ZÁPADOČESKÁ UNIVERZITA V PLZNI

FAKULTA ELEKTROTECHNICKÁ ZČU V PLZNI

Řešení přechodných dějů na transformátoru v nástrojích jazyka python: NumPy, Matplotlib, SciPy, Spyder

Cvičení PJS

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ZÁPADOČESKÁ UNIVERZITA V PLZNI

FAKULTA ELEKTROTECHNICKÁ ZÁPADOČESKÉ UNIVERZITY V PLZNI

KATEDRA ELEKTROENERGETIKY

Výpočet přechodného děje na transformátoru

Pro výpočet přechodného děje zapnutí do stavu nakrátko využit programovací jazyk python a jeho knihovny NumPy, SciPy a Matplotlib v prostředí nástroje Spyder

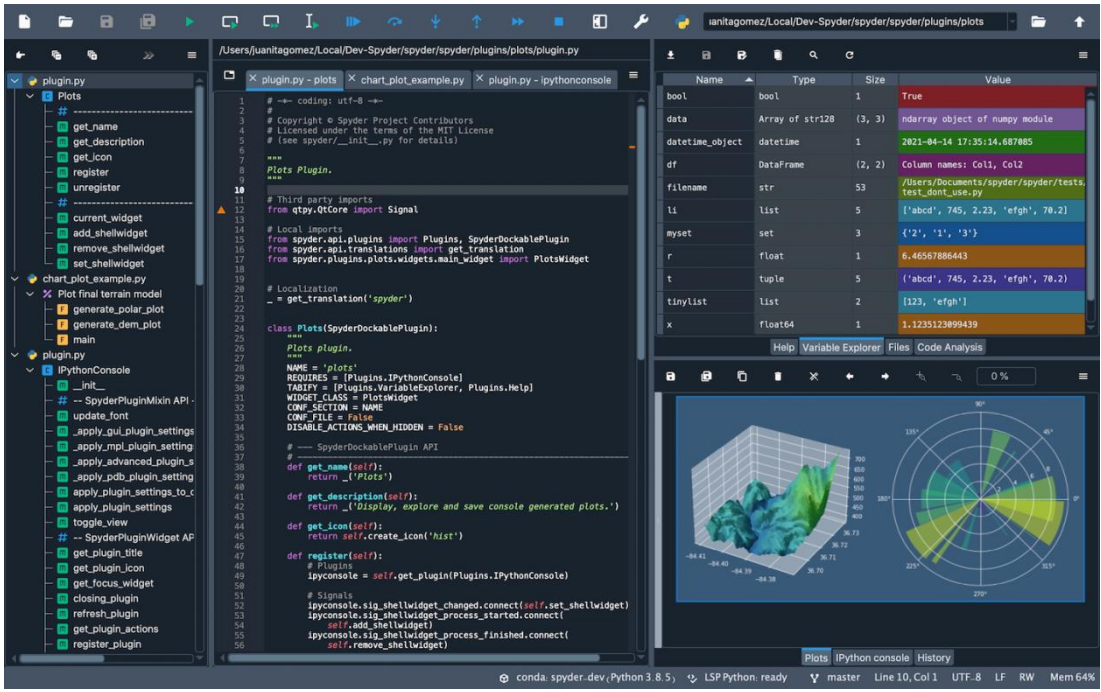
https://www.python.org/

https://numpy.org/

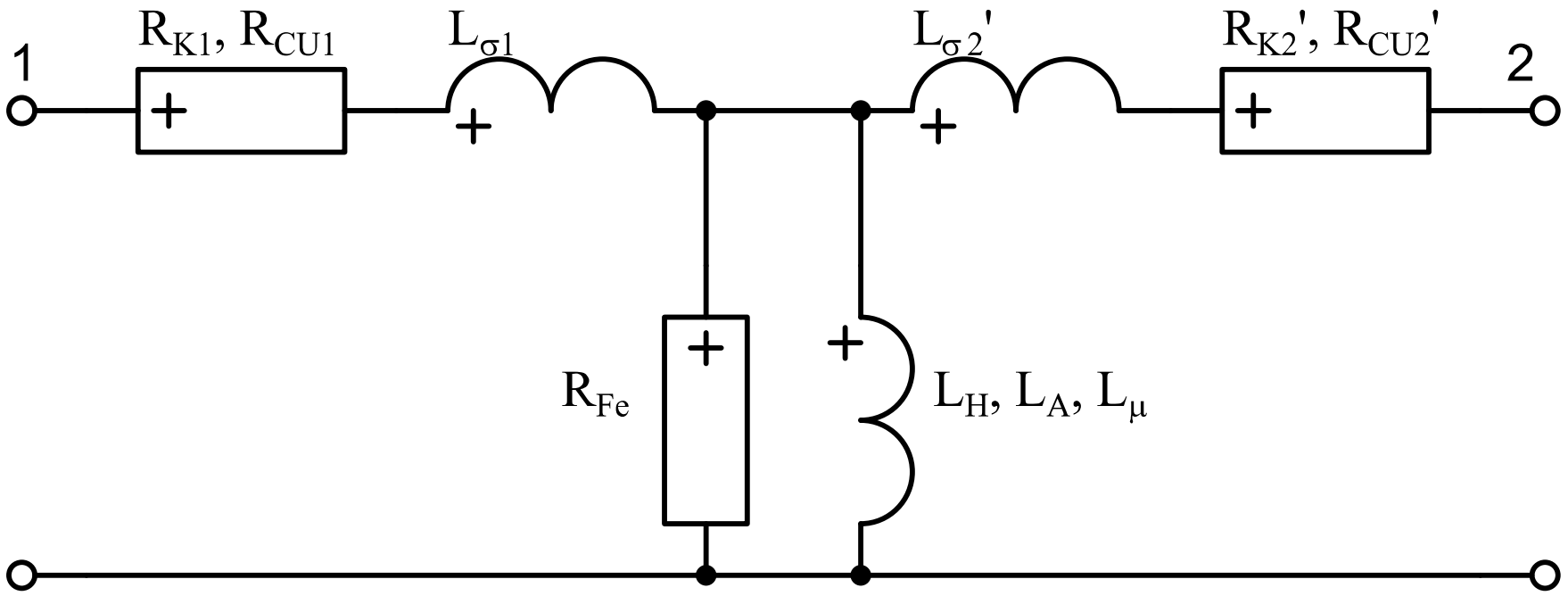
https://scipy.org/

https://matplotlib.org/

https://www.spyder-ide.org/



Náhradní schéma transformátoru



Parametry transformátoru

$u_K = 10\,\%$

$i_0 = 1\,\%$

$U_{N1} = 110\ kV$

$U_{N2} = 22\ kV$

$S_{NT} = 10\ MVA$

$\Delta P_0 = 0.3\,\%$

$\Delta P_K = 1.0\,\%$

```
Ukp=10.0
I0p=1.0
Un1=110.0
Un2=22.0
Snt=10.0
dP0p=0.3
dPkp=1.0
```

Parametry transformátoru

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

