Scilab Textbook Companion for Electric Machinery by A. E. Fitzgerald, C. Kingsley And S. D. Umans[1]

Created by
Dheeraj Agrawal
B.Tech. (pursuing)
Electrical Engineering
Indian Institute of Technology Roorkee
College Teacher
R.P. Maheshwari
Cross-Checked by
Prashant Dave, IIT Bombay

August 10, 2013

[1]Funded by a grant from the National Mission on Education through ICT, http://spoken-tutorial.org/NMEICT-Intro. This Textbook Companion and Scilab codes written in it can be downloaded from the "Textbook Companion Project" section at the website http://scilab.in

Book Description

Title: Electric Machinery

Author: A. E. Fitzgerald, C. Kingsley And S. D. Umans

Publisher: McGraw - Hill

Edition: 5

Year: 1992

ISBN: 0-07-707708-3

Scilab numbering policy used in this document and the relation to the above book.

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

AP Appendix to Example(Scilab Code that is an Appednix to a particular Example of the above book)

For example, Exa 3.51 means solved example 3.51 of this book. Sec 2.3 means a scilab code whose theory is explained in Section 2.3 of the book.

Contents

List of Scilab Codes

List of Figures

Chapter 1

Magnetic Circuits and Magnetic Materials

Scilab code Exa 1.1 Finding reluctances and flux

```
// Caption: Finding reluctances and flux

clear;
close;
clc;
U_r=70000;
U_o=4*%pi*10^-7;

function [R_c]=reluctance_core(l,A)
  R_c=l/(U_r*U_o*A);
endfunction
disp(reluctance_core(.3,9*10^-4),'Reluctance of the
   core=')

function [R_g]=reluctance_gap(g,A)
  R_g=g/(U_o*A);
endfunction
disp(reluctance_gap(5*10^-4,9*10^-4),'Reluctance of
   the gap=')
```

```

phy=1.0*9*10^-4;
disp(phy,'flux=')

i=phy*(reluctance_core(.3,9*10^-4)+reluctance_gap
    (5*10^-4,9*10^-4))/500;
disp(i,'current=')
```

Scilab code Exa 1.2 Finding air gap flux

```
// Caption: Finding air gap flux
clear;
close;
clc;
N=1000;
I=10;
U_o=4*%pi*10^-7;
A_g=.2;
g=.01;
phy=(N*I*U_o*A_g)/(2*g);
disp(phy,'flux=')
B_g=phy/A_g;
disp(B_g,'flux density=')
```

Scilab code Exa 1.4b Finding Induced voltage of a magnetic circuit

```
// Caption: Finding Induced voltage of a magnetic
    circuit

close;
clc;
syms t

```

```
w=2*%pi*60//angular frequency

B=1.0*sin(w*t);
N=500;
A=9*10^-4;
e=N*A*diff(B,t);

disp(e,'Induced Voltage = ');
```

Scilab code Exa 1.5 Finding current from dc magnetization curve

```
// Caption: Finding current from dc magnetization
   curve
clear;
close;
clc;
H_c=12;//from fig at B_c=1 T
l_c=0.3;
F_c=H_c*l_c;//mmf of core path
F_g=(5*10^-4)/(4*%pi*10^-7);//mmf of air gap
i=(F_c+F_g)/500;//current in Amperes
disp(i,'current=');
```

Scilab code Exa 1.6a Finding applied voltage to the windinds with magnetic core

```
// Finding applied voltage to the windinds with
   magnetic core
close;
clc;
syms t

w=377;//angular frequency
```

```
B=1.5*sin(w*t);
N=200;
A=16*10^-4;//area
a=0.94;//steel occupies 0.94 times the gross core
    volume
e=N*A*a*diff(B,t);

disp(e,'applied Voltage = ');
```

Scilab code Exa 1.8 Finding minimum magnet volume

```
// Caption: Finding minimum magnet volume
clear;
close;
clc;

function [A_m]=area(B_g,B_m)
 A_m=2*B_g/B_m;
endfunction
a=area(0.8,1.0);//from fig
L_m=-0.2*0.8/(4*%pi*10^-7*-40*10^3);

volume=a*L_m;//minimum magnet volume
disp(volume,'minimum magnet volume in cm cube');
```

