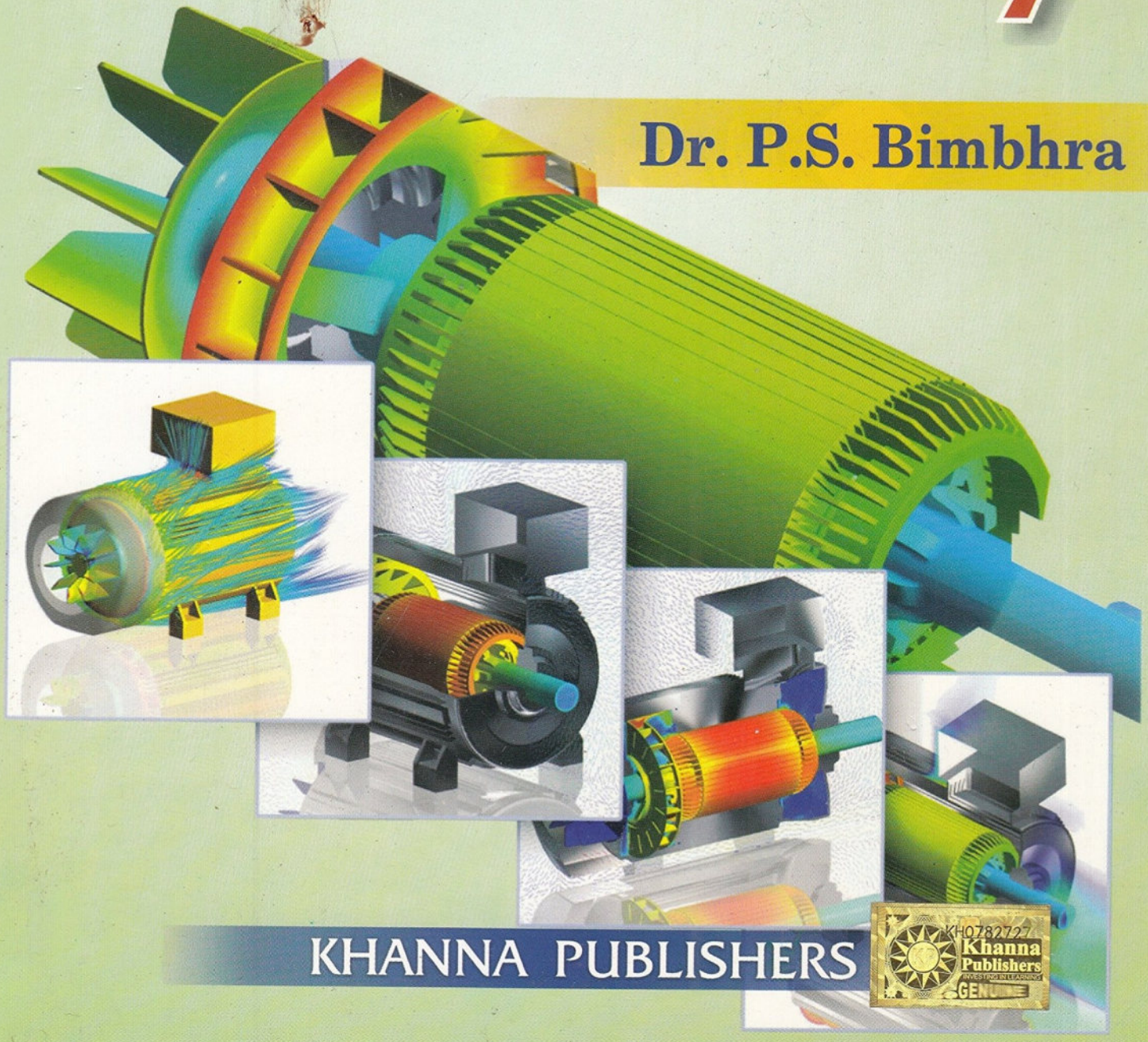
Electrical Machinery

Dr. P.S. Bimbhra



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Created by
Tejash Ajay Sharma
B.Tech
Electrical Engineering
Visvesvaraya National Institute of Technology
College Teacher
None
Cross-Checked by
None

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Book Description

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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

Chapter 1

Transformers

Scilab code Exa 1.1 finding number of primary and secondary turns and net cross section area of core

```
1
2 clc;
3 f=50; // frequency in Hz
4 Et=13; // emf per turn in volts
5 E1=2310; // primary voltage in volts
6 E2= 220; // secondary voltage in volts
7 B=1.4; // maximum flux density in Tesla
8 // calculating the number of turns in primary and
    secondary side
9 N2= round(E2/Et); //secondary side turns
10 printf('Number of secondary turns is %f\n',N2);
11 N1=round(N2*(E1/E2));// primary side turns
12 printf('Number of primary turns is %f\n',N1);
13 disp('The value of primary turns does not satisfy
    with the');
14 disp('value of secondary turns so taking value of N2
    =18(next nearest integer)');
15 N2=18; // new value of secondary turns
16 N1=18*(E1/E2);
17 printf('Number of primary turns is %f\n',N1);
```

```
18 printf('Number of secondary turns is %f\n',N2);
19 // calculating net core area
20 A=(220/(18*sqrt(2)*%pi*B*50))*10^4; // where N2=18
21 printf('Net area of core is %f cm^2',A);
```

Scilab code Exa 1.2 Determining number of turns in all three windings of transformer

```
1  clc;
2  f=50; // frequency in hertz
3  B=1.2; // maximum flux density in Tesla
4  A=75*10^-4; // net core area in m^2
5  E1=220; // primary side voltage in volts
6  E2=600; // secondary side voltage in volts
7  E3=11; // tertiary side voltage in volts
8  n3=round(E3/2); // number of turns in half of the
      tertiary winding
9  Et=round(sqrt(2)*%pi*50*B*A); // calculating emf per
       turn
10 N3=Et*n3; // total number of turns in tertiary
      winding
11 printf('total number of turns in  tertiary winding
      is %f\n',N3);
12 N2=round(E2*(n3/E3)); // total number of turns in
      secondary winding
13 printf('total number of turns in  secondary winding
      is %f\n',N2);
14 N1=round(E1*(n3/E3)); //  total number of turns in
      secondary winding
15 printf('total number of turns in primary winding is
      %f',N1);
```

Scilab code Exa 1.3 the components of exciting current primary current and power factor

```
clc;
f=50; // frequency in hertz
E1=2200; // supply voltage in volts
E2=220; // secondary side voltage in volts
P=361; // core loss in watts
Io=0.6; // exciting current in Ampere
Is=60; // secondary load current in Ampere
pf=0.8; // power factor
Ic=P/E1; // core loss component of current
printf('core loss component of exciting current is %f A\n',Ic);
Im=sqrt(Io^2-Ic^2); // magnetising component of current
printf('magnetising component of exciting current is %f A\n',Im);
ip=Is*(E2/E1); // primary current required to neutralise the secondary current
Iv=ip*pf+Ic; // total vertical compartment of primary current
Ih=ip*0.6+Im; // total horizontal compartment of primary current,pf cos(theta)=0.8 so sin(theta)=0.6
Ip=sqrt(Iv^2+Ih^2); // toatl primary current
printf('Total primary current is %f A\n',Ip);
ppf=Iv/Ip; // primary power factor
printf('primary power factor is %f (lagging)',ppf);
```

Scilab code Exa 1.4 finding saving in weight of core and wire material

```
clc;
disp('weight of laminations is directly proportion to core volume density, which is directly
```

```
    proportional to  product of area and height of
    limbs and while taking the ratio of weight of
    CRGO laminations and hot rolled  laminations,
    height of limbs gets cancelled out(height of
    limbs are assumed to be equal). So, in the end
    ratio of weights of laminations is equal to ratio
     of area of core.Now area of core is given by
    maximum flux/flux density.According to question
    maximum flux remain same so ,while taking ratio
    of areas the maximum flux gets cancelled')
B1=1.2; //flux density in hot rolled steel
    laminations
B2=1.6; //flux density in CRGO steel laminations
W1=100; // weight of H.R core in kg
W2=W1*(B1/B2); // calculating weight of CRGO
    laminations in kg
s=((W1-W2)/W1)*100; // calculating saving in core
    material
printf('percentage saving in core material is %f
    percent\n',s);
disp('weight of wire is directly proportional to
    product of length of turn around core and cross
    section of wire.(Wire cross section is assumed to
     be same in CRGO and HR laminations so gets
    cancelled out while taking  ratio) also the
    length of turn is inversely proportional to
    square root of flux density  ')
w1= 80 // weight of Hot rolled wire
w2=w1*(sqrt(1.2/1.6)); // weight of CRGO wire
s=((w1-w2)/w1)*100; //saving in weight of wire
printf('Percentage saving in weight of wire is %f
    percent',s);
```

Scilab code Exa 1.5 determination of no load voltage and frequency of secondary side

```
clc;
v1=240; // high voltage side voltage
v2=120; // low voltage side voltage
f1=50; // frequency in Hz
disp('v1 is directly proportional to product of
   frequency and maximum flux. considering q1 be
   maximum flux for v1 and q2 be maximum flux for
   v11 then Q=q2/q1 can be calculated as follow ')
disp('case a')
v11=240; // new supply voltage
f2=40; // new supply frequency
Q=(v11*f1)/(v1*f2);
v22=(v2*f2*Q)/f1;
printf('secondary voltage for case a is %f v\n',v22)
   ;
disp('case b')
v11=120; // new supply voltage
f2=25; // new supply frequency
Q=(v11*f1)/(v1*f2);
v22=(v2*f2*Q)/f1;
printf('secondary voltage for case a is %f v\n',v22)
   ;
disp('case c')
v11=120; // new supply voltage
f2=50; // new supply frequency
Q=(v11*f1)/(v1*f2);
v22=(v2*f2*Q)/f1;
printf('secondary voltage for case a is %f v\n',v22)
   ;
disp('case d')
v11=480; // new supply voltage
f2=50; // new supply frequency
Q=(v11*f1)/(v1*f2);
v22=(v2*f2*Q)/f1;
printf('secondary voltage for case a is %f v\n',v22)
   ;
disp('case e')
v11=240; // new supply voltage
```

```
32 f2=0; // new supply frequency
33 disp('since frequency is zero. Source is a DC source
       so a very  high current will flow in primary
      side which will damage the transformer and the
      secondary induced emf is zero ')
```

Scilab code Exa 1.6 finding primary winding current and power factor

```
1  clc;
2  N1=100; // no. of primary turns
3  N2=160; // No. of secondary turns
4  N3=60; // No. of tertiary turns
5  I2=10; // secondary side current
6  I3=20; // tertiary side current
7  F2=N2*I2; // mmf of secondary winding
8  F3=N3*I3; // mmf of tertiary winding
9  disp('load connected to secondary is purely
      resistive and load connected to tertiary is
      purely capacitive' );
10 F23=sqrt(F2^2+F3^2); //resultant load mmf
11 F1=F23; // primary winding mmf balances this load
      mmf
12 I1=F1/N1;
13 printf('primary current is %f A\n',I1);
14 pf=F2/F1;
15 printf('primary side power factor is %f leading',pf)
      ;
```