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

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

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

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

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

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

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

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

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

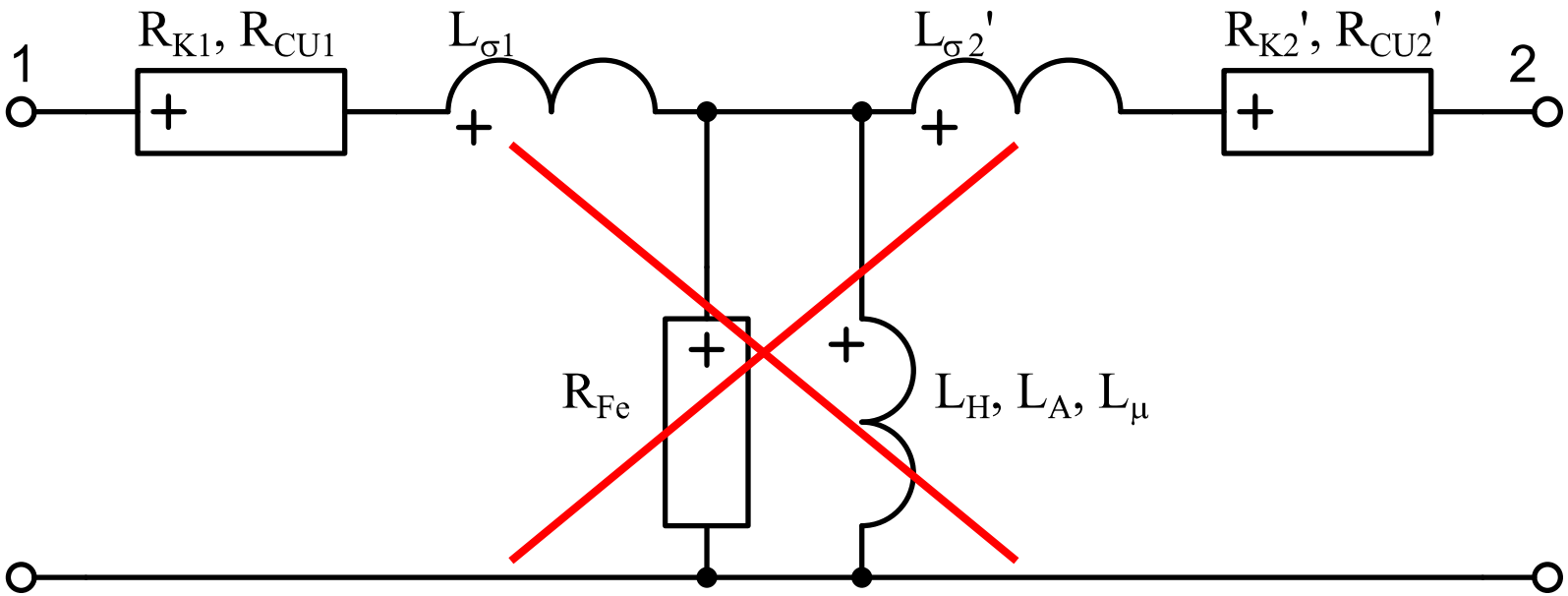
```
frekv=50.0
omega=2.0*np.pi*frekv

Rk=(dPkp/100.0)*(Un1**2/Snt)
Rk1=Rk/2.0
Zk=(Ukp/100.0)*(Un1**2/Snt)
Xs=np.sqrt(Zk**2-Rk**2)
Ls=Xs/omega
Ls1=Ls/2.0

Gfe=(dP0p/100.0)*(Snt/Un1**2)
Rfe=1/Gfe
Y0=(I0p/100.0)*(Snt/Un1**2)
Xh=1/np.sqrt(Y0**2-Gfe**2)
Lh=Xh/omega
```

Transformátor nakrátko

Řešení numerickou metodou se zanedbáním příčné části:

$$L_\sigma \frac{di_K}{dt} + i_K \cdot R_K = \frac{u_K[\%]}{100} U_m \sin(\omega \cdot t) \qquad U_m = \frac{U_n}{\sqrt{3}} \sqrt{2}$$

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



Transformátor nakrátko

Řešení numerickou metodou se zanedbáním příčné části:

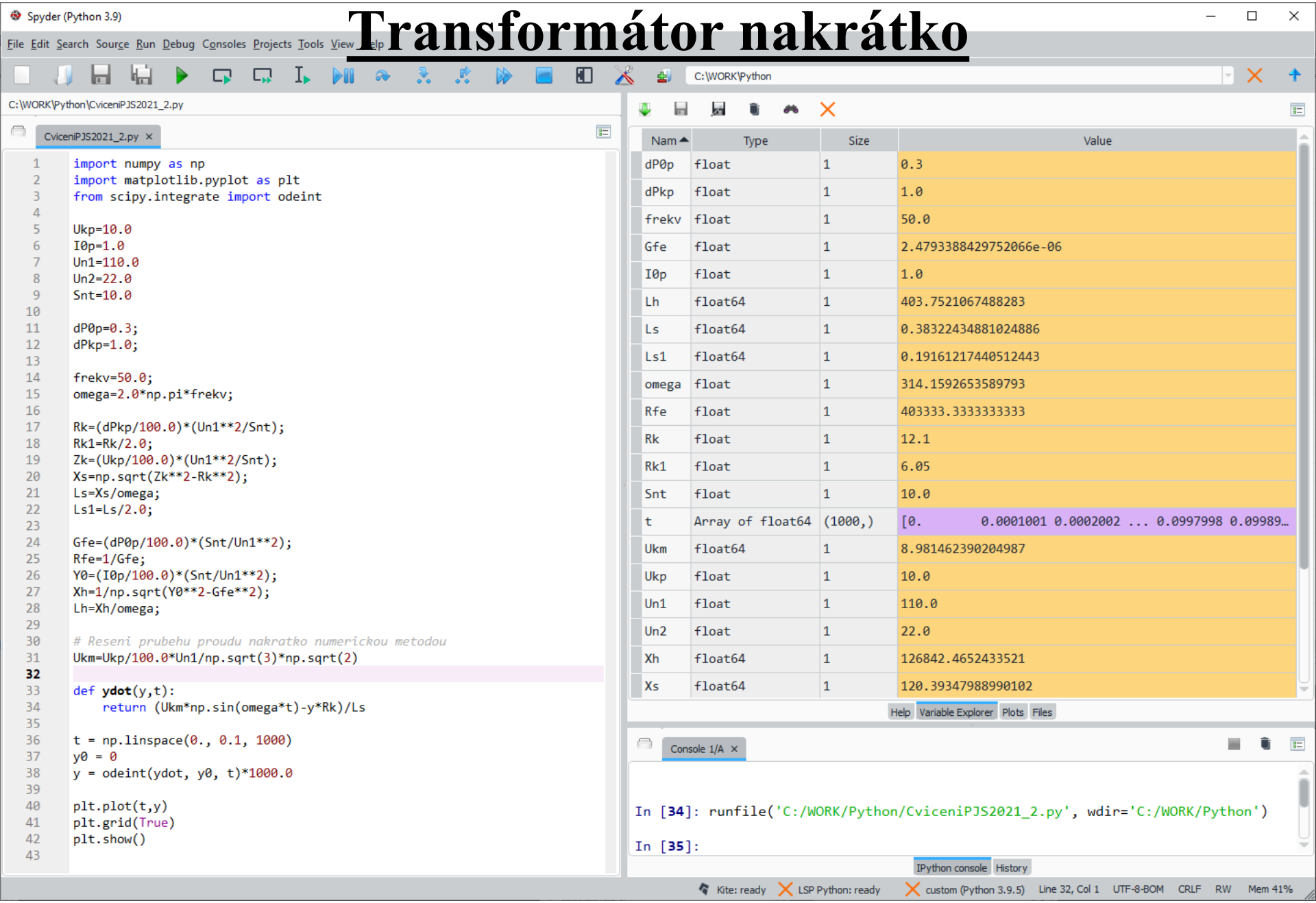
$$L_\sigma \frac{di_K}{dt} + i_K \cdot R_K = \frac{u_K[\%]}{100} U_m \sin(\omega \cdot t) \qquad U_m = \frac{U_n}{\sqrt{3}} \sqrt{2}$$

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

```
# Reseni prubehu proudu nakratko numerickou metodou
Ukm=Ukp/100.0*Un1/np.sqrt(3)*np.sqrt(2)

def ydot(y,t):
    return (Ukm*np.sin(omega*t)-y*Rk)/Ls
t = np.linspace(0., 0.1, 1000)
y0 = 0
y = odeint(ydot, y0, t)*1000.0

plt.plot(t,y)
plt.grid(True)
plt.show()
```

Zpracování pomocí integrační metody pro ODE

Transformátor nakrátko



Zpracování pomocí integrační metody pro ODE

Transformátor nakrátko

Spyder (Python 3.9)

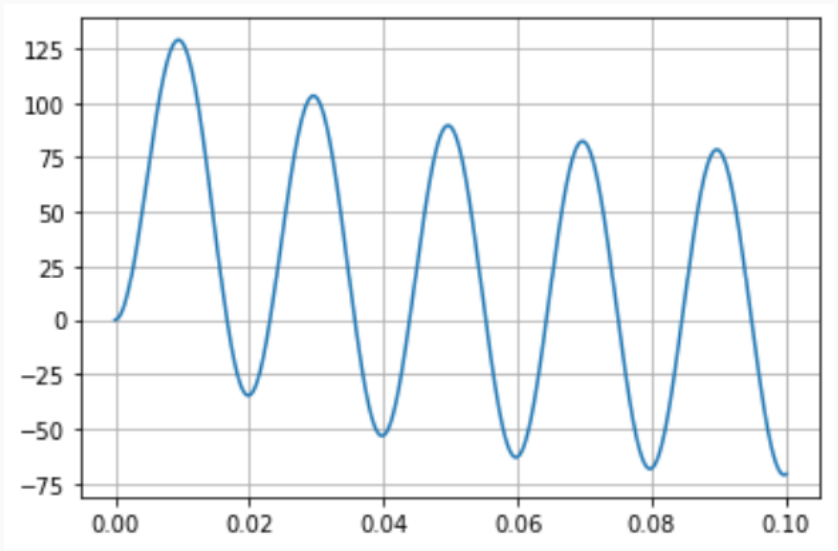
File Edit Search Source Run Debug Consoles Projects Tools View Help

