statistics: 1017 steps, 0 rejected steps, 1024 iterations
Order:      1      2      3      4      5      6
Steps:      4     989    24     0     0     0

Number of errors: 0, Number of warnings: 0
Total seconds used up by DYNAST: 0.047
Program DYNAST exited on November 25, 2021 at 20:26:04
```

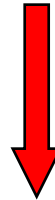
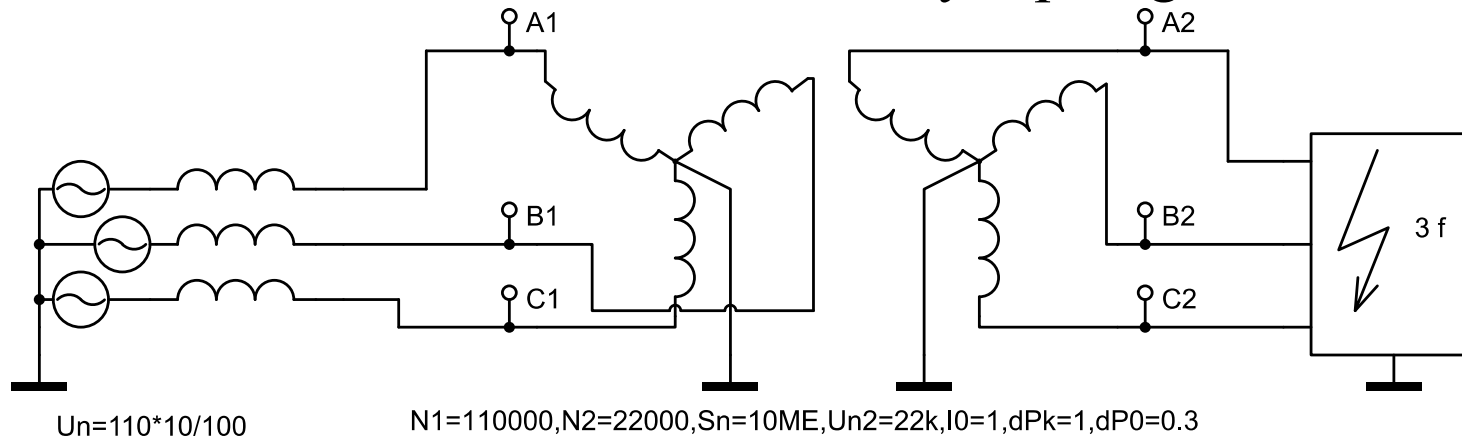
$$I_{km} = 0.074227$$

$$\Psi_{Kc} = 4.8126$$

Zpracování pomocí obvodového schéma a frekvenční analýzy

# Transformátor nakrátko

Řešení numerickou metodou 3f varianty topologie:



```
Source_3f1 > @PowerSource3f A1,B1,C1,0 / Un=110*10/100;  
Tr3fYy1 > @Tr3fYy A1,B1,C1,A2,B2,C2,0,0 / N1=110000,  
N2=22000,Sn=10ME,Un2=22k,I0=1,dPk=1,dP0=0.3;  
Short_Circuit_3f1 > @ShortCircuit3f A2,B2,C2,0 / 0;
```

Zpracování pomocí obvodového schéma a knihovny DPL

# Transformátor nakrátko

The image shows a screenshot of the DYNAST Shell software interface. The main window displays a circuit diagram of a transformer with a short circuit on the secondary side. The transformer is labeled 'Tr3fYy1' and has three primary terminals (A1, B1, C1) and three secondary terminals (A2, B2, C2). A three-phase voltage source 'Source\_3f1' is connected to the primary terminals. A short circuit 'Short\_Circuit\_3f1' is connected across the secondary terminals. The transformer parameters are listed as:  $Un=110 \cdot 10/100$ ,  $N1=110000$ ,  $N2=22000$ ,  $Sn=10ME$ ,  $Un2=22k$ ,  $I0=1$ ,  $dPk=1$ ,  $dP0=0.3$ .

A 'Submodel Properties' dialog box is open, showing the transformer model 'Tr3fYy1' with the following parameters:

Parameter	Value	Description
N1	110000	[-] Počet zavitu vinuti 1.
N2	22000	[-] Počet zavitu vinuti 2.
Sn	10ME	[VA] Jmenovity zdanlivy vykon
Un2	22k	[V] Jmenovite napeti vinuti 2.