Scilab code Exa 1.8 Determining 1 primary resistance and reactance referred to secondary 2 secondary resistance and reactance referred to primary 3 equivalent resistance and leakage reactance referred to primary and secondary 4 total ohmic losses 5 voltage applied to hv side

```
clc;
P=33000; // rated power of transformer
E1=2200; // primary voltage
E2=220; // secondary voltage
k=E2/E1; // turn's ratio
r1=2.4; //primary winding resistance in ohm
x1=6; // primary winding reactance in ohm
r2=0.03; //secondary winding resistance in ohm
x2=0.07; //secondary winding reactance in ohm
r12=r1*k^2; //primary resistance referred to
   secondary
x12=x1*k^2; //primary reactance referred to
   secondary
printf('primary resistance and reactance referred to
    secondary are %f ohm and %f ohm\n',r12,x12);
r21=r2/k^2; //secondary resistance referred to
   primary
x21=x2/k^2; //secondary reactance referred to
   primary
printf('secondary resistance and reactance referred
   to primary are %f ohm and %f ohm\n',r21,x21);
re1=r1+r21;
xe1=x1+x21;
printf('equivalent resistance and reactance referred
    to primary are %f ohm and %f ohm\n',re1,xe1);
re2=r2+r12;
xe2=x2+x12;
printf('equivalent resistance and reactance referred
    to secondary are %f ohm and %f ohm\n',re2,xe2);
Ip=P/E1;
printf('primary full load current is %f A\n',Ip);
Is=P/E2;
printf('secondary full load current is %f A\n',Is);
O=Ip^2*re1;
printf('ohmic losses at full load is %f W\n',O);
Ils=160; // secondary side load current
Ilp=Ils*k; // primary side load current
Ze1=sqrt(re1^2+xe1^2);
```

```
31 V=Ilp*Ze1;
32 printf('Voltage applied to h.v side in order to
      obtain 160A short circuit cirrent in low voltage
      winding is %f V\n',V);
33 Pi=Ilp^2*re1;
34 printf('power input is %f W',Pi);
```

Scilab code Exa 1.9 finding secondary terminal voltage

```
1  clc;
2  P=10000; //rated power of transformer
3  E1=2500; // rated primary side voltage
4  E2=250; // rated secondary side voltage
5  // initialising primary side parameters
6  r1=4.8; // primary resistance in ohm
7  x1=11.2; // primary leakage reactance in ohm
8  //initialising secondary side parameters
9  r2=0.048; // secondary resistance in ohm
10 x2=0.112; // secondary leakage reactance in ohm
11 k=E2/E1; // turn's ratio1
12 z=5+%i*3.5;
13 re2=r2+r1*k^2; //resistance referred to secondary
14 xe2=x2+x1*k^2; //reactance referred to secondary
15 ze2=re2+%i*xe2;
16 zt=z+ze2; // total load on secondary
17 Z=abs(zt);
18 I2=E2/Z; // load current on secondary
19 disp ('case a');
20 V2=round(I2*abs(z));
21 printf('secondary terminal voltage is %f V\n',V2 );
22 disp ('case b');
23 pf=0.8; // power factor
24 I2l=P/E2; // rated current of secondary side
25 VD=I2l*(re2*pf+xe2*sqrt(1-pf^2)); // voltage drop in
     transformer leakage impedance
```

```
26 Vt=E2-VD;
27 printf('secondary terminal voltage is %f V',Vt)
```

Scilab code Exa 1.10 finding primary current secondary terminal voltage power factor power output and efficiency

```
1
2 clc;
3 E1=250;// voltage on low tension side
4 E2=2500; // voltage on high tension side
5 k=E2/E1; //turns ratio
6 Z=380+230*%i; // given load connected to high
     tension side
7 Zl=Z/k^2; // load referred to low tension side
8 zl=0.2+0.7*%i; // leakage impedance of transformer
9 zt=Zl+zl; // total series impedance
10 ztm=abs(zt); // magnitude of total series impedance
11 I1=E1/zt;
12 I1m=abs(I1); // magnitude of primary load current
13 I2=I1m/k; // secondary load current
14 vt=5*abs(Z);
15 printf('secondary terminal voltage is %f V\n',vt);
16 R=500; // shunt branch resistance
17 X=250; // shunt branch leakage reactance
18 Ic=E1/R; // core less component of current
19 Im=E1/(%i*X); // magnetizing component of current
20 Ie=Ic+Im;// total exciting current
21 It=I1+Ie;// total current on low tension side
22 Itm=abs(It);
23 printf('primary current is %f A\n',Itm);
24 pf=cos(atan(imag(It),real(It)));
25 printf('power factor is %f lagging\n',pf),
26 lpf=real(Z)/abs(Z);
27 op=vt*I2*lpf;
28 printf('output power is %f W\n',op);
```

```
pc=Ic^2*R; // core less power
poh=I1m^2*real(zl); // ohmic losses
pin=E1*Itm*pf; // input power
n=(op/pin)*100; // efficiency
printf('efficiency of transformer is %f percent',n);
```

Scilab code Exa 1.11 determining parameters of equivalent circuit referred to l v and h v sides

```
clc;
p=10000; // rated output of transformer
E1=2500; // primary side rated voltage
E2=250; // secondary side rated voltage
k=E2/E1; // turn's ratio
// initialising results of open circuit results on l
   .v side
Vo=250; //open circuit voltage
Io=1.4; // no load current
Po=105; // open circuit voltage
// initialising the results of short circuit results
    on h.v side
Vsc=104; // short circuit voltage
Isc=8; // short circuit current
Psc=320; // power dissipated
theta=Po/(Vo*Io); // no load power factor
Ic=Io*theta; // core less component of current
Im=Io*sqrt(1-theta^2); // magnetising component of
   current
Ro=round(Vo/Ic); // shunt branch resistance
Xo=round(Vo/Im); // shunt branch impedance
Zsc=Vsc/Isc; // short circuit impedance
reh=Psc/Isc^2; // total transformer resistance
xeh=sqrt(Zsc^2-reh^2); // total transformer leakage
   impedance
// equivalent circuit referred to l.v side
```

```
23 rel=reh*k^2;
24 xml=xeh*k^2;
25 printf('shunt branch resistance and reactance is %f
      ohm and %f ohm\n',Ro,Xo);
26 printf('value of transformer resistance and leakage
      reactance referred to l.v side is %f ohm and %f
      ohm\n',rel,xml);
27 // equivalent circuit referred to h.v side
28 Rch=Ro/k^2;
29 Xmh=Xo/k^2;
30 printf('shunt branch resistance and reactance
      referred to h.v side is %f ohm and %f ohm\n',Rch,
      Xmh);
31 printf('value of transformer resistance and leakage
      reactance referred to h.v side is %f ohm and %f
      ohm\n',reh,xeh);
```

Scilab code Exa 1.12 determining equivalent circuit parameters referred to h v side and its efficiency

```
1  clc;
2  P=200000; // rated power output of transformer
3  E1=11000; // primary side voltage
4  E2=400; // secondary side voltage
5  // initialising the results of the open circuit test
       performed on l v side
6  Vo=400; // open circuit voltage in V
7  Io=9; // no load current in A
8  Po=1500; // core loss in W
9  // initialising the results of short circuit test
      performed on h v side
10 Vsc=350; // voltage applied in short circuit test
11 Isc=P/(3*E1); // short circuit current
12 Psc=2100; // power dissipated in short circuit test
13 E2p=E2/sqrt(3); // per phase voltage
```

```
pop=Po/3; // per phase core loss
Ic=pop/E2p; // core loss current
Im=sqrt(Io^2-Ic^2); // magnetising component of
   current
R=E2p/Ic; // core loss resistance in ohm
X=E2p/Im; // magnetizing reactance
Rh=R*(E1/E2p)^2; // core loss resistance referred to
    h v side
Xh=floor(X*(E1/E2p)^2); // magnetizing component
   referred to h v side
printf('coreloss resistance and magnetizing
   reactance referred to h v side is %f ohm and %f
   ohm\n ',Rh,Xh);
Pscp=Psc/3; // ohmic loss per phase
Z=Vsc/Isc; // total impedance of transformer
Re=Pscp/Isc^2; // Total resistance of transformer
   refrred to high voltage side
Xe=sqrt(Z^2-Re^2); // total leakage impedance of
   transformer  referred to h v side
printf('transformer resistance and leakage impedance
    referred to h v side are %f ohm and %f ohm\n',Re
   ,Xe);
n=(1-(pop+Pscp/2^2)/(P/6+pop+Pscp/2^2))*100; //
   efficiency at half load
printf('efficiency at half load is %f percent',n);
```

Scilab code Exa 1.14 p u value of leakage impedance exciting current referred to l v and h v sides

```
clc;
p=20000; // rated power of transformer
vbh=2500; // base voltage in volts for h. v. side
vbl=250; // base voltage in volts for l. v. side
ibh=p/vbh; // base current in Ampere for h. v. side
zbh=vbh/ibh; // base impedance in ohm
```

```
ze=2.6+4.3*%i; // equivalent leakage impedance
   referred to h. v. side in ohm
zepu=ze/zbh; // per unit value in ohm
disp('Per unit value of equivalent leakage impedance
    referred to h. v. side is');
disp(zepu);
k=vbl/vbh; // turn's ratio
zel=ze*k^2; //  equivalent leakage impedance
   referred to l. v. side in ohm
ibl=p/vbl; //  base current in Ampere for l. v. side
zbl=vbl/ibl; // base impedance for l. v. side
zelpu=zel/zbl; // per unit value in ohm
disp('Per unit value of equivalent leakage impedance
    referred to l. v. side is');
disp(zelpu);
zepum=abs(zepu); // magnitude of per unit impedance
vhl=zepum*vbh; // total leakage impedace drop on h.
   v. side
vbl=zepum*vbl; // total leakage impedace drop on l.
   v. side
printf('Total leakage impedance drop on h. v. side
   and l. v. side are %f V and %f V respectively\n',
   vhl,vbl);
Ieh=4.8; // exciting current in Ampere
Iepu=Ieh/ibh; // p u value of exciting current
   referred to h. v. side
printf('Per unit value of exciting current referred
   to h. v. side is %f p.u. \n',Iepu);
Iel=Ieh/k;  // exciting current referred to l. v.
   side
Ielpu=Iel/ibl; // p u value of exciting current
   referred to l. v. side
printf('Per unit value of exciting current referred
   to l. v. side is %f p.u. \n',Ielpu);
```