C:\WORK\Python

C:\WORK\Python\CviceniPJS2021_2.py

CviceniPJS2021_2.py

```
import numpy as np
import matplotlib.pyplot as plt
from scipy.integrate import odeint

Ukp=10.0
I0p=1.0
Un1=110.0
Un2=22.0
Snt=10.0

dP0p=0.3;
dPkp=1.0;

frekv=50.0;
omega=2.0*np.pi*frekv;

Rk=(dPkp/100.0)*(Un1**2/Snt);
Rk1=Rk/2.0;
Zk=(Ukp/100.0)*(Un1**2/Snt);
Xs=np.sqrt(Zk**2-Rk**2);
Ls=Xs/omega;
Ls1=Ls/2.0;

Gfe=(dP0p/100.0)*(Snt/Un1**2);
Rfe=1/Gfe;
Y0=(I0p/100.0)*(Snt/Un1**2);
Xh=1/np.sqrt(Y0**2-Gfe**2);
Lh=Xh/omega;

# Reseni prubehu proudu nakratko numerickou metodou
Ukm=Ukp/100.0*Un1/np.sqrt(3)*np.sqrt(2)

def ydot(y,t):
    return (Ukm*np.sin(omega*t)-y*Rk)/Ls

t = np.linspace(0., 0.1, 1000)
y0 = 0
y = odeint(ydot, y0, t)*1000.0

plt.plot(t,y)
plt.grid(True)
plt.show()
```



Help Variable Explorer Plots Files

Console 1/A

```
In [34]: runfile('C:/WORK/Python/CviceniPJS2021_2.py', wdir='C:/WORK/Python')

In [35]:
```

IPython console History

Kite: ready LSP Python: ready custom (Python 3.9.5) Line 32, Col 1 UTF-8-BOM CRLF RW Mem 41%

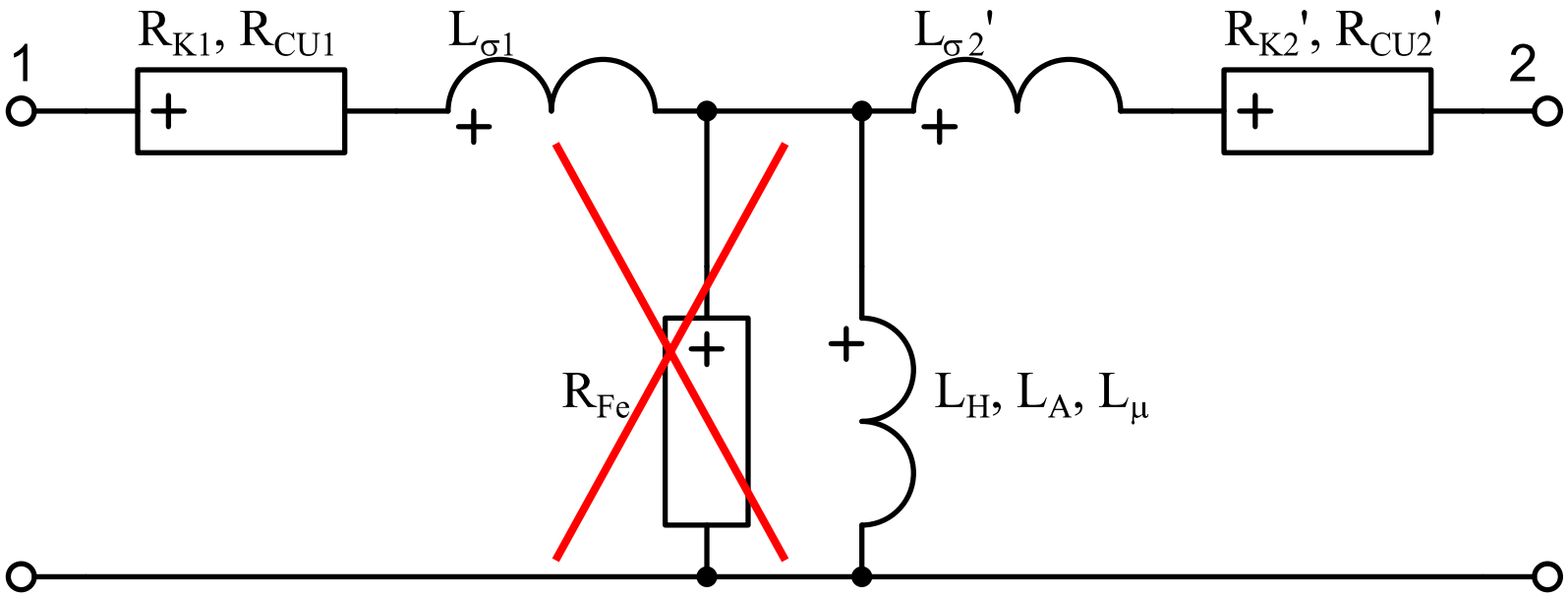
Zpracování pomocí integrační metody pro ODE