I0	1	[%] Proud naprazdno
Uk	10	[%] Napeti nakratko
dPk	1	[%] Cinne ztraty nakratko
dP0	0.3	[%] Cinne ztraty naprazdno

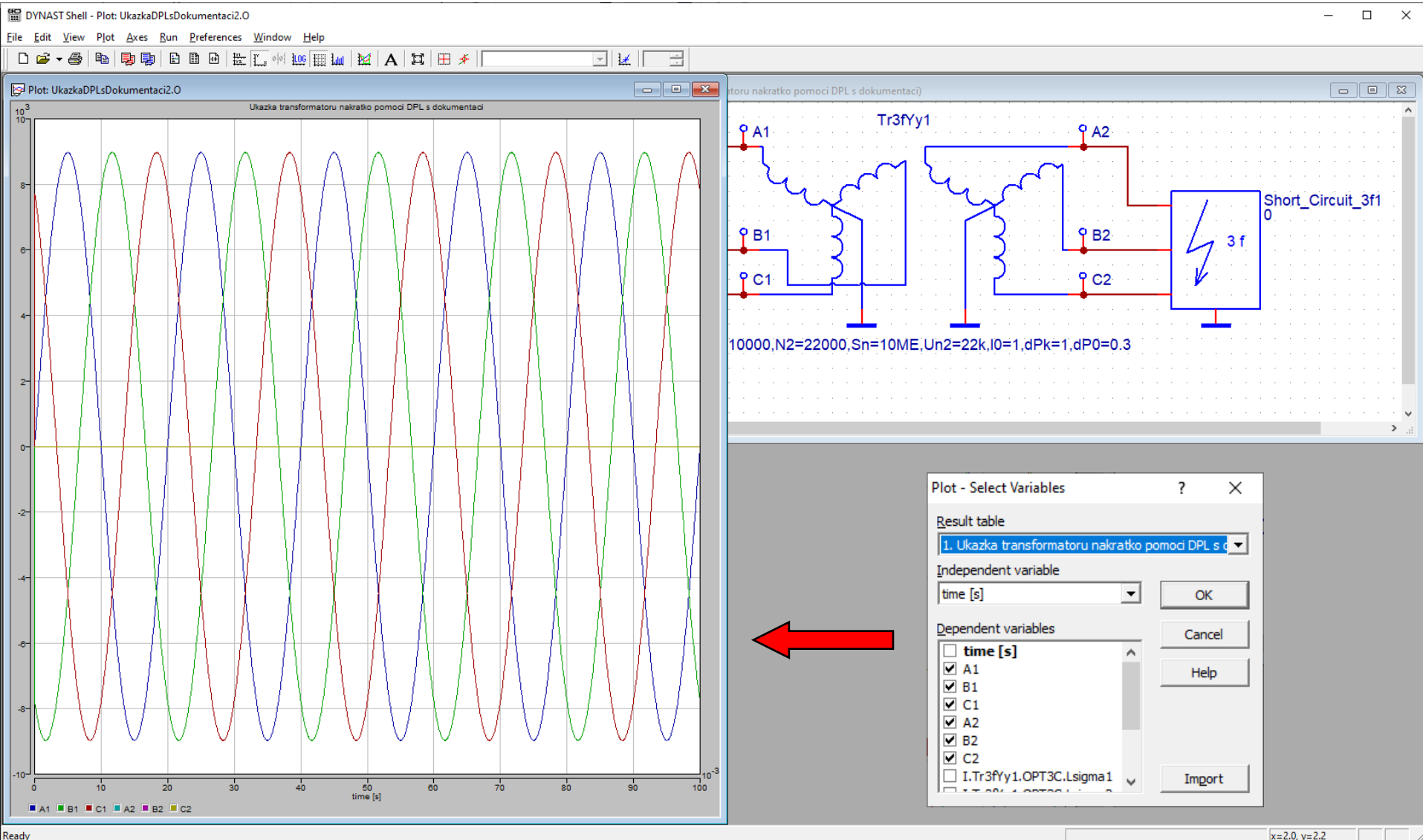
A red arrow points from the transformer model in the diagram to the 'Submodel Properties' dialog box.