Chapter 2

Transformers

Scilab code Exa 2.1 Finding power factor and core loss current

```
// Caption: Finding power factor,core loss current
clear;
close;
clc;
alpha=acos(16/20);
pf=cos(alpha);//power factor
disp(pf,'power factor=');

I_e=20/194;//exciting current
I_c=16/194;//core loss component
I_m=I_e*0.6;//magnetizing componentminimum magnet
    volume
```

Scilab code Exa 2.3 Finding peak mmf and flux

```
// Caption: Finding peak mmf and flux
clear;
close;
```

```
clc;
function [F_peak]=mmf(k,N,m,I)
  F_peak=(1.5*4*k*N*I)/(%pi*2*m);
endfunction

f=mmf(.92,45,3,700);
U_o=4*%pi*10^-7;
B_peak=U_o*8.81*10^3/.01;//flux density
vel=25*0.5;//in m/s
```

Scilab code Exa 2.4 Finding regulation

```
// Caption: Finding regulation
clear;
close;
clc;
Z_eq=48/20.8;
R_eq=617/20.8^2;
X_eq=sqrt(Z_eq^2-R_eq^2);//in ohms
I_h=50000/2400;//full load high tension current
Loss=I_h^2*R_eq;
Input=40000+186+Loss;//in watts
Efficiency=1-803/Input;
disp(Efficiency,'efficiency is=');

V_1h=2400+(20.8*(0.8-0.6*%i)*(1.42+1.82*%i));
Reg=((2446-2400)/2400)*100;
disp(Reg,'percentage regultion=')
```

Scilab code Exa 2.5 Finding kVA rating

```
// Caption: Finding kVA rating
clear;
```

```
close;
clc;
I_h=50000/240;
V_h=2640;
kva=V_h*I_h/1000;
disp(kva,'kVA rating of transformer=')

eff=1-803/(0.8*550000);//from ex 2.4
disp(eff,'efficiency is=')
```

Scilab code Exa 2.7 Finding current in feeder wires

```
// Caption: Finding current in feeder wires
clear;
close;
clc;
V_s=2400/sqrt(3);
X_eqs=2.76/3;//per phase
X_eqr=1.82/3;//at recieving end
total_X=X_eqs+X_eqr+0.8;
I_win=594/sqrt(3);//at 2400V windings
I_feeder=1385/2.33;//at 2400V feeder
```

Scilab code Exa 2.8 Finding per unit system

```
// Caption: Finding per unit system
clear;
close;
clc;
Z_baseH=2400/20.8;
Z_baseX=240/208;

I_x=5.41/208;//per unit at low voltage side
```

```
Z_eqH=(1.42+%i*1.82)/115.2;//per unit
disp(Z_eqH,'equivalent impedence referred to high
    voltage side')
```

Scilab code Exa 2.9 Finding current in feeder wires in per unit

```
// Caption: Finding current in feeder wires in per
    unit
clear;
close;
clc;
V_base=2400/sqrt(3);//for 2400V feeder and line to
    neutral
I_base=50000/1385;//phase Y
Z_base=V_base/I_base;//phase Y
X_feeder=0.8/Z_base;//per unit

SC_current=1.00/.0608;// short circuit current in
    per unit
disp(SC_current,'short circuit current in per unit='
    )
```

Chapter 3

Electromechanical Energy Conversion Principles

Scilab code Exa 3.1 Finding Torque acting on the rotor

```
// Caption: Finding Torque acting on the rotor

close;
clc;
syms alpha;
I=10;//current
B_o=0.5;//magnetic field
R=0.1;
l=0.6;

T=2*I*B_o*R*l*sin(alpha);

disp(T,'Torque acting on the rotor=');
```

Scilab code Exa 3.2 Finding magnetic stored energy

```
// Caption: Finding magnetic stored energy

close;
clc;
syms x d;
constt=0.5*1000^2*4*%pi
    *10^-7*0.15*0.1*10^2/(2*0.002);

W_fld=constt*(1-x/d);//in joules

disp(W_fld,'magnetic stored energy=');
```

Scilab code Exa 3.3 Finding force on the plunger

```
// Caption: Finding force on the plunger
clear;
close;
clc;
U_o=4*%pi*10^-7;

function [f]=force(N,l,g,i)
  f=-(N^2*U_o*l*i^2/(4*g));
endfunction

f_fld=force(1000,0.1,0.002,10);//force in N

disp(f_fld,'force on the plunger when current=10A');
```