Transformátor nakrátko

Řešení numerickou metodou bez zanedbání L_H:

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

$$-L_h \frac{di_1}{dt} + L_h \frac{di_2}{dt} + \frac{L_\sigma}{2}\frac{di_2}{dt} + i_2 \cdot \frac{R_K}{2} = 0$$



Transformátor nakrátko

Řešení numerickou metodou bez zanedbání L_H:

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

$$-L_h \frac{di_1}{dt} + L_h \frac{di_2}{dt} + \frac{L_\sigma}{2}\frac{di_2}{dt} + i_2 \cdot \frac{R_K}{2} = 0$$

$$P_1 = \frac{L_\sigma}{2} + L_h \qquad P_2 = \frac{L_\sigma}{2} + L_h - \frac{L_h^{\,2}}{P_1}$$

$$\frac{di_1}{dt} = \frac{\frac{u_K[\%]}{100} U_m \sin(\omega \cdot t) - i_1 \cdot \frac{R_K}{2} - L_h \cdot i_2 \frac{R_K}{2} \cdot \frac{1}{P_1}}{P_2}$$

$$\frac{di_2}{dt} = \frac{\frac{L_h \cdot \frac{u_K[\%]}{100} U_m \sin(\omega \cdot t)}{P_1} - \frac{L_h \cdot i_1 \cdot \frac{R_K}{2}}{P_1} - i_2 \frac{R_K}{2}}{P_2}$$

Transformátor nakrátko

$$P_1 = \frac{L_\sigma}{2} + L_h \qquad P_2 = \frac{L_\sigma}{2} + L_h - \frac{L_h^{\,2}}{P_1}$$

$$\frac{di_1}{dt} = \frac{\frac{u_K[\%]}{100} U_m \sin(\omega \cdot t) - i_1 \cdot \frac{R_K}{2} - L_h \cdot i_2 \frac{R_K}{2} \cdot \frac{1}{P_1}}{P_2}$$

$$\frac{di_2}{dt} = \frac{\frac{L_h \cdot \frac{u_K[\%]}{100} U_m \sin(\omega \cdot t)}{P_1} - \frac{L_h \cdot i_1 \cdot \frac{R_K}{2}}{P_1} - i_2 \frac{R_K}{2}}{P_2}$$

```
# Reseni prubehu proudu nakratko numerickou metodou
def ydot(y,t):
    Un1=110
    Ukp=10
    Um=Un1/np.sqrt(3)*np.sqrt(2)
    omega=314.16
    Rk =  12.100
    Ls =  0.38322
    Lh =  403.75
    pom1=Ls/2+Lh
    pom2=Ls/2+Lh-Lh**2/pom1
    return [(Ukp/100*Um*np.sin(omega*t)-y[0]*Rk/2-Lh*y[1]*Rk/2/pom1)/pom2 ,
            (Lh*Ukp/100*Um*np.sin(omega*t)/pom1-Lh*y[0]*Rk/2/pom1-y[1]*Rk/2)/pom2 ]
```

```
t = np.linspace(0., 0.1, 1000)
y0 = [ 0, 0 ]
y = odeint(ydot, y0, t)*1000.0

plt.plot(t,y)
plt.grid(True)
plt.show()
```

Zpracování pomocí integrační metody pro ODE

Transformátor nakrátko

Spyder (Python 3.9)

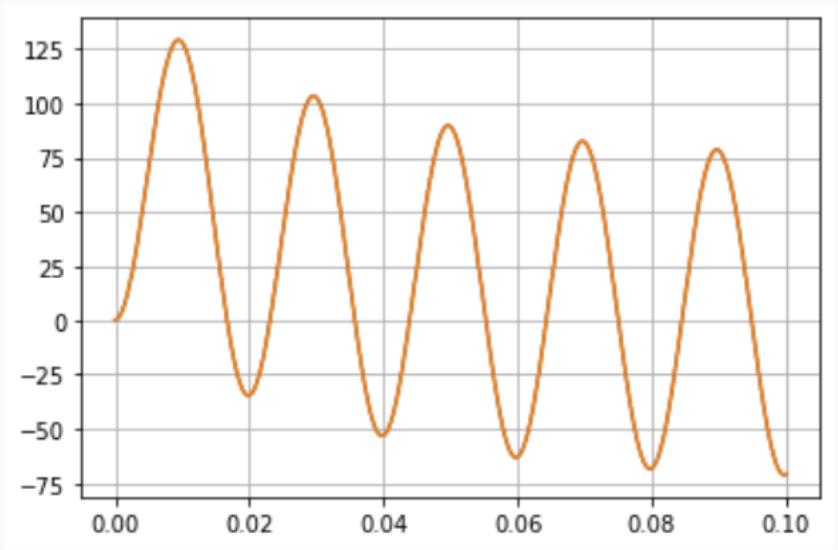
File Edit Search Source Run Debug Consoles Projects Tools View Help

C:\WORK\Python

C:\WORK\Python\CviceniPJS2021_3.py

CviceniPJS2021_2.py × CviceniPJS2021_3.py ×

```
1  # Reseni prubehu proudu nakratko numerickou metodou
2
3  import numpy as np
4  import matplotlib.pyplot as plt
5  from scipy.integrate import odeint
6
7  def ydot(y,t):
8      Un1=110
9      Ukp=10
10     Um=Un1/np.sqrt(3)*np.sqrt(2)
11     omega=314.16
12     Rk =  12.100
13     Ls =  0.38322
14     Lh =  403.75
15     pom1=Ls/2+Lh
16     pom2=Ls/2+Lh-Lh**2/pom1
17     return [ (Ukp/100*Um*np.sin(omega*t)-y[0]*Rk/2-Lh*y[1]*Rk/2/
18
19 t = np.linspace(0., 0.1, 1000)
20 y0 = [ 0, 0 ]
21 y = odeint(ydot, y0, t)*1000.0
22
23 plt.plot(t,y)
24 plt.grid(True)
25 plt.show()
26
```