Scilab code Exa 1.15 determining p u values of circuit parameters referred to both sides

```
1  clc;
2  P=10000; // rated power of transformer
3  vbh=2000; // base voltage for h v side in volts
4  ibh=P/vbh; // base current for h v side in Ampere
5  vbl=200; // base voltage for l v side in volts
6  ibl=P/vbl; // base current for l v side in Ampere
7  k=vbl/vbh; // turns ratio
8  r1=3.6; // resistance of h v side of transformer in
       ohm
9  x1=5.2; //leakage reactace h v side of transformer
       in ohm
10 z=vbh/ibh; // base impedance for h v side'
11 r1pu=r1/z; // p u value for resistance of h v side
       of transformer in ohm
12 x1pu=x1/z; // p u value for leakage reactance of h v
       side of transformer in ohm
13 r2=0.04; //resistance of l v side of transformer in
       ohm
14 x2=0.056; //leakage reactace l v side of transformer
       in ohm
15 // total resistance referred to  h v side
16 re=r1+r2/k^2;
17 repu=re/z;
18 // total leakage impedance referred to h v side
19 xe=x1+x2/k^2;
20 xepu=xe/z;
21 printf('total  per unit resistance and per unit
       leakage impedance referred to  h v side are %f
       and %f\n',repu,xepu);
22 Z=vbl/ibl; // base impedance for l v side
23 Re=r2+r1*k^2; // total resistance referred to  l v
       side
24 Repu=Re/Z;
25 Xe=x2+x1*k^2; //total leakage impedance referred to
       l v side
```

```
26 Xepu=Xe/Z;
27 printf('total  per unit resistance and per unit
      leakage impedance referred to  l v side are %f
      and %f ',Repu,Xepu);
```

Scilab code Exa 1.16 Determining parameters of equivalent circuit diagram

```
1  clc;
2  P=200000; //rated power of transformer
3  E1=4000; // primary side rated voltage
4  E2=1000; // secondary side rated voltage
5  n=0.97; // efficiency
6  pfn=0.25; // power factor at no load
7  pff=0.8; // power factor at full load
8  vr=5; // percentage voltage regulation
9  Pl=((1/n)-1)*200000; // total losses at full load
10 Pf=Pl*0.6; // total losses at 60% of full load
11 Po=(Pl-Pf)/(1-0.36); // ohmic losses
12 Pc=Pl-Po; // core losses
13 re2=(Po/P)*100; // P U total resistance referred to
      l. v. side
14 xe2=(vr-re2*pff)/sqrt(1-pff^2); // P U total leakage
       reactance referred to l. v. side
15 re2=(re2*E2^2)/(100*P); // total resistance in ohms
16 disp('Total resistance referred to l. v. side is ');
17 printf('%f ohm',re2);
18 xe2=(xe2*E2^2)/(100*P); // total leakage reactance
      in ohms
19 disp('Total leakage reactance referred to l. v. side
       is ');
20 printf('%f ohm',xe2);
21 Rc=E2^2/Pc;
22 disp('Coreloss resistance is');
23 printf('%f ohm',Rc);
```

```
24 Ie2=Pc/(E2*pfn); // exciting current in Ampere
25 Ic=Pc/E2; // core loss current
26 Im=sqrt(Ie2^2-Ic^2); // magnetizing component of
      exciting current
27 Xm=E2/Im; // magnetizing reactance
28 disp('Magnetizing reactance is ');
29 printf('%f ohm',Xm);
30 disp('All parameters are known. So, equivalent
      circuit diagram referred to l. v. side can be
      drawn.');
```

Scilab code Exa 1.18 Determining voltage regulation and terminal voltage at different power factor

```
1  clc;
2  P=20000; // rated power of transformer
3  E1=2500; // primary side voltage
4  E2=500; // secondary side voltage
5  r1=8; // primary resistance in ohm
6  x1=17; // primary leakage reactance in ohm
7  r2=0.3; // secondary resistance in ohm
8  x2=0.7; // secondary leakage reactane in ohm
9  k=E2/E1; // turns ratio
10 re2=r2+r1*k^2; // equivalent resistance referred to
      secondary winding
11 xe2=x2+x1*k^2; // equivalent leakage reactance
      referred to secondary winding
12 Il=P/E2; // full load secondary current
13 disp('case a');
14 pf=0.8; // lagging power factor
15 vd=Il*(re2*pf+xe2*sqrt(1-pf^2)); // Voltage drop in
      impedance in volts
16 vt=E2-vd; // secondary terminal voltage
17 printf('secondary terminal voltage for a lagging
      power factor is %f v\n',vt);
```

```
18 vr=((E2-vt)/E2)*100; // voltage regulation
19 printf('voltage regulation for a lagging power
      factor is %f percent\n',vr);
20 disp('case b');
21 pf=0.8; // leading power factor
22 vd=Il*(re2*pf-xe2*sqrt(1-pf^2)); // Voltage drop in
      impedance in volts
23 vt=E2-vd; // secondary terminal voltage
24 printf('secondary terminal voltage for a leading
      power factor is %f v\n',vt);
25 vr=((E2-vt)/E2)*100; // voltage regulation
26 printf('voltage regulation for a leading power
      factor is %f percent\n',vr);
```

Scilab code Exa 1.19 Determining voltage regulation and secondary terminal voltage

```
1 clc;
2 rpu=0.02; // P U equivalent resistance
3 xpu=0.05; // P U equivalent leakage reactance
4 E2=440; // Secondary full load voltage
5 pf=0.8; // lagging power factor
6 vr=rpu*pf+xpu*sqrt(1-pf^2); // P U voltage
      regulation
7 printf('Full load p.u. voltage regulation is %f or
      %f percent\n',vr,vr*100);
8 dv=E2*vr; // change in terminal voltage
9 V2=E2-dv; // secondary terminal voltage
10 printf('Secondary terminal voltage is %f V',V2);
```

Scilab code Exa 1.20 Determining voltage applied to high voltage side

```
1 clc;
```

```
P=10000; // rated power of transformer in VA
E1=2000; // full load primary voltage
E2=400; // full load secondary voltage
k=E2/E1; // turns ratio
pf=0.8; // lagging power factor
// initialising results of short circuit test
v=60; // voltage applied for short circuit test
i=4; // short circuit current
p=100; // power dissipated in short circuit;
reh=p/i^2; // total resistance referred to h v side
zeh=v/i; // total impedance referred to h v side
xeh=sqrt(zeh^2-reh^2); // total leakage reactance
   referred to h v side
rel=reh*k^2; // resistance referred to l v side
xel=xeh*k^2; // reactance referred to l v side
i2l=P/E2; // full load secondary current
vr=i2l*(rel*pf+xel*sqrt(1-pf^2)); // voltage
   regulation
v2=E2+vr; // total voltage of secondary when
   transformer is operating on full load
v1=v2/k; // voltage applied to primary to deliver
   full load
printf('voltage applied to primary to deliver full
   load is %f v',v1);
```

Scilab code Exa 1.21 voltage at sending end of feeder primary terminals active and reactive power power factor

```
clc;
zf=30+120*%i; // feeder impedance
E1=33000; // primary side voltage
E2=3300; // secondary side voltage
k=E2/E1; // turns ratio
P=100000; // load power
pf=0.8;// leading power factor of load
```

```
zl=0.3+1.4*%i; // leakage impedance referred to l v
    side
zfl=zf*k^2; // feeder impedance referred to l v side
vt=3300; // terminal voltage
il=P/(vt*pf); // load current
R=real(zfl)+real(zl); // total resistance referred
    to l v side
X=imag(zfl)+imag(zl); // total impedance referred to
     l v side
vfl=vt+il*(R*pf-X*sqrt(1-pf^2)); // voltage at the
    sending end of feeder referred to l v side
vf=vfl/k; // voltage at the sending end of feeder
printf('Voltage at the sending end of feeder is %f v
    \n',vf);
v2=vt+il*(real(zl)*pf-imag(zl)*sqrt(1-pf^2)); //
    voltage induced in secondary windings
v1=round(v2/k);
printf('voltage at the primary terminals of
    transformer is %f v\n',v1);
ap=il^2*R;
printf('active power loss is %f W\n',ap);
ar=il^2*X;
printf('reactive power loss is %f W\n',ar);
cp=P-P*%i*tan(acosd(pf)*(%pi/180)); // complex power
     at load end in VA
cps=cp+((ap+ar*%i) ); // complex power at feeder end
     in VA
pfs=cos(atan(imag(cps),real(cps)));
printf('power factor at the sending end is %f
    leading',pfs);
```

Scilab code Exa 1.22 input power and power factor

```
clc;
P=10000; // rated power of transformer
```

```
3  E1=2000; // primary side voltage
4  E2=200; // secondary side voltage
5  f=50; // frequency in hertz
6  po=125; // no load power
7  pfo=0.15; // no load power factor
8  zbh=E1^2/P; // base impedance on h v side
9  k=E2/E1; // turns ratio
10 zl=0.5+1*%i; // percent leakage impedance
11 zlh=zl*(zbh*k^2); // percent leakage impedance
     referred to h v side
12 Rc=E1^2/po; // coreloss resistance
13 Io=po/(E1*pfo); // No load current
14 Xm=E1/(Io*sqrt(1-pfo^2)); // magnetizing reactance
15 p=10000; // load power
16 pf=0.8; // power factor of load
17 il=p/(E2*pf); // secondary load current
18 ilp=il*k; // primary load current
19 vp=E1+ilp*(real(zlh)*pf+imag(zlh)*sqrt(1-pf^2));
20 ap=ilp^2*real(zlh); // active power loss in series
     resistance
21 ar=ilp^2*imag(zlh); // reactive power loss in series
      reactance
22 Ap=vp^2/Rc; // active power loss in coreloss
     resistance
23 Ar=vp^2/Xm; // reactive power loss in magnetizing
     reactance
24 cpl=p*(1+%i*tan(acos(0.8))); // complex power at
     load end in VA
25 cpi=(real(cpl)+ap+Ap)+%i*(imag(cpl)+ar+Ar); //
     complex power input to transformer VA
26 printf('real power input to transformer is %f W\n',
     real(cpi));
27 ipf=cos(atan(imag(cpi),real(cpi)));
28 printf('input power factor is %f lagging',ipf);
```

Scilab code Exa 1.24 hysteresis and eddy current losses

```
clc;
pc1=52; // core loss at f=40
f1=40; // frequency in hertz
pc2=90; // core loss at f=60
f2=60; // frequency in hertz
f=[f1 f1^2;f2 f2^2];
pc=[pc1;pc2];
k=inv(f)*pc;
// proportionality constants for hysteresis and eddy
    current losses are
kh=k(1);disp(kh) // proportionality constants for
   hysteresis losses
ke=k(2);disp(ke) //  proportionality constants for
   eddy current losses
// determining both losses at 50 hertz
f=50;
ph=kh*f;
printf('hysteresis losses at 50 hertz is %f W\n',ph)
   ;
pe=ke*f^2;
printf('eddy current losses at 50 hertz is %f W',pe)
   ;
// answer for eddy current losses is misprinted in
   book
```