Scilab code Exa 3.4 Finding Torque acting on the rotor

```
// Caption: Finding Torque acting on the rotor
clear;
close;
```

```
clc;

U_o=4*%pi*10^-7;

function [T]=torque(B,h,g,r)
    T=(B^2*g*h*(r+g*.5))/U_o;
  endfunction

  T_fld=torque(2,0.02,0.002,0.02);//Maximum torque
      in N.m

  disp(T_fld,'Torque acting on the rotor');
```

Scilab code Exa 3.5 Finding Torue of given system

```
// Caption: Finding Torue of given system
clear;
close;
clc;
syms x i1 i2
L_11=(3+cos(2*x))*10^(-3);
L_12=0.1*cos(x);
L_22=30+10*cos(2*x);
W=0.5*L_11*i1^2+L_12*i1*i2+0.5*L_22*i2^2;
T=diff(W,x);
disp(T,'Torque = ');
i1=1;//in Ampere
i2=0.01;//in Ampere
k=eval(T);
disp(k,'Torue of given system  = ');
```

Chapter 4

Rotating Machine Basic Concept

Scilab code Exa 4.1 Finding peak mmf and flux

```
// Caption: Finding peak mmf and flux
clear;
close;
clc;

function [F_peak]=mmf(k,N,p,I)
  F_peak=(4*k*N*I)/(%pi*p);
endfunction
f=mmf(.9,46,2,1500);//peaf fundamental mmf

B_peak=(4*%pi*10^-7*f)/(7.5*10^-2);//peak flux
    density

phy=2*B_peak*4*0.5;//flux per pole
E_rms=sqrt(2)*%pi*60*.833*24*2.64;//rms voltage
disp(E_rms,'RMS value of voltage generated=')
```

Chapter 5

Synchronous Machines in Steady State

Scilab code Exa 5.1 Finding unsaturated value of the synchronous reactance and the SCR ratio

```
// Caption: Finding unsaturated value of the
   synchronous reactance and the SCR ratio
// Example 5.1

clear;
close;
clc;
E_af_ag=202/3^.5;//voltage to neutral on air-gap
   line at 2.20A
I_a_sc=118;//at 2.20A
X_s_ag=E_af_ag/I_a_sc;//Reactance per phase
disp(X_s_ag,'Reactance in ohm per phase=')
I_a_r=45000/(3^.5*220);//Rated Ia
I_a_sc=118/I_a_r;//per unit
E_af_ag=202/220;//per unit
X_s_ag=E_af_ag/I_a_sc;//per unit
disp(X_s_ag,'reactance per unit=')
X_s=220/3^.5*152;//per phase
```

```
disp(X_s,'saturated reactance per phase=')
I_a_sc_dash=152/118;//per unit
X_s=1.00/I_a_sc_dash;//per unit
SCR=2.84/2.20;
disp(SCR,'short circuit ratio=')
//Result
// Reactance in ohm per phase=0.9883454
//reactance per unit=0.9189162
//saturated reactance per phase=19306.593
//short circuit ratio=1.2909091
```

Scilab code Exa 5.2 Finding effective armature resistance

```
// Caption: Finding effective armature resistance
// Example 5.2

clear;
close;
clc;
L_loss_sc=1.8/45;//per unit
I_a=1.00;//per unit
R_a_eff=L_loss_sc/I_a^2;//per unit
disp(R_a_eff,'effective armature resistance in per
    unit=')
R_a_eff=1800/((118^2)*3);//per phase
disp(R_a_eff,'effective armature resistance in ohms
    per phase=')
//Result
//effective armature resistance in per unit=0.04
//effective armature resistance in ohms per phase
    =0.0430911
```