Help Variable Explorer Plots Files

Console 1/A ×

```
In [34]: runfile('C:/WORK/Python/CviceniPJS2021_2.py', wdir='C:/WORK/Python')

In [35]: runcell(0, 'C:/WORK/Python/CviceniPJS2021_3.py')

In [36]:
```

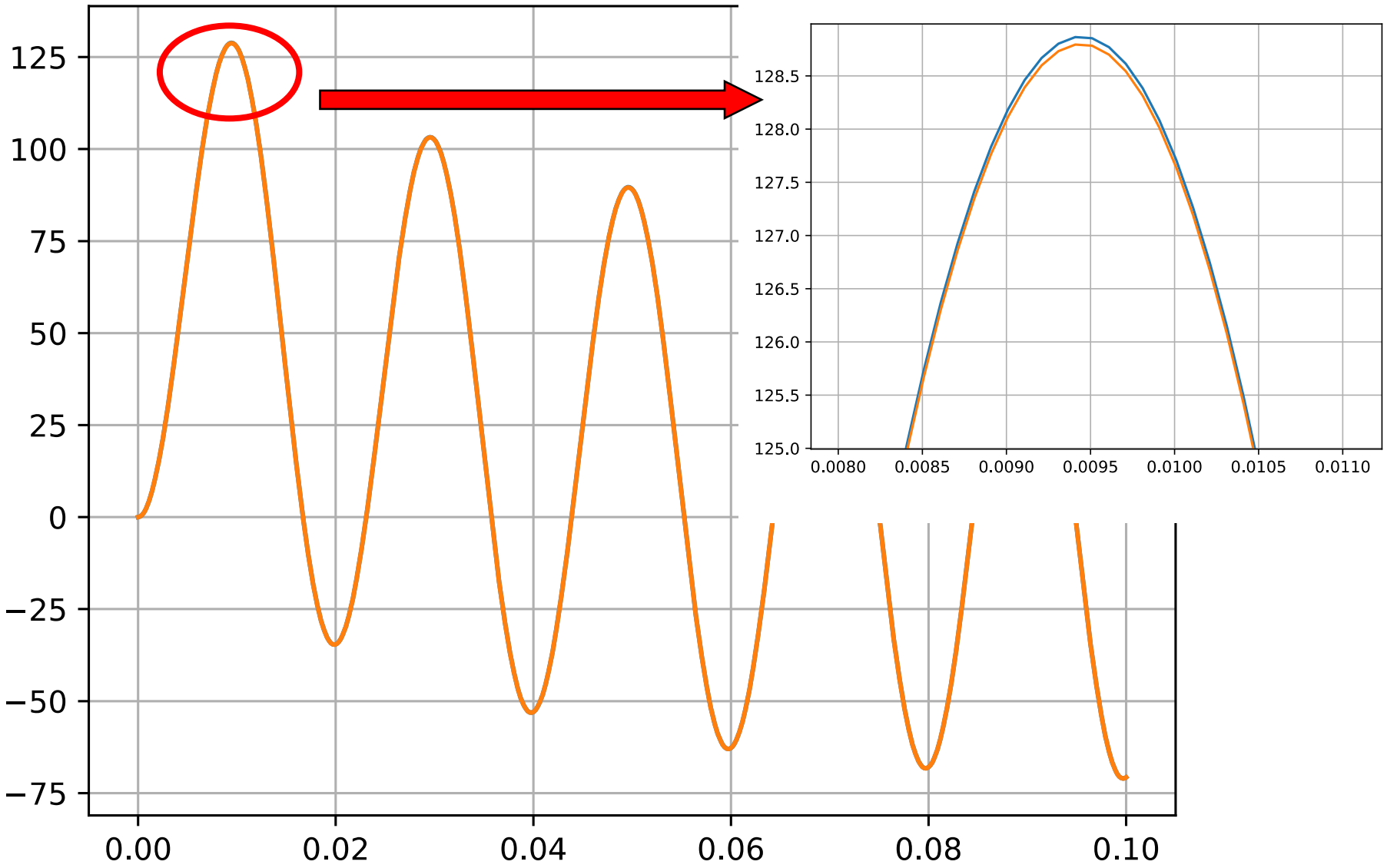
IPython console History

Kite: ready | LSP Python: ready | custom (Python 3.9.5) | Line 23, Col 1 | UTF-8-BOM | CRLF | RW | Mem 41%

Zpracování pomocí integrační metody pro ODE

Transformátor nakrátko

Řešení numerickou metodou bez zanedbání L_H:



Zpracování pomocí integrační metody pro ODE

Transformátor nakrátko

Řešení implicitní numerickou metodou bez zanedbání L_H:

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

$$-L_h \frac{di_1}{dt} + L_h \frac{di_2}{dt} + \frac{L_\sigma}{2}\frac{di_2}{dt} + i_2 \cdot \frac{R_K}{2} = 0$$

$$P_1 = \frac{L_\sigma}{2} + L_h \qquad P_2 = \frac{L_\sigma}{2} + L_h - \frac{L_h^{\,2}}{P_1}$$

$$\frac{di_1}{dt} = \frac{\frac{u_K[\%]}{100} U_m \sin(\omega \cdot t) - i_1 \cdot \frac{R_K}{2} - L_h \cdot i_2 \frac{R_K}{2} \cdot \frac{1}{P_1}}{P_2}$$

$$\frac{di_2}{dt} = \frac{\frac{L_h \cdot \frac{u_K[\%]}{100} U_m \sin(\omega \cdot t)}{P_1} - \frac{L_h \cdot i_1 \cdot \frac{R_K}{2}}{P_1} - i_2 \frac{R_K}{2}}{P_2}$$