Scilab code Exa 1.25 total core loss

```

clc;
// subscripts 1 and 2 are used the quantities
   referred to 60 hz and 50 hz frequency
   respectively
v1=220; // rated voltage at 60 hz
```

```
f1=60; // operating frequency
ph1=340; // hysteresis loss at 60 hz
pe1=120; // eddy current loss at 60 hz
v2=230; // rated voltage at 50 hz
f2=50; // operating frequency
s=1.6; // Steinmetz's constant
B=(f1/f2)*(v2/v1); // ratio of flux densities Bm2/
   Bm1
ph2=ceil(ph1*(50/60)*B^s); // hysteresis loss at 50
   hz
pe2=pe1*(f2/f1)^2*(B)^2;// eddy current loss at 50
   hz
pc=ph2+pe2;
printf('Total core loss at 50 hz is %f W',pc);
```

Scilab code Exa 1.26 determining losses and output at 60 hz

```
clc;
// subscripts 1 and 2 are used to refer 50 hz and 60
    hz quantity respectively
// voltage and current is same for both the cases
s=1.6; // Steinmetz's coefficient
poh1=1.6; // percentage ohmic losses
ph1=0.9; // percentage hysteresis losses
pe1=0.6; // percentage eddy current losses
f1=50; // frequency in hertz
f2=60; // frequency in hertz
B=f1/f2 // since voltage level are same for both
   cases ratio of flux densities i.e Bm2/Bm1=f1/f2
ph2=ph1*(f2/f1)*B^s; // percentage hysteresis losses
pe2=pe1*(f2/f1)^2*B^2; // percentage eddy current
   losses
poh2=poh1; // since the voltage and current levels
   are same therefore ohmic losses are same
// for the total losses to be remain same at both
```

```
    the frequencies only ohmic losses can be  varied
15 p=poh1+ph1+pe1; // total losses at 50 hz
16 pc=ph2+pe2; // total core losses at 60 hz
17 pnoh=p-pc; // permissible value for new ohmic losses
18 x=sqrt(pnoh/poh1); // factor by which output at 50
    hz should be multiplied to get the same output at
     60 hz
19 printf('ohmic losses at 60 hz is %f percent\n',poh2)
    ;
20 printf('hysteresis losses at 60 hz is %f percent\n',
    ph2);
21 printf('eddy current losses at 60 hz is %f percent\n
    ',pe2);
22 printf('factor by which output at 50 hz should be
    multiplied to get the same output at 60 hz is %f
    ',x);
```

Scilab code Exa 1.27 finding efficiency and losses

```
1 clc;
2 // subscripts 1 and 2 are used to indicate
    transformer of 11kv at 25hz and 22kv at 50 hz
    respectively
3 // for same current power is doubled therefore P2=2
    P1
4 poh1=1.8; // ohmic losses as a percentage of total
    power P1
5 ph1=0.8; // hysteresis losses as a percentage of
    total power P1
6 pe1=0.3; // eddy current losses as a percentage of
    total power P1
7 poh2=poh1/2; // ohmic losses do not change with
    frequency but changes with voltage since p1=2p1
    we get the result shown
8 // since frequency also gets doubled whwn voltage
```

```
    levels double therefore there is no change in
    flux density i.e is Bm1=Bm2
f1=25; // frequency in hertz
f2=50; // frequency in hertz
ph2=(f2/f1)*ph1; // hysteresis losses are directly
    proportional to frequency
pe2=(f2/f1)^2*pe1; // eddy current losses are
    directly proportional to frequency
// we know p2=2p1
ph2p=ph2/2; //  hysteresis losses as a percentage of
     total power P2
pe2p=pe2/2; // eddy current losses as a percentage
    of total power P2
printf('ohmic losses as a percentage of total power
    at 50 hz is %f percent\n',poh2);
printf('hysteresis losses as a percentage of total
    power at 50 hz is %f percent\n',ph2p);
printf('eddy current losses as a percentage of total
     power at 50 hz is %f percent\n',pe2p);
// efficiency at f1,v1
n1=(1-((poh1+ph1+pe1)/100)/(1+((poh1+ph1+pe1)/100)))
    *100;
printf('efficiency at 25 hz is %f percent\n',n1);
// efficiency at f2,v2
n2=(1-((poh2+ph2p+pe2p)/100)/(1+((poh2+ph2p+pe2p)
    /100)))*100;
printf('efficiency at 50 hz is %f percent',n2);
```

Scilab code Exa 1.28 determining efficiency load voltage regulation and secondary terminal voltage

```
clc;
P=10000; // rated power of transformer in VA
E1=2500; // primary side voltage
E2=250; // secondary side voltage
```

```
5  pf=0.8; // power factor
6  //initialising the results of open circuit test
7  vo=250; // open circuit voltage
8  io=0.8; //no load current
9  po=50; // open circuit voltage
10 // initialising the results of open circuit test
11 vsc=60; // short circuit voltage
12 isc=3; // short circuit current
13 psc=45; // power dissipated in test
14 ifl=P/E1; // full load current on primary side
15 poh=psc*(ifl/isc)^2; // ohmic losses at full load
      current
16 disp('case a(1)');
17 n=(1-(po+(poh/4^2))/(po+(poh/4^2)+(P*pf)/4))*100; //
       efficiency at 1/4 load
18 printf('efficiency at 1/4 load is %f percent\n',n);
19 disp('case a(2)');
20 n=(1-(po+(poh/2^2))/(po+(poh/2^2)+(P*pf)/2))*100; //
       efficiency at 1/2 load
21 printf('efficiency at 1/2 load is %f percent\n',n);
22 disp('case a(3)');
23 n=(1-(po+(poh/1^2))/(po+(poh/1^2)+(P*pf)/1))*100; //
       efficiency at full load
24 printf('efficiency at full load is %f percent\n',n);
25 disp('case a(4)');
26 n=(1-(po+((poh*5^2)/4^2))/(po+((poh*5^2)/4^2)+(P*pf
      *5)/4))*100; // efficiency at 1*1/4 load
27 printf('efficiency at 5/4 load is %f percent\n',n);
28 // let maximum efficiency occurs at x times the
      rated KVA
29 // maximum efficiency occurs when core loss becomes
      equal to ohmic losses
30 x=sqrt(po/poh);
31 nm=(x*P)/1000; // VA output at maximum
32 nmax=(1-(2*po)/(nm*1000*pf+2*po))*100;
33 printf('KVA load at which maximum efficiency occurs
      is %f KVA\n',nm);
34 printf('Maximum efficiency is %f percent\n',nmax);
```

```
// from short circuit test
reh=psc/isc^2; // total resistance referred to h v
   side
zeh=vsc/isc; // total impedance referred to h v side
xeh=sqrt(zeh^2-reh^2); // total leakage reactance
   referred to h v side
er=(ifl*reh)/E1; //p u resistance
ex=(ifl*xeh)/E1; // p u reactance
vr=(er*pf+ex*sqrt(1-pf^2))*100; // p u voltage
   regulation
printf(' p u voltage regulation for lagging power
   factor is %f percent\n',vr);
dv=E2*(vr/100); // voltage drop in series impedance
v2=E2-dv;
printf('secondary terminal voltage for lagging power
    factor of 0.8 is %f v\n',v2);
// voltaage regulation for leading power factor
vr=(er*pf-ex*sqrt(1-pf^2))*100; // p u voltage
   regulation
printf(' p u voltage regulation for leading power
   factor is %f percent\n',vr);
dv=E2*(vr/100); // voltage drop in series impedance
v2=E2-dv;
printf('secondary terminal voltage for leading power
    factor of 0.8 is %f v\n',v2);
```

Scilab code Exa 1.29 Determining transformer core loss ohmic loss and pu value of equivalent resistance

```
clc;
p=20000; // rated capacity of transformer
n=0.98; // efficiency of transformer at full load
   and half load
c=[ 1 1; 1 1/4];
o=[ ((1/n)-1)*p; ((1/n)-1)*(p/2)];
```

```
l=inv(c)*o;
printf('Core losses are %f W\n',l(1));
printf('Ohmic losses are %f W\n',l(2));
re=l(2)/p;
printf('p.u. value of equivalent resistance is %f ',
   re);
```

Scilab code Exa 1.30 determining voltage regulation at given power factor

```
clc;
P=100000; // VA of transformer
nmax=0.98; // maximum efficiency of transformer
pf=0.8; // power factor at which maximum efficiency
   occurs
l=80; // percentage of full load at which maximum
   efficiency occurs
po=P*pf*(l/100); // output at maximum efficiency
pl=((1/nmax)-1)*po; // total losses
pc=pl/2; // core loss
poh=pc; // at maximum efficiency variable losses are
    equal to constant losses
pohl=poh*(100/l)^2; // ohmic losses at full load
z=0.05; // p u leakage impedance
r=pohl/P; // p u resistance
x=sqrt(z^2-r^2); // p u leakage reactance
vr=(r*pf+x*sqrt(1-pf^2))*100; // voltage regulation
printf('Voltage regulation at 0.8 p.f. lagging is %f
    percent ',vr);
```

Scilab code Exa 1.31 Determining efficiency on full load full load power factor and load power factor for zero voltage drop

```
clc;
vdr=2; // percentage full load voltage drop in
    resistance
vdx=4; // percentage full load voltage drop in
    leakage reactance
// full load ohmic losses are equal to 0.02*VA
    rating of transformer which is equal to iron
    losses
n=100/(1+(vdr/100)+(vdr/100));
printf('Efficiency on full load at unity p.f is %f
    percent\n',n);
// maximum voltage drop means voltage regulation is
    also maximum
pf=vdr/sqrt(vdr^2+vdx^2);
printf('Full load power factor at which voltage
    regulation is maximum is %f lagging\n',pf);
pf=vdx/sqrt(vdr^2+vdx^2);
printf(' load power factor at which voltage
    regulation is zero is %f leading',pf);
```

Scilab code Exa 1.32 Determine input power and power factor at a certain load

```
clc;
P=20000; // rated VA of transformer
E1=3300; // rated voltage of primary
E2=220; // rated voltage of secondary
v2=220; // voltage at which load is getting
    delivered
p=14960; // load power in Watts
pf=0.8; // power factor at on load
pc=160; // core loss
pfo=0.15; // power factor at no load
il=p/(v2*pf); // load current
is=P/E2; // rated current of secondary
```

```
12 vr=1 ; // percentage voltage drop of rated voltage
      in total resistance
13 vx=3 ; // percentage voltage drop of rated voltage
      in total leakage reactance
14 re2=(E2*vr)/(is*100); // total resistance referred
      to secondary
15 xe2=(E2*vx)/(is*100); // total leakage reactance
      referred to secondary
16 poh=il^2*re2; // ohmic losses
17 pi=poh+pc+p; // total input power
18 // E2 as a reference
19 i2=il*(pf-%i*sqrt(1-pf^2));
20 E2n=v2+i2*(re2+%i*xe2); // secondary winding voltage
21 io=pc/(pfo*E2); // no load current
22 ic=pc/E2; // core loss current
23 im=sqrt(io^2-ic^2); // magnetizing current
24 I=i2+(ic-im*%i); // total input current, negative
      sign before im indicates that it lags behind E2
      by 90 degree
25 pfi=cos(atan(imag(I),real(I))); // input power
      factor
26 printf('Total input power is %f W \n',pi);
27 printf('Input power factor is %f lagging',pfi);
```