Scilab code Exa 5.3 Finding maximum torque deliver by motor when it is supplied with the power from infinite bus and turbine generator

```
// Caption: Finding maximum torque deliver by motor
   when it is supplied with the power from a)
   infinite bus b)turbine generator
// Example 5.3

clear;
close;
clc;
kVA_r=1500/3;//per phase
V_ta=2300/sqrt(3);//per phase
I_r=500000/V_ta;//per phase
X_sm=1.95;
I_a_X_sm=I_r*X_sm;//syn-reactance V-drop
E_afm=sqrt(V_ta^2+I_a_X_sm^2);
p_max=(V_ta*E_afm)/X_sm;//per phase
P_max=3*p_max;//power in 3 phase
W_s=2*%pi*4;
T_max=P_max/W_s;//torque-max
disp(T_max,'Maximum torque in newton-meteres=')
//Result
//Maximum torque in newton-meteres=123341.2

V_ta=2300/sqrt(3);//per phase
I_r=500000/V_ta;//per phase
X_sm=1.95;X_sg=2.65;//synchronous reactance of motor
    ang generator
I_a_X_sg=I_r*X_sg;//syn-reactance V-drop
E_afg=sqrt(V_ta^2+I_a_X_sg^2);
p_max=(E_afg*E_afm)/(X_sm+X_sg);//per phase
P_max=3*p_max;//power in 3 phase
W_s=2*%pi*4;
T_max=P_max/W_s;//torque-max
disp(T_max,'Maximum torque in newton-meteres=')
//Result
//Maximum torque in newton-meteres=65401.933
```

```

I_a=sqrt(E_afm^2+E_afg^2)/(X_sg+X_sm);
alpha=acos(E_afm/(I_a*(X_sg+X_sm)));

V_ta=E_afm-I_a*X_sm*cos(alpha)+%i*I_a*X_sm*sin(alpha
    );
disp(V_ta,'terminal voltage=')
//Result
//terminal voltage=874.14246 + 704.12478i
```

Scilab code Exa 5.4 Finding efficiency of machine

```
// Caption: Finding efficiency of machine
// Example 5.4

clear;
close;
clc;
I_a=45000/(sqrt(3)*230*.8);//armature current
R_f=29.8*((234.5+75)/(234.5+25));//field resistance
    at 75 degree celsius
R_a=0.0335*((234.5+75)/(234.5+25));//armature dc
    resistance at 75 degree celsius
I_f=5.5;
L_f=(I_f^2*R_f)/1000;//field loss
L_a=(3*I_a^2*R_a)/1000;//armature loss
V_i=230/sqrt(3)-I_a*(.8+%i*.6)*R_a;//internal
    voltage
L_s=.56;//stray load loss
L_c=1.2;//open circuit core loss
L_w=.91;//frictional and winding loss
L_t=L_f+L_a+L_s+L_c+L_w//total losses
Input=46.07;
Eff=1-L_t/Input;
disp(Eff*100,'efficiency of the system is(%) ')
```

```
//Result
//efficiency of the system is(%)86.683487
```

Chapter 6

Synchronous Machines A Transient Performance

Scilab code Exa 6.2a Graph on steady state and transient power angle characteristics

```
clear
clc
xset('window',1)
xtitle("My Graph","radians","power per unit")
x=linspace(0,%pi,100)
y=6.22*sin(x)

plot(x,y)
```

Scilab code Exa 6.2b Graph on steady state and transient power angle characteristics

```
clear
```