Transformátor nakrátko

Řešení implicitní numerickou metodou bez zanedbání L_H:

$$L_{\sigma 1}\frac{di_1}{dt}+i_1\cdot R_{K1}+L_h\frac{di_1}{dt}-L_h\frac{di_2}{dt}=U_{km}\sin(\omega\cdot t) \qquad U_{km}=\frac{u_K[\%]}{100}U_m$$

$$-L_h\frac{di_1}{dt}+L_h\frac{di_2}{dt}+L_{\sigma 1}\frac{di_2}{dt}+i_2\cdot R_{K1}=0$$

```
# Reseni prubehu proudu nakratko numerickou metodou
Ukm=Ukp/100.0*Un1/np.sqrt(3)*np.sqrt(2)

m= GEKKO()
m.time = np.linspace(0.0, 0.1, 1000)
t = m.Param(value=m.time)
m.options.IMODE=4
i1 = m.Var(value=0.0)
i2 = m.Var(value=0.0)

# Ls1*i1' + Rk1*i1 + Lh*i1' + Lh*i2' = Ukm*sin(omega*t)
# - Lh*i1' + Lh*i2' + Ls1*i2' + Rk1*i2 = 0
m.Equation(Ls1*i1.dt() + Rk1*i1 + Lh*i1.dt() - Lh*i2.dt() == Ukm*m.sin(omega*t))
m.Equation(-Lh*i1.dt() + Lh*i2.dt() + Ls1*i2.dt() + Rk1*i2 == 0)
```

```
m.solve(disp=False)
plt.plot(t,i1)
plt.plot(t,i2)
plt.grid()
plt.show()
```

Zpracování pomocí soustavy implicitních diferenciálních rovnic a nástroje GEKKO https://github.com/BYU-PRISM/GEKKO

Transformátor nakrátko

Spyder (Python 3.9)

File Edit Search Source Run Debug Consoles Projects Tools View Help

C:\WORK\Python

C:\WORK\Python\CviceniPJS2021_5.py

temp.py × CviceniPJS2021_5.py ×

```
1  # Reseni prubehu proudu nakratko numerickou metodou
2
3  from gekko import GEKKO
4  import numpy as np
5  import matplotlib.pyplot as plt
6
7  Ukp=10.0
8  I0p=1.0
9  Un1=110.0
10 Un2=22.0
11 Snt=10.0
12
13 dP0p=0.3
14 dPkp=1.0
15
16 frekv=50.0
17 omega=2.0*np.pi*frekv
18
19 Rk=(dPkp/100.0)*(Un1**2/Snt)
20 Rk1=Rk/2.0
21 Zk=(Ukp/100.0)*(Un1**2/Snt)
22 Xs=np.sqrt(Zk**2-Rk**2)
23 Ls=Xs/omega
24 Ls1=Ls/2.0
25
26 Gfe=(dP0p/100.0)*(Snt/Un1**2)
27 Rfe=1/Gfe
28 Y0=(I0p/100.0)*(Snt/Un1**2)
29 Xh=1/np.sqrt(Y0**2-Gfe**2)
30 Lh=Xh/omega
31
32 # Reseni prubehu proudu nakratko numerickou metodou
33 Ukm=Ukp/100.0*Un1/np.sqrt(3)*np.sqrt(2)
34
35 m= GEKKO()
36 m.time = np.linspace(0.0, 0.1, 1000)
37 t = m.Param(value=m.time)
38 m.options.IMODE=4
39 i1 = m.Var(value=0.0)
40 i2 = m.Var(value=0.0)
41
42 # Ls1*i1' + Rk1*i1 + Lh*i1' + Lh*i2' = Ukm*sin(omega*t)
43 # - Lh*i1' + Lh*i2' + Ls1*i2' + Rk1*i2 = 0
44 m.Equation(Ls1*i1.dt() + Rk1*i1 + Lh*i1.dt() - Lh*i2.dt() == Ukm*m.sin(omega*t))
45 m.Equation(-Lh*i1.dt() + Lh*i2.dt() + Ls1*i2.dt() + Rk1*i2 == 0)
46
47 m.solve(disp=False)
48 plt.plot(t,i1)
49 plt.plot(t,i2)
50 plt.grid()
51 plt.show()
```

Nam	Type	Size	Value
dP0p	float	1	0.3
dPkp	float	1	1.0
frekv	float	1	50.0
Gfe	float	1	2.4793388429752066e-06
I0p	float	1	1.0
i1	gk_variable.GKVariable	1000	GKVariable object of gekko.gk_variable module
i2	gk_variable.GKVariable	1000	GKVariable object of gekko.gk_variable module
Lh	float64	1	403.7521067488283
Ls	float64	1	0.38322434881024886
Ls1	float64	1	0.19161217440512443
m	gekko.GEKKO	1	GEKKO object of gekko.gekko module
omega	float	1	314.1592653589793
Rfe	float	1	403333.3333333333
Rk	float	1	12.1
Rk1	float	1	6.05
Snt	float	1	10.0
t	gk_parameter.GKParameter	1000	GKParameter object of gekko.gk_parameter module
Ukm	float64	1	8.981462390204987
Ukp	float	1	10.0
Un1	float	1	110.0
Un2	float	1	22.0
Xh	float64	1	126842.4652433521
Xs	float64	1	120.39347988990102
Y0	float	1	8.264462809917356e-06
Zk	float	1	121.0