Scilab code Exa 1.33 determining load power factor at minimum secondary terminal voltage and minimum secondary terminal voltage

```
1 clc;
2 P=500000; // VA rating of transformer
3 E2=400; // rated secondary voltage
4 nmax=0.98; // maximum efficiency of transformer
5 l=80; // percentage of full load at which maximum
      efficiency occurs
6 ze2=4.5; // percentage impedance
7 pt=((1/nmax)-1)*P*(l/100); // total losses
```

```
pc=pt/2; // core loss = ohmic loss at maximum
   efficiency
poh=pc; // ohmic loss
pohl=poh*(100/l)^2; // full load ohmic losses
re2=(pohl/P)*100; // percentage resistance
xe2=sqrt(ze2^2-re2^2); // percentage leakage
   reactance
pfl=re2/ze2; // load power factor
vr=re2*pfl+xe2*sqrt(1-pfl^2); // voltage regulation
dv=(E2*vr)/100; // change in terminal voltage
V2=E2-dv; // Secondary terminal voltage
printf('Load power factor at which secondary
   terminal voltage is minimum is %f\n',pfl);
printf('Secondary terminal voltage is %f v',V2);
// answer for total losses is given wrong in the
   book
```

Scilab code Exa 1.34 Determining full day efficiency

```
clc;
P=5000; // rated VA of transformer
pc=40; // core loss , it remains fixed for whole day
poh=100; // ohmic losses
// data for duration 7 A.M to 1 P.M
p1=3000; // power consumed
pf1=0.6 // power factor of load
pk1=p1/pf1; // VA load
poh1=poh*(pk1/P)^2; // ohmic losses for given
   duration
// data for duration 1 P.M to 6 P.M
p2=2000; // power consumed
pf2=0.8 // power factor of load
pk2=p2/pf2; // VA load
poh2=poh*(pk2/P)^2; // ohmic losses for given
   duration
```

```
15 // data for duration 6 P.M to 1 A.M
16 p3=6000; // power consumed
17 pf3=0.9 // power factor of load
18 pk3=p3/pf3; // VA load
19 poh3=poh*(pk3/P)^2; // ohmic losses for given
      duration
20 // data for duration 1 A.M to 7 A.m =no load
21 poht=poh1*6+poh2*5+poh3*7; // energy lost in ohmic
      losses
22 pct=(pc*24); // daily energy lost as core loss
23 ptl=poht+pct; // total energy lost
24 po=p1*6+p2*5+p3*7; // output
25 n=(1-(ptl/(ptl+po)))*100;
26 printf('All day efficiency is %f percent',n);
```

Scilab code Exa 1.35 Determining hysteresis and eddy current losses at given frequencies

```
1 clc;
2
3 //V/f ratio is same for every case hence hysteresis
      losses and eddy current losses can be calculated
      separately
4 // data for column 1
5 vt1=214; // terminal voltage
6 f1=50; // frequency in hz
7 p1=100; // power input in Watts
8 vp1=vt1; // per phase voltage
9 pv1=p1/3; // per phase power
10 pc1=pv1/f1; // core loss per cycle
11 // data for column 2
12 vt2=171; // terminal voltage
13 f2=40; // frequency in hz
14 p2=72.5; // power input in Watts
15 vp2=vt2; // per phase voltage
```

```
16 pv2=p2/3; // per phase power
17 pc2=pv2/f2; // core loss per cycle
18 // data for column 3
19 vt3=128; // terminal voltage
20 f3=30; // frequency in hz
21 p3=50; // power input in Watts
22 vp3=vt3; // per phase voltage
23 pv3=p3/3; // per phase power
24 pc3=pv3/f3; // core loss per cycle
25 // data for column 4
26 vt4=85.6; // terminal voltage
27 f4=20; // frequency in hz
28 p4=30; // power input in Watts
29 vp4=vt4; // per phase voltage
30 pv4=p4/3; // per phase power
31 pc4=pv4/f4; // core loss per cycle
32 // Values of k1 and k2 have been obtained from graph
33 k1=0.39;
34 k2=(pc1-k1)/50;
35 F1=60; //frequency at which losses has to be
      calculated
36 ph1=k1*F1; //per phase hysteresis loss at 60 hz
37 pe1=k2*F1^2; // per phase eddy curent loss at 60 hz
38 pht=3*ph1; // total hysteresis loss
39 pet=3*pe1; // total eddy current loss
40 printf('Total hysteresis and eddy current losses at
      60 hz are %f W and %f W respectively\n',pht,pet);
41 F2=40; //frequency at which losses has to be
      calculated
42 ph2=k1*F2; //per phase hysteresis loss at 40 hz
43 pe2=k2*F2^2; // per phase eddy curent loss at 40 hz
44 pht=3*ph2; // total hysteresis loss
45 pet=3*pe2; // total eddy current loss
46 printf('Total hysteresis and eddy current losses at
      40 hz are %f W and %f W respectively',pht,pet);
```

Scilab code Exa 1.36 Determining reading of wattmeter connected on l v side

```
clc;
E1=230; // primary rating of transformer 1 and
   transformer 2
E2=400; // secondary rating of transformer 1
e2=410; // secondary rating of transformer 2
iv=25; // current feeded by voltage regulator to h v
    series winding
pc=200; // core loss in each transformer
r=1 // assuming resistance of transformer to be 1
x=3*r // as per question leakage reactance is thrice
    of resistance
il1=(iv*E2)/E1; // primary current of transformer 1
il2=(iv*e2)/E1; // primary current of transformer 2
pf=r/sqrt(r^2+x^2); // power factor during short
   circuit
// As per the circuit diagram given in question, by
   Kirchoffs current law current through current
   coil of wattmeter W1 is given by
I=il2-il1;
// 2*core loss is the reading of wattmeter 2
W=E1*I*pf; // reading of wattmeter 1 connected on l
   v side
// in circuit diagram if terminal a is connected to
   c and terminal b is connected to d the current I
   and Io (no load current) flow in the same
   direction of current coil of Wattmeter.Hence its
   reading is increased to
Wt=2*pc+W;
printf('reading of wattmeter as per the connection
   described is %f W\n',Wt);
// in circuit diagram if terminal c is connected to
```

```
    b and terminal d is connected to a the current I
    and Io (no load current) flow in the opposite
    direction through current coil of Wattmeter.Hence
     its reading is decreased to
Wt=2*pc-W;
printf('reading of wattmeter as per the connection
    described is %f W',Wt);
```

Scilab code Exa 1.37 Determine leakage impedance per phase in ohm and p u system

```
clc;
E1=3300; // rated phase voltage of primary of a
    three phase transformer
v=360; // voltage injected in open delta h v winding
     to circulate full load current
vph=v/3; // voltage across each phase
P=300; // rated KVA of transformer
Pph=P/3; // KVA per phase
Iph=(Pph*1000)/E1; // per phase current
z=vph/Iph;
printf('Per Phase leakage impedance is %f ohms\n',z)
    ;
zb=E1/Iph; // base impedance
zpu=z/zb;
printf('leakage impedance per phase in per unit
    system is %f p.u',zpu);
```

Scilab code Exa 1.38 Determine power transformed power conducted power output and auto transformer efficiency at same power factor

```
clc;
P=20000; // rated VA of transformer
```

```
E1=2300; // rated voltage of primary
E2=230; // rated voltage of secondary
pf=0.6; // power factor
n=0.96; // efficiency
ih=P/E1; // rated current of h v winding
il=P/E2; // rated current of l v winding
// As per the connections given in fig 14.1(a), two
   voltages are in series aiding
Et=E1+E2; // output voltage of autotransformer
disp('case a');
// By Kirchoffs law at point b , supply current is
   given by
I=il+ih;
Pa1=Et*il; // VA rating of autotransformer
Po1=(Pa1/1000); // power output at full load unity
   power factor
Pt1=(E2*il)/1000; // power transformed
Pc1=(Po1-Pt1); // power conducted
printf('For the given connection, output power is %f
    kW\n',Po1);
printf('For the given connection, transformed power
   is %f kW\n',Pt1);
printf('For the given connection, conducted power is
    %f kW\n',Pc1);
disp('case b');
// As per the connections given in fig 14.1(b), two
   voltages are in series opposition
Et=E1-E2; // output voltage of autotransformer
// By Kirchoffs law at point b , supply current is
   given by
I=il-ih;
Pa2=E1*I; // VA rating of autotransformer
Po2=Pa2/1000; // power output at full load unity
   power factor
Pt2=(E2*il)/1000; // power transformed
Pc2=(Po2-Pt2); // power conducted
printf('For the given connection, output power is %f
    kW\n',Po2);
```

```
31 printf('For the given connection, transformed power
      is %f kW\n',Pt2);
32 printf('For the given connection, conducted power is
      %f kW\n',Pc2);
33 pl=((1/n)-1)*P*pf; // losses in 2-winding
      transformer
34 // autotransformer operates at rated current and
      rated voltage so efficiency and losses remain
      constant
35 disp('Efficiency for case a');
36 n1=(1-(pl/(Po1*1000*pf+pl)))*100;
37 printf('Efficiency of autotransformer for %f VA is
      %f percent\n',Po1,n1);
38 disp('Efficiency for case b');
39 n2=(1-(pl/(Po2*1000*pf+pl)))*100;
40 printf('Efficiency of autotransformer for %f VA is
      %f percent',Po2,n2);
```

Scilab code Exa 1.39 Determine current in various parts of circuit

```
1 clc;
2 // connections have been made in fig 1.42 in book to
      suit voltage requirement of 3000V, 3500V and
      1000V.
3 E1=1000; // primary winding of transformer
4 E2=2000; // secondary winding of transformer
5 E3=500; // tertiary winding of transformer
6 l1=1050; // load in KVA across 3500 V
7 l2=180; // load in KVA across 1000 V
8 i1=(l1*1000)/(E1+E2+E3); // current through load of
      1050 KVA
9 i2=(l2*1000)/(E1); // current through load of 180
      KVA
10 kt=l1+l2; // Total KVA load supplied
11 I=(kt*1000)/(E1+E2);
```

```
12 printf('current through %f KVA load is %f A\n',l1,i1
   );
13 printf('current through %f KVA load is %f A\n',l2,i2
   );
14 printf('current drawn from supply is %f A',I);
```