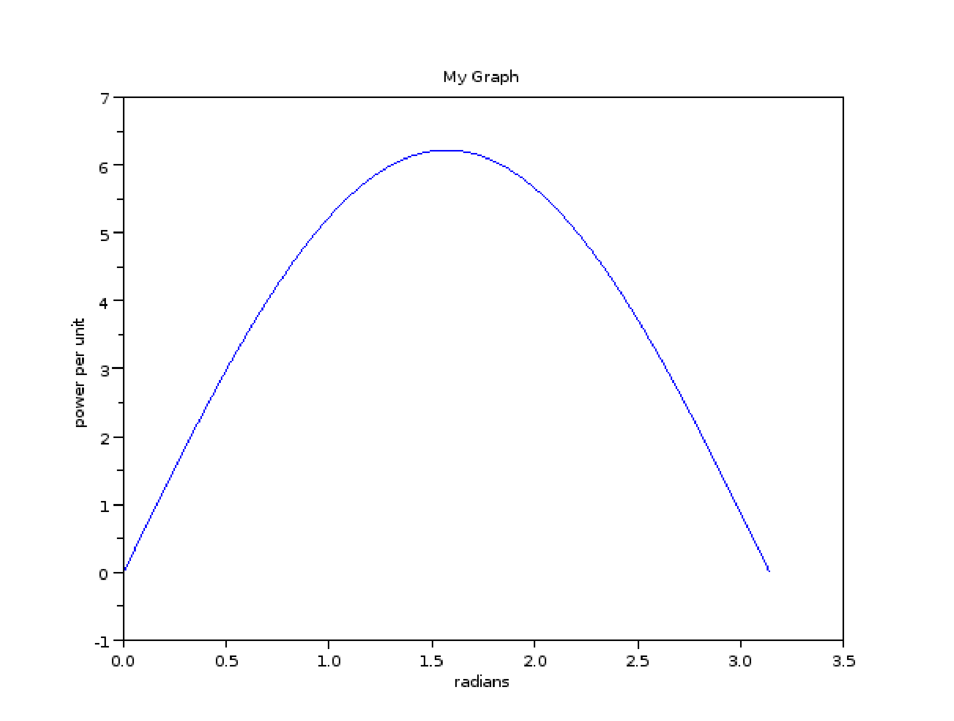

Figure 6.1: Graph on steady state and transient power angle characteristics

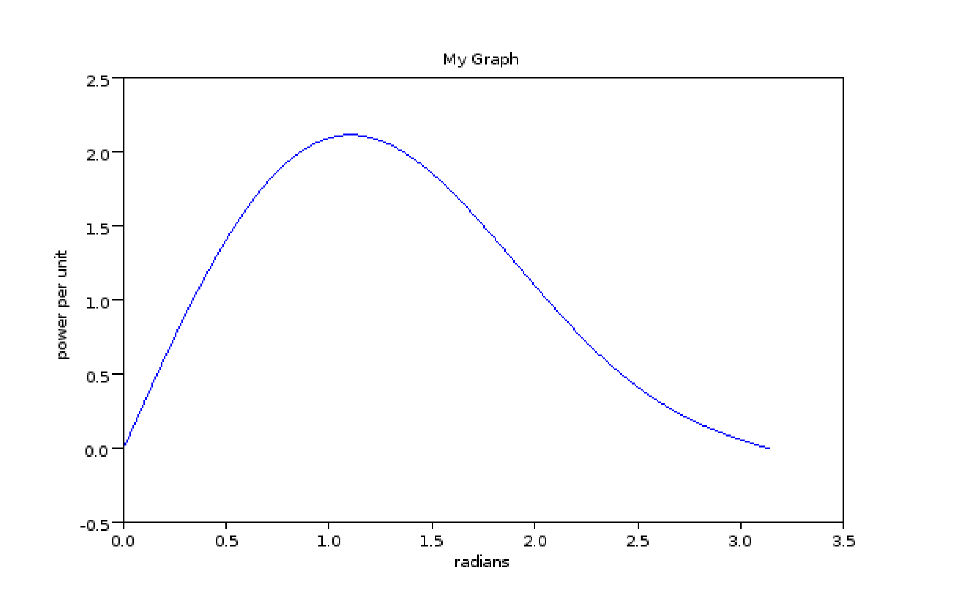

Figure 6.2: Graph on steady state and transient power angle characteristics

```
clc
xset('window',1)
xtitle("My Graph","radians","power per unit")
x=linspace(0,%pi,100)
y=1.77*sin(x)+0.67*sin(2*x)
plot(x,y)
```

Chapter 7

Polyphase Induction Machines

Scilab code Exa 7.1 Finding stator current and efficiency

```
// Caption: Finding stator current and efficiency
clear;
close;
clc;
V_app=220/sqrt(3);//applied voltage to neutral
I_s=127/6.75;//stator current
pf=cos(.565);//in radians

speed=120/6;// synchronous speed in r/s
S_r=(1-.02)*speed*60;//rotor spped in r/min
P_g=3*18.8^2*5.41;
P=.98*5740;//internal mechanical power

eff=1-830/6060;
disp(eff,'efficiency=')
```

Scilab code Exa 7.2 Finding internal torque

```
// Caption:Finding internal torque
clear;
close;
clc;
V_a=122.3;
I_two= V_a/sqrt(5.07^2+0.699^2);//load component of
    stator current
T=3*23.9^2*4.8/125.6;//internal torque
P=3*23^2*4.8*.97;//internal power

// at maximum torque point
s_max=0.144/0.75;
speed=(1-s_max)*1200;//speed in r/min
T_max=(0.5*3*122.3^2)/(125.6*(0.273+0.750));//
    maximum internal torque

T_start=3*150.5^2*0.144/125.6;//starting torque in N
    −mFinding stator current and efficiency
```