Help Variable Explorer Plots Files

Console 1/A ×

```
Python 3.9.5 (tags/v3.9.5:0a7dcbd, May  3 2021, 17:27:52) [MSC v.1928 64 bit (AMD64)]
Type "copyright", "credits" or "license" for more information.

IPython 7.25.0 -- An enhanced Interactive Python.

In [1]: runfile('C:/WORK/Python/CviceniPJS2021_5.py', wdir='C:/WORK/Python')
```

IPython console History

Kite: indexing LSP Python: ready custom (Python 3.9.5) Line 1, Col 1 ASCII CRLF RW Mem 42%

Zpracování pomocí soustavy implicitních diferenciálních rovnic a nástroje GEKKO https://github.com/BYU-PRISM/GEKKO

Transformátor nakrátko

Spyder (Python 3.9)

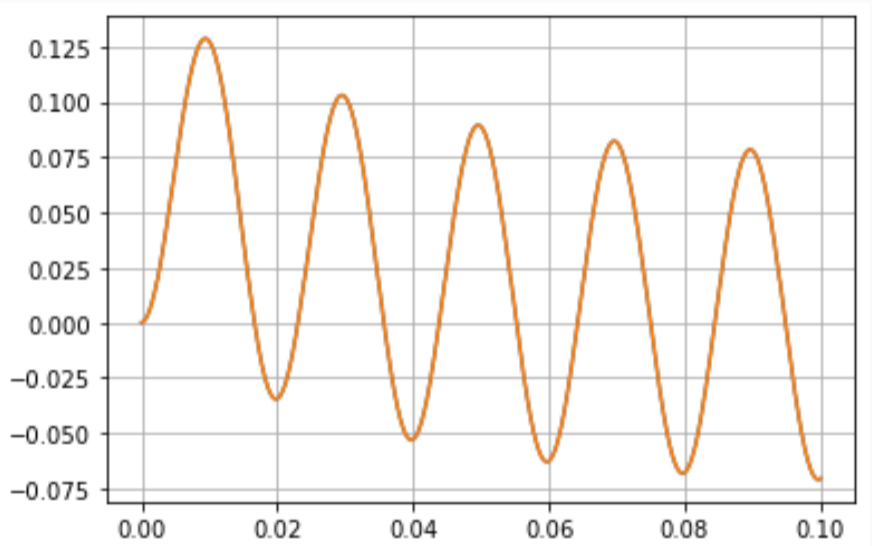
File Edit Search Source Run Debug Consoles Projects Tools View Help

C:\WORK\Python

C:\WORK\Python\CviceniPJS2021_5.py

temp.py | CviceniPJS2021_5.py

```
# Reseni prubehu proudu nakratko numerickou metodou

from gekko import GEKKO
import numpy as np
import matplotlib.pyplot as plt

Ukp=10.0
I0p=1.0
Un1=110.0
Un2=22.0
Snt=10.0

dP0p=0.3
dPkp=1.0

frekv=50.0
omega=2.0*np.pi*frekv

Rk=(dPkp/100.0)*(Un1**2/Snt)
Rk1=Rk/2.0
Zk=(Ukp/100.0)*(Un1**2/Snt)
Xs=np.sqrt(Zk**2-Rk**2)
Ls=Xs/omega
Ls1=Ls/2.0

Gfe=(dP0p/100.0)*(Snt/Un1**2)
Rfe=1/Gfe
Y0=(I0p/100.0)*(Snt/Un1**2)
Xh=1/np.sqrt(Y0**2-Gfe**2)
Lh=Xh/omega

# Reseni prubehu proudu nakratko numerickou metodou
Ukm=Ukp/100.0*Un1/np.sqrt(3)*np.sqrt(2)

m= GEKKO()
m.time = np.linspace(0.0, 0.1, 1000)
t = m.Param(value=m.time)
m.options.IMODE=4
i1 = m.Var(value=0.0)
i2 = m.Var(value=0.0)

# Ls1*i1' + Rk1*i1 + Lh*i1' + Lh*i2' = Ukm*sin(omega*t)
# - Lh*i1' + Lh*i2' + Ls1*i2' + Rk1*i2 = 0
m.Equation(Ls1*i1.dt() + Rk1*i1 + Lh*i1.dt() - Lh*i2.dt() == Ukm*m.sin(omega*t))
m.Equation(-Lh*i1.dt() + Lh*i2.dt() + Ls1*i2.dt() + Rk1*i2 == 0)

m.solve(disp=False)
plt.plot(t,i1)
plt.plot(t,i2)
plt.grid()
plt.show()
```



Help | Variable Explorer | Plots | Files

Console 1/A

```
Python 3.9.5 (tags/v3.9.5:0a7dcbd, May  3 2021, 17:27:52) [MSC v.1928 64 bit (AMD64)]
Type "copyright", "credits" or "license" for more information.

IPython 7.25.0 -- An enhanced Interactive Python.

In [1]: runfile('C:/WORK/Python/CviceniPJS2021_5.py', wdir='C:/WORK/Python')
```

IPython console | History

Kite: indexing | LSP Python: ready | custom (Python 3.9.5) | Line 1, Col 1 | ASCII | CRLF | RW | Mem 43%

Zpracování pomocí soustavy implicitních diferenciálních rovnic a nástroje GEKKO https://github.com/BYU-PRISM/GEKKO