Scilab code Exa 1.40 Determine KVA output KVA transformed and KVA conducted of auto transformer

```
1  clc;
2  E1=2500; // primary side voltage
3  E2=250; // secondary side voltage
4  P=10000; // rated VA of transformer
5  // to achieve a voltage level of 2625, two equal
      parts of 125 V each of secondary winding are
      connected in parallel with each other and in
      series with primary winding
6  Eo=E1+E2/2; //  desired output of autotransformer
7  il=P/E2; // rated current of l v winding
8  i=2*il; // Total output current
9  K=(i*Eo)/1000; // Auto transsformer KVA rating
10 ip=P/E1; // rated current of h v winding
11 I=i+ip; // current drawn from supply
12 Pt=(i*(E2/2))/1000; // KVA transformed
13 Pc=K-Pt; // KVA conducted
14 printf('KVA output of autotransformer is %f KVA\n',K
   );
15 printf('KVA transformed is %f KVA\n',Pt);
16 printf('KVA conducted is %f KVA',Pc);
```

Scilab code Exa 1.41 determining currents in various branch of autotransformer

```
clc;
E1=440; // primary supply voltage
E2=380; // voltage at which load at secondary
   terminal is being supplied
l1=40000; // power rating of load in watts
pf=0.8; // lagging power factor
I2=l1/(sqrt(3)*E2*pf);
// per phase KVA input=per phase KVA output
I1=(E2/E1)*I2;
In=I2-I1;
printf('Current in primary branch is %f A\n',I1);
printf('current in secondary branch is %f A\n',I2);
printf('current between neutral and tapping points
   is %f A',In);
```

Scilab code Exa 1.42 Finding primary current and primary input

```
clc;
// From fig 1.45
N1=1000; // no of turns on primary
N2=400; // no. of turns on secondary
n2=300; // no. of turns across points A and B
l1=600; // a load of 600 KW connected between points
    A and C
l2=60+60*%i; // load connected between points A and
   B
E=30000; // primary supply voltage
vac=E*(N2/N1); // secondary side voltage
I1=(l1*1000)/vac; // current through load of 600 KW
vab=(vac/N2)*n2; // volatge across pints A and B
I2=vab/l2 ; // load current through load of 60+60i
iba=I1+I2; // current through section Ab of winding
mfs=iba*n2+I1*(N2-n2); // seconadry mmf
ip=mfs/N1;
printf('primary current is %f%fi A\n',real(ip),imag(
```

```
    ip));
17 Pi=(E*abs(ip)*cos(atan(imag(ip),real(ip))))/1000;
18 printf('primary power input is %f KW\n',Pi);
19 pf=cos(atan(imag(ip),real(ip)))
20 printf('power factor at primary terminal is %f
    lagging',pf)
```

Scilab code Exa 1.43 Finding current in three section of autotransformer

```
1  clc;
2  E=400; // supply voltage
3  l1=200; // load connected across 75% tapping
4  l2=400; // load connected between 25% and 100%
     tapping
5  t1=25; // 25% tapping point
6  t2=50; // 50% tapping point
7  t3=75; // 75% tapping point
8  V2=(t3/100)*E; // voltage across 200 ohm load
9  I2=V2/l1; // current through 200 ohm load
10 I1=(V2*I2)/E;
11 // from fig.(1.46 b), KCL at point d gives
12 idb=I2-I1;
13 // same secondary voltage is applied against load of
     400 ohm
14 I2=V2/l2; // current through 400 ohm load
15 I1=(V2*I2')/E;
16 // from fig (1.46 c), KCL at point c gives
17 ica=I2-I1;
18 // superimposing the currents of above results
     current in three portion of winding can be known
19 icd=ica;
20 disp('current in section cd of winding is')
21 printf('%f A\n',icd);
22 ibc=I1;
23 disp('current in section bc of winding is')
```

```
24 printf('%f A\n',ibc);
25 iab=idb+I1;
26 disp('current in section ab of winding is')
27 printf('%f A\n',iab);
```

Scilab code Exa 1.44 voltage and current rating KVA rating efficiency percentage impedance regulation and short circuit current on each side

```
1  clc;
2  P=100000; // VA rating of two winding transformer
3  E1=2000; // rated voltage of h v side
4  E2=200; // rated voltage of l v side
5  l=2.5; // percentage of loss in two winding
       transformer
6  vr=3; //  percentage of voltage regulation in two
       winding transformer
7  z=4; //  percentage of leakage impedance in two
       winding transformer
8  ih=P/E1; // full load current of h v side
9  il=P/E2; // full load current of l v side
10 V1=E1; // rated voltage on l v side of
       autotransformer
11 V2=E1+E2; // rated voltage on h v side of
       autotransformer
12 Il=il+ih; // rated current on l v side of
       autotransformer
13 printf('Rated voltage on l v and h v side of
       autotransformer are %f v and %f v respectively\n,
       ',V1,V2);
14 printf('Rated current on h v and l v side of
       autotransformer are %f A and %f A respectively\n,
       ',il,Il);
15 k=E1/V2; // turns ratio for auto transformer
16 K=((1/(1-k))*P)/1000;
17 printf('Rated KVA of autotransformer is %f KVA\n',K)
```

```
    ;
18 pl=(1-k)*l; //percent full load losses in
    autotransformer
19 n=100-pl;
20 printf('Efficiency of auto transformer is %f percent
    \n',n);
21 Z=(1-k)*z;
22 printf('Percentage impedance as an auto transformer
    is %f \n',Z);
23 VR=(1-k)*vr;
24 printf('percentage voltage regulation as an auto
    transformer is %f \n',VR);
25 Is=(1/(1-k))*(100/z); // short circuit p u current
26 Ish=(Is*il)/1000;
27 printf('Short circuit of auto transformer on h v
    side is %f KA \n',Ish);
28 Isl=(Is*Il)/1000;
29 printf('Short circuit of auto transformer on l v
    side is %f KA \n',Isl);
```

Scilab code Exa 1.45 Determining load voltage at given power factors

```
1 clc;
2 v1=10; // voltage applied to primary when secondary
    is short circuited
3 ip=60; // primary current when secondary is short
    circuited
4 k=0.8; // turns ratio
5 E1=250; // input voltage for load voltage has to be
    calculated
6 E2=200; // rated voltage of secondary
7 il=100; // load current
8 pfo=0.24; // power factor during short circuit test
9 f=(1-k)^2/k^2; // factor by which secondary
    impedance has to be multiplied for referring it
```

```
    to primary
// ze1=z1+f*z2 therefore by ohm s law
ze1=v1/ip; // total impedance referred to primary
re1=ze1*pfo; // total resistance referred to primary
xe1=ze1*sqrt(1-pfo^2); // total leakage reactance
    referred to primary
disp('case a');
pf=0.8; //  lagging power factor of load
Ip=(E2*il)/E1; // current in primary due to load
    current
v2=(E1-Ip*(re1*pf+xe1*sqrt(1-pf^2)))*k;
printf('Secondary terminal voltage at %f lagging
    power factor is %f v\n',pf,v2);
disp('case b')
pf=1; // unity power factor
v2=(E1-Ip*(re1*pf+xe1*sqrt(1-pf^2)))*k;
printf('Secondary terminal voltage at unity power
    factor is %f v',v2);
```

Scilab code Exa 1.46 Finding ratio of full load KVA delivered to sum of individual KVA ratings

```
clc;
r1=9 ; // ratio of reactance to resistance for
    transformer 1
r2=3 ; // ratio of reactance to resistance for
    transformer 2
d=atand(r1)-atand(r2); // differene between angles
    of transformer's leakage impedance
// leakage impedance of both transformers are equal
    z1=z2, threefore currents in both transformers
    are equal that is i1=i2;
I=1/cos((d/2)*(%pi/180)); // ratio of numerical sum
    of i1 and i2 to phasor sum of i1 and i2
k=cos((d/2)*(%pi/180));
```

```
8 printf('ratio of full load KVA delivered to sum of
    both transformers KVA ratings is %f',k);
```

Scilab code Exa 1.48 Determining greatest load that can be put across parallel combination of transformers and secondary terminal voltage

```
1  clc;
2  P=400000; // rated KVA of transformer
3  P1=11000; // rated primary voltage
4  S2=6600; // rated secondary voltage
5  v1=360; // voltage recorded during short circuit of
     l v winding for first transformer
6  p1=3025; // power dissipated during short circuit of
     l v winding for first transformer
7  v2=400; // voltage recorded during short circuit of
     l v winding for second transformer
8  p2=3200; // power dissipated during short circuit of
     l v winding for second transformer
9  v3=480; // voltage recorded during short circuit
     test of l v winding third transformer
10 p3=3250; // power dissipated during short circuit of
     l v winding for third transformer
11 l1=(P+(v1/v2)*P+(v1/v3)*P)/1000;
12 printf('The greatest load that can be put on the
    transformers is %f KVA\n',l1);
13 is=P/S2; // secondary rated current
14 // transformer 1 is fully loaded , its carries full
    load current
15 re2=p1/is^2; // total resistance referred to
    secondary side
16 vd=is*re2; // voltage drop for transformer 1
17 E2=S2-vd;
18 printf('Secondary terminal voltage is %f v',E2);
```

Scilab code Exa 1.49 1 How transformers share a given load 2 Determine the greatest load that can be supplied by parallel combination of transformers and 3 Determining magnitude of the equivalent leakage impedance under normal loading

```
clc;
disp('case b');
// KVA ratings and leakage impedances for the
   transformers are
k1=100; // KVA rating for transformer 1;
z1=0.02; // p u impedance for transformer 1;
k2=75; // KVA rating for transformer 2;
z2=0.03; // p u impedance for transformer 2;
k3=50; // KVA rating for transformer 3;
z3=0.025; // p u impedance for transformer 3;
disp('case b(1)');
// assumng k1 as a base KVA
S=225; // load which has to be shared by three
   transformers
ze1=z1*100; // percentage impedance for transformer
   1
ze2=(k1/k2)*z2*100; // percentage impedance for
   transformer 2
ze3=(k1/k3)*z3*100; // percentage impedance for
   transformer 3
zt=(1/ze1)+(1/ze2)+1/(ze3); // total percentage
   leakage impedance
s1=S/(ze1*zt);
s2=S/(ze2*zt);
s3=S/(ze3*zt);
printf('load shared by transformer 1,2 and 3 are %f
   KVA, %f KVA and %f KVA respectively\n',s1,s2,s3);
disp('case b(2)');
// since transformer 1 has lowest leakage impedance
```

```
    among three, it will be loaded to its rated
    capacity
23 S=k1*ze1*zt ; // total KVA shared
24 printf('greatest load that can be shared by
    transformers is %f KVA\n',S);
25 disp('case b(3)');
26 // for successful parallel operation of transformer
    all the three leakage impedances based on their
    KVA rating should be equal. Since magnitude of
    leakage impedance of transformer1 is fixed that
    is 2 percent z2=z3=2 percent
27 ze1=2;
28 ze2=ze1*(k1/k2);
29 ze3=ze1*(k1/k3);
30 zt=(1/ze1)+(1/ze2)+(1/ze3); // Total leakage
    impedance
31 printf('magnitude of equivalent leakage impedance is
    %f percent\n',zt);
```