The simulation log window shows the following output:

```
Ukazka transformatoru nakratko pomoci DPL s dokumentaci
Number of nodes: 21
Number of implicit equations: 45
Ukazka transformatoru nakratko pomoci DPL s dokumentaci
X ... time [s]
1 ... A1
2 ... B1
3 ... C1
4 ... A2
5 ... B2
6 ... C2
7 ... I.Tr3fYy1.OPT3C.Lsigma1
8 ... I.Tr3fYy1.OPT3C.Lsigma2
9 ... I.Tr3fYy1.OPT2B.Lsigma1
10 ... I.Tr3fYy1.OPT2B.Lsigma2
11 ... I.Tr3fYy1.OPT1A.Lsigma1
12 ... I.Tr3fYy1.OPT1A.Lsigma2
```

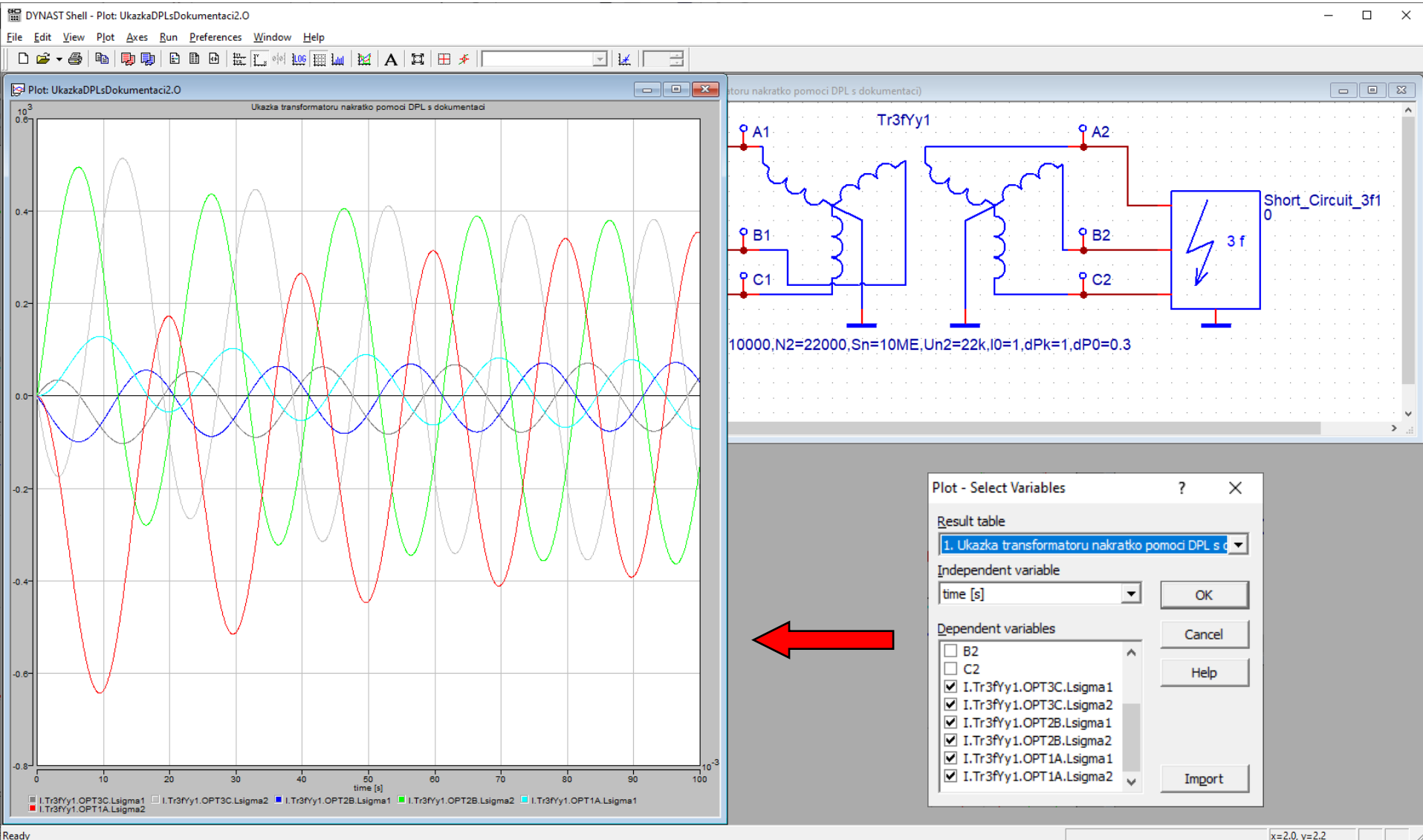
Zpracování pomocí obvodového schéma a knihovny DPL

# Transformátor nakrátko



Zpracování pomocí obvodového schéma a knihovny DPL

# Transformátor nakrátko



Zpracování pomocí obvodového schéma a knihovny DPL