Scilab code Exa 7.3 Finding internal starting torque

```
// Caption: Finding internal starting torque
clear;
close;
clc;
P_r=380-3*5.7^2*0.262;
//from test 1
Z_nl=219/(sqrt(3)*5.7);//phase Y
R_nl=380/(3*5.7^2);

//from test 2
Z_bl=26.5/(sqrt(3)*18.57);//phase at 15 hz
R_bl=675/(3*18.75^2)//

//internal starting torque
```

```
P_g=20100-3*83.3^2*0.262;//air gap power

T_start=P_g/188.5;//starting torque in N-m
```

Chapter 8

Polyphase Induction Machines Dynamics and Control

Scilab code Exa 8.3 Finding short circuit current

```
// Caption: Finding short circuit current
clear;
close;
clc;
X=.060+2.5-(2.5^2/(.06+2.5));//transient reactance
I=300*10^3/(.9*.93*440*sqrt(3));//prefault stator
    current
I_initial=232/.12;//initial current
T_o=(2.5+.06)/(2*%pi*60*.0064);//open circuit time
    constant
T_s=T_o*.12/2.56;//short circuit time constant
```

Chapter 9

DC Machines in Steady State

Scilab code Exa 9.1 Finding electromagnetic torque

```
// Caption: Finding electromagnetic torque
clear;
close;
clc;
V_t=128;
E_a=125;
R_a=.02;
I_a=(V_t-E_a)/R_a;//armature current

P_t=V_t*I_a;//terminal power;
P_e=E_a*I_a;//electromagnetic power;
T=P_e/(100*%pi);//torque
disp(T,'electromagnetic torque=');
```

Scilab code Exa 9.2 Finding terminal voltage

```
// Caption: Finding terminal voltage
clear;
```

```
close;
clc;
V=274;//voltage when Ia=0
E_a=274*1150/1200;//actual emf
V_t=E_a-405*(0.025+0.005);//terminal voltage
```

Scilab code Exa 9.4 Finding speed and output power

```
// Caption: Finding speed and output power
clear;
close;
clc;
E_ao=250*1200/1100;//at 1200 r/min
E_a=250-400*.025;//at Ia=400A
n=240*1200/261;//actual spped
P_em=240*400;
disp(P_em,'electromagnetic power=')
```

Chapter 10

Variable Reluctance Machines

Scilab code Exa 10.1a Finding maximum inductance for phase

```
// Caption: Finding maximum inductance for phase
clear;
close;
clc;
N=100;
U_o=4*%pi*10^-7;
alpha=%pi/3;
R=3.8*10^-2;
D=0.13;
g=2.54*10^-4;
L_max=N^2*U_o*alpha*R*D/(2*g);

disp(L_max,'maximum inductance for phase 1=')
```

Scilab code Exa 10.4 Finding switching times T on and T off

```
// Caption: Finding switching times T on and T off
clear;
```

```
close;
clc;
//off time at i=Imin
T_off=-0.25*log(10/12)/2.5;

//on time
T_on=-0.25*log((12-20)/(10-20))/5;//in seconds

disp(T_on,'On time=')
```

Chapter 11

Fractional and subfractional Horsepower Motors

Scilab code Exa 11.2 Finding efficiency at rated voltage and frequency with starting winding open

```
// Caption: Finding efficiency at rated voltage and
   frequency with starting winding open
clear;
close;
clc;
s=0.05;
//rotor speed
speed=(1-s)*1800;//in r/min
//torque
T=147/179;// in N.m

//Efficiency
op=244;//output
ip=147;//input
eff=ip/op;
disp(eff,'Efficiency=')
```

Scilab code Exa 11.3d Finding internal mechanical power

```
// Caption: Finding internal mechanical power
clear;
close;
clc;
I_f=11.26;
R_f=16.46;
//power delivered to forwaed field
P_gf=2*I_f^2*R_f;
I_b=4;
R_b=0.451;
//power delivered to the backward field
P_gb=2*I_b^2*R_b;

P=.95*(P_gf-P_gb);
disp(P,'internal mechanical power=')
```

Scilab code Exa 11.6 Finding speed voltage constant

```
// Caption: Finding speed voltage constant
clear;
close;
clc;
V_t=50;
I_a=1.25;
R_a=1.03;
E_a=V_t-I_a*R_a;

W=220;//rad/s
K_m=E_a/W;// V/rad/s

```

```
//At 1700 r/min
W_m=1700*2*%pi/60;//rad/s
E_anew=K_m*W_m;

I_anew=(48-E_anew)/1.03;
P_shaft=E_anew*I_anew;
P=P_shaft-61;

disp(P,'output power=')
```