Scilab code Exa 1.50 1 How transformers share a given load 2 Determine the secondary terminal voltage for part1

```
1 clc;
2 // shorts circuits test on two transformers gave
    the following results
3 P1=200000; // KVA of transformer 1
4 V1=3; // percentage rated voltage
5 pf1=0.25; // lagging power factor for Xmer1
6 P2=500000; // KVA of transformer 2
7 V2=4; // percentage rated voltage
8 pf2=0.3 // lagging power factor for Xmer2
9 l=560000; // load connected across parallel
    combination of transformers in KW
10 pf=0.8; // power factor of load
11 E1=11000; // Rated primary voltage
```

```
E2=400; // Rated secondary voltage
ib=1; // base current
vb=1; // base voltage
z1=(V1/100)*1; // base impedance
Ze1=z1*(pf1+%i*sqrt(1-pf1^2)); // p u impedance
z2=(V2/100)*1; // base imedance
Ze2=z2*(pf2+%i*sqrt(1-pf2^2)); // p u impedance
pb=P2; // base for p u conversion
ze1=(pb/P1)*Ze1;
ze2=(pb/P2)*Ze2;
zt=ze1+ze2; // total impedance
s=1/pf; // KVA rating of transformer
S=s*(pf-%i*sqrt(1-pf^2)); // complex form of KVA
   rating
s1=(S*ze2)/(zt); // KVA shared by first transformer
PF1=cos(atand(imag(s1),real(s1))*(%pi/180));
s1w=round((abs(s1)*PF1)/1000);
printf('KW load shared by transformer 1 is %f at %f
   power factor lagging\n',s1w,PF1);
s2=(S*ze1)/(zt); // KVA shared by first transformer
PF2=cos(atand(imag(s2),real(s2))*(%pi/180));
s2w=ceil((abs(s2)*PF2)/1000);
printf('KW load shared by transformer 2 is %f at %f
   power factor lagging\n',s2w,PF2);
i1=abs(s1)/P1; // p u current shared by transformer
   1
i2=abs(s2)/P2; // p u current shared by transformer
   2
vr=i1*(real(Ze1)*PF1+imag(Ze1)*sqrt(1-PF1^2)); //
   voltag regulation
dv=E2*vr; // change in terminal voltage
Vt=E2-dv; // terminal voltage
printf('Secondary terminal voltage is %f v',Vt);
```

Scilab code Exa 1.51 Determining largest KVA that can be shared by parallel combination of transformer without overloading

```
clc;
k1=1000; // Rated KVA of transformer1
k2=500; // Rated KVA of transformer2
ze1=0.02+%i*0.06; // p u leakage impedance of
   transformer 1
ze2=0.025+%i*0.08; // p u leakage impedance of
   transformer 2
zb=1000; // base impedance
Z1=(zb/k1)*ze1; // impedance of transformer 1
Z2=(zb/k2)*ze2; // impedance of transformer 2
zt=Z1+Z2; // total impedance
S=k1*(abs(zt)/abs(Z2)); // since ze1<ze2 transformer
    1 reaches its rated KVA threrfore load shared by
    transformer 2 is given by
l2=S-k1; // load shared by transformer 2
printf('Largest KVA load that can be loaded on
   parallel combination of transformer is given by
   %f KVA',S);
```

Scilab code Exa 1.52 Determining no load circulating current and ohmic loss caused by it and no load terminal voltage

```
clc;
// two transformers are connected in parallel and
   has following data
P1=100; // rated KVA of transformer 1
E11=6600; // rated primary voltage for transformer 1
E21=230; // rated secondary voltage for transformer
   1
z1=1.5+4*%i // percentage leakage impedance for
   transformer 1
P2=200; // rated KVA of transformer 2
```

```
E12=6600; // rated primary voltage for transformer 2
E22=220; // rated secondary voltage for transformer
   2
z2=1+5*%i // percentage leakage impedance for
   transformer 2
i1=(P1*1000)/E21; // full load current for
   transformer 1
ze1=(z1/100)*(E21^2/(P1*1000)); // leakage impedance
    for transformer 1 in ohm
i2=(P2*1000)/E22; // full load current for
   transformer 2
ze2=(z2/100)*(E22^2/(P2*1000)); // leakage impedance
    for transformer 2 in ohm
io=(E21-E22)/abs(ze1+ze2); // circulating current at
    no load
printf('No load circulating current is %f A\n',real(
   io));
poh=abs(io)^2*(real(ze1)+real(ze2));
printf(' Ohmic losses due to circulting current is
   %f W\n',poh);
vd=abs(io)*abs(ze1); // voltage drop in leakage
   impedance
vt=E21-vd; // secondary terminal voltage
printf('secondary terminal voltage is %f v',vt);
```

Scilab code Exa 1.53 Finding no load circulating current current supplied by each transformer and KVA KW and power factor of each transformer

```
clc;
k1=500000; // rated VA of transformer 1
r1=0.015; // p u resistance of transformer 1
x1=0.05; // p u reactance of transformer 1
s1=405; // secondary no load voltage for transformer
    1
k2=250000; // rated VA of transformer 2
```

```
r2=0.01; // p u resistance of transformer 2
x2=0.05; // p u reactance of transformer 2
s2=415; // secondary no load voltage for transformer
    2
l=750000; // KVA rating of load
pf=0.8; // power factor of load
v=400; // voltage at which load is being delivered
z1=(r1+%i*x1)*(v^2/k1); // impedance for transformer
    1 in ohms
z2= (r2+%i*x2)*(v^2/k2); // impedance for
   transformer 2 in ohms
il=l/v; // load current
zl=v/il; // load impedance
zl=zl*(pf+%i*sqrt(1-pf^2)); // complex form of load
   impedance
zt=z1+z2; // equivalent impedance of both
   transformer
io=(s2-s1)/abs(zt); // circulating current at no
   load
aio=cos(atand(imag(zt),real(zt))*(%pi/180)); //
   power factor
printf('Circulating current at no load is %f A at a
   power factor of %f lag\n',io,aio);
Ia=((s1*z2)+(s1-s2)*zl)/((z1*z2)+(zl*zt));
ia=abs(Ia);
printf('Current shared by transformer 1 is %f A\n',
   ia);
Ib=((s2*z1)-(s1-s2)*zl)/((z1*z2)+(zl*zt));
ib=abs(Ib);
printf('Current shared by transformer 2 is %f A\n',
   ib);
kv1=(ia*v)/1000;
pf1=cos(atand(imag(Ia),real(Ia))*(%pi/180));
kw1=kv1*pf1;
printf('KVA shared by transformer 1 is %f KVA at %f
   lagging power factor\n',kv1,pf1);
printf('KW shared by transformer 1 is %f KW\n',kw1);
kv2=(ib*v)/1000;
```

```
34 pf2=cos(atand(imag(Ib),real(Ib))*(%pi/180));
35 kw2=kv2*pf2;
36 printf('KVA shared by transformer 2 is %f KVA at %f
     lagging power factor\n',kv2,pf2);
37 printf('KW shared by transformer 2 is %f KW\n',kw2);
```

Scilab code Exa 1.54 Determining value of reactance connected in series with transformer B so that load current is equally shared

```
1 clc;
2 z1=0.4+2.2*%i; // leakage impedance referred to
     secondary for transformer 1
3 s1=510; // secondary no load voltage for transformer
     1
4 z2=0.6+1.7*%i; // leakage impedance referred to
     secondary for transformer 2
5 s2=500; // secondary no load voltage for transformer
     2
6 zl=5+3*%i; // load impedance
7 // current shared by both transformers should be
     equal i.e. I1=I2
8 t=(s2*(z1)-(s1-s2)*zl-(s1-s2)*zl)/s1;
9 xn=sqrt(abs(t)^2-real(z2)^2);
10 xe=xn-imag(z2); // external reactance to be added in
     series
11 printf('External reactance connected in series with
     leakage impedance of transformer 2 so that the
     current shared by both transformers are equal is
     %f ohm',xe);
```

Scilab code Exa 1.55 Determining tap setting to maintain rated voltage on secondary side for given loads

```
clc;
k=100; // Kva rating of transformer
disp('case(a)');
l1=90; // KVA rating of load
pf=0.8; // lagging pf of load
z=0.0075+0.09*%i; // p u leakage impedance of
   transformer
l1=l1/k; // load expressed in p u with base KVA=100
vd=l1*(real(z)*pf+imag(z)*sqrt(1-pf^2)); // p u
   voltage regulation
ts=vd*100; // tap setting
printf('Number of turns in the primary winding
   should be tapped down by %f percent\n',ts);
disp('case(b)');
lk=100; // KW rating of load
pf=0.8; // lagging pf of load
l1=lk/pf; // KVA rating of load
z=0.0075+0.09*%i; // p u leakage impedance of
   transformer
l1=l1/k; // load expressed in p u with base KVA=100
vd=l1*(real(z)*pf+imag(z)*sqrt(1-pf^2)); // p u
   voltage regulation
ts=vd*100; // tap setting
printf('Number of turns in the primary winding
   should be tapped down by %f percent\n',ts);
```

Scilab code Exa 1.56 Determining tap setting to maintain given voltage at load terminal

```
clc;
p=11000; // per phase h v side voltage
s=433; // l v side voltage
sp=s/sqrt(3); // per phase l v side voltage
K=10000; // VA rating of star connected load
pf=0.8; // power factor of load
```

```
7  z=0.5+1*%i; // Impedance per lead
8  zh=300+1500*%i; // per phase h v side leakage
       impedance
9  zl=0.2+1*%i; // per phase l v side leakage impedance
10 vl=400; // load voltage
11 k=p/sp; // turns ratio
12 zhl=zh/k^2; // h v side leakage impedance referred
       to l v side
13 zt=zhl+zl+z; // total impedance per phase between
       transformer and seconday load
14 il=K/(sqrt(3)*vl); // per phase load current
15 vd=round(il*(real(zt)*pf+imag(zt)*sqrt(1-pf^2))); //
       voltage drop per phase
16 vlp=vl/sqrt(3); // per phase load terminal voltage
17 E2=vlp+vd; // per phase voltage that must maintained
       l v terminals
18 vb=E2-sp; // voltage boost that tap changer must
       provide
19 ts=round((vb/sp)*100);
20 printf('tap down if the tapped coils are on h v side
       or tap up if the tapped coils are on l v side by
       %f percent',ts);
```

Scilab code Exa 1.57 Calculating primary winding current and line current

```
1  clc;
2  k=5; // Effective turns ratio
3  E1=400; // supply voltage for primary
4  il=10; // load current
5  E2=E1/k; // magnitude of maximum secondary induced
6  E1o=E1+E2; // maximum possibe value of output
       voltage
7  P=(il*E2)/1000; // Rating of secondary winding
8  ip=(il*E2)/E1; // neglecting noload current, primary
```

```
    winding current
I=ip+il;
printf('Total primary line current is %f A',I);
```

Scilab code Exa 1.58 Calculating KVA required to maintain the given voltage

```
clc;
E1=430; // supply voltage
k=100000; // VA rating of load
il=k/(sqrt(3)*E1); // load current
v1=380; v2=460; // range in which voltage at feeder
   end varies
vr=E1-v1; // maximum variation in output side of
   regulator
P=(sqrt(3)*vr*il)/1000;
printf('KVA rating of induction regulator is %f KVA'
   ,P);
```

Scilab code Exa 1.59 Calculating the rating of the primary and secondary winding

```
clc;
V1=400; // supply voltage
E2=50; // induced secondary voltage
l=8; // KW rating of load
pf=0.8; // power factor of load
n=0.85; // efficiency of induction regulator
ip=(l*1000)/(sqrt(3)*pf*n*V1); // input current
vmo=V1-E2; // minimum output voltage
imo=(l*1000)/(sqrt(3)*pf*vmo); // maximum output
   current
```

```
10 ks=(sqrt(3)*E2*imo)/1000; // KVA rating of secondary
     winding
11 Vmo=V1+E2; // maximum output voltage
12 Imo=(l*1000)/(sqrt(3)*pf*Vmo); // minimum output
     current
13 //primary winding has to carry the current induced
     in it by secondary current due to transformer
     action and the difference of input current and
     output current
14 ipm=((Imo*E2)/V1)+ip-Imo; // maximum primary winding
     current
15 kp=(sqrt(3)*V1*ipm)/1000;
16 printf('Rating of primary winding is %f KVA\n',kp);
17 printf('Rating of secondary winding is %f KVA\n',ks)
     ;
```

Scilab code Exa 1.60 Determining the magnitude of maximum induced emf and For supply voltage finding the limit of output voltage and finding the rating of regulator for given load current

```
1  clc;
2  p=10; // number of full pitch coil in stator
3  t=120; // phase spread of coil
4  q=10.5*10^-3; // flux per pole in Weber
5  f=50; // frequency  of induction regulator
6  n=2; // number of turns in each coil;
7  E1=230; // supply voltage
8  il=30; // load current
9  N=p*n; // Total number of turns
10 kw=sin((t/2)*(%pi/180))/((t/2)*(%pi/180)); //
     distribution factor
11 E2=sqrt(2)*%pi*f*N*q*kw; // maximum secondary
     induced EMF
12 Vo1=E1+E2; Vo2=E1-E2; // range of output voltage
13 k=(il*E2)/1000;
```

```
14 printf('Maximum induced voltage is %f v\n',E2);
15 printf('range of output voltage is %f v-%f v\n',Vo2,
      Vo1);
16 printf('KVA rating of induction regulator is %f KVA'
      ,k);
```

Scilab code Exa 1.61 1 Determining self impedances of primary and secondary windings 2 Finding the value of equivalent circuit parameter referred to both sides 3 Determining secondary terminal voltage for given load

```
1  clc;
2  // subscript 1 and 2 indicates h v and l v winding
3  P=10000; // rated VA of transformer
4  E1=2300; // rated voltage
5  E2=230; // rated voltage
6  r1=10; // total resistance
7  r2=0.10; // total resistance
8  l1=40*10^-3 ; l2=4*10^-4; // self-inductances
9  m=10; // mutual inductance
10 k=E2/E1; // turns ratio
11 f=50; // frequency of supply;
12 disp('case 1');
13 L1=(m/k)+l1;
14 printf('Primary self inductance is %f H\n',L1);
15 L2=(m*k)+l2;
16 printf('Secondary self inductance is %f H\n',L2);
17 disp('case b');
18 r21=r2/k^2; // l v side resistance referred to h v
      side
19 l21=l2/k^2; // l v side self inductance referred to
      h v side
20 M1=m/k; // mutual inductance referred to h v side
21 printf('circuit parameters referred to primary
      winding are R1=%f ohm,R2=%f ohm,L1=%f H,L2=%f H
      and Lm1=%f H\n',r1,r21,l1,l21,M1);
```

```
22 r12=r1*k^2; // h v side resistance referred to l v
     side
23 l12=l1*k^2; // h v side self inductance referred to
     l v side
24 M2=m*k; // mutual inductance referred to l v side
25 printf('circuit parameters referred to secondary
     winding are R1=%f ohm,R2=%f ohm,L1=%f H,L2=%f H
     and Lm2=%f H\n',r12,r2,l12,l2,M2);
26 disp('case c');
27 lo=5+5*%i; // load connected to secondary
28 x1=2*%pi*f*l12; // leakage reactance
29 x2=2*%pi*f*l2; // leakage reactance
30 re2=real(lo)+r2+r12; // total resistance after
     referring to l v side
31 xe2=imag(lo)+x1+x2; //  total reactance after
     referring to l v side
32 Z=re2+%i*xe2; // total impedance
33 vt=(E2/abs(Z))*abs(lo);
34 printf('Secondary terminal voltage is %f v',vt);
```

Scilab code Exa 1.62 1 Determining self inductances of hv and lv windings 2 Calculating mutual inductance between h v and l v windings 3 Finding coupling factors k1 and k2 for both windings and coefficient of coupling

```
1 clc;
2 n1=590; // primary side turns
3 n2=295; // secondary side turns
4 V1=230; // voltage source from which h v side was
     energised during test
5 io1=0.35; // no load current for when h v side is
     energised
6 V2=110; // induced voltage  across open circuited l
     v winding due energised h v side
7 v2=115; // voltage source from which l v side was
     energised during test
```

```
io2=0.72; // no load current for when l v side is
    energised
v1=226; // induced voltage across open circuited  h
    v winding due energised l v side
f=50; // frequency of supply;
w1=V1/(sqrt(2)*%pi*50); // Maximum value of flux
    linkage with h v winding
L1=w1*(1/(sqrt(2)*io1));
printf('self inductance of h v winding i %f H\n',L1)
    ;
w2=v2/(sqrt(2)*%pi*50); // Maximum value of flux
    linkage with l v winding
L2=w2*(1/(sqrt(2)*io2));
printf('self inductance of l v winding i %f H\n',L2)
    ;
M=(V2/(sqrt(2)*%pi*f))*(1/(sqrt(2)*io1));
printf('mutual inductance between h v and l v
    winding is %f H\n',M);
k1=(n1/n2)*(M/L1); // coupling factor for h v side
k2=(n2/n1)*(M/L2); // coupling factor for l v side
k=sqrt(k1*k2); // coefficient of coupling
printf('coupling factor for h v side is %f\n',k1);
printf('coupling factor for l v side is %f\n',k2);
printf('coefficient of coupling is %f\n',k);
```

Scilab code Exa 1.63 Calculating the current that would flow in the winding 1 when the winding is connected to given supply and given load

```
clc;
L1=4*10^-3; // self indutance of winding 1
L2=6*10^-3; // self indutance of winding 2
M=1.8*10^-3; // mutual inductance of two windings
E1=130; // supply voltage for winding 1
f=500/%pi; // frequency of supply
l=0.2*10^-3; // load connected to winding 2
```

```
// writing voltage in rms form in matrix form V1=r1*I1+jw*L1*I1-jw*m*I2 , V2=-r2*I2-jw*L2*I2+jw*m*I1 to determine I1 and I2
t1=%i*2*%pi*f*L1;
t2=-%i*2*%pi*f*M;
t3=%i*2*%pi*f*M;
t4=-%i*2*%pi*f*l-%i*2*%pi*f*L2; // writing different terms of matrix
s=[t1 t2;t3 t4];
v=[130;0];
i=inv(s)*v; // calculating current in two windings
p=-imag(i(1));
printf('magnitude of current in primary winding is %f A',p);
```

Scilab code Exa 1.64 1 Determining the transformers turns ratio for maximum transfer of power 2 Determining load current voltage and power under maximum transfer of power

```
clc;
r=60; // resistive load which is coupled to electronic circuit
v=5; R=3000; // electronic circuit represented by a voltage source in series with a internal resistance
// for maximum transfer of power, load resistance referred to primary must be equal to internal resitance of source
k=sqrt(R/r);
printf('turns ratio for maximum transfer of power is %f\n',k);
// referrig all quantities to load side
vl=v/k; // source voltage referred to load side
Rl=R/k^2; // source referred to load side
il=(vl/(Rl+r))*1000 ; // load current
```

```
11 vld=(il*r)/1000; // load voltage
12 p=(il^2*r)/1000; // load power
13 printf('load voltage is %f v\n',vld);
14 printf('load current is %f mA\n',il);
15 printf('load power is %f mW\n',p);
```

Scilab code Exa 1.65 Finding turns ratio for maximum transfer of power 2 Computing the load voltage at given frequencies

```
1  clc;
2  r1=20; // resistance of primary side
3  l1=1*10^-3; // leakage inductance of primary side
4  r2=0.5; // resistance of secondary side
5  l2=0.025*10^-3; // leakage inductance of secondary
     side
6  m=0.2; //  mutual inductance
7  l=50; // load in ohm connected to transformer
8  v=5; // voltage source
9  R=2000; // internal resistance of source
10 k=sqrt(R/l); // turns ratio for maximum power
     transfer
11 printf('Turns ratio is %f\n',k);
12 r21=0.5*k^2; // secondary resistance referred to
     primary
13 l21=l2*k^2; // secondary inductance referred to
     primary
14 lp=l*k^2; // load resistance referred to primary
15 rs=r1+r21+lp+R; // total series resistance
16 rp=((R+r1)*(R+r1))/rs; // equivalent resistance
17 leq=l1+l21; // equivalent inductance
18 f1=100; // frequency in hertz at which load voltage
     has to be calculated
19 Vl=(1/k)*(R/rs)*v*(1/(sqrt(1+(rp/(2*%pi*f1*m))^2)));
20 printf('load voltage at %f hz is %f v\n',f1,Vl);
21 f2=5000; // frequency in hertz at which load voltage
```

```
    has to be calculated
Vl=(1/k)*(R/rs)*v;
printf('load voltage at %f hz is %f v\n',f2,Vl);
f3=15000; // frequency in hertz at which load
   voltage has to be calculated
Vl=(1/k)*(R/rs)*(1/(sqrt(1+((2*%pi*f3*l1)/rs)^2)))*v
   ;
printf('load voltage at %f hz is %f v\n',f3,Vl);
```

Scilab code Exa 1.66 Computing secondary line voltage line current and output KVA for the given connection

```
clc;
// Answer for case c , secondary line voltage is
   given wrong in book
k=12; // per phase turns ratio
E1=11000; // supply voltage from feeder line
ip=20; // primary line current
disp('case a:star-delta');
vph=E1/sqrt(3); // primary phase voltage
iph=ip; // phase current on primary
sph=vph/k; // secondary phase voltage
vls=sph;
printf('Line voltage on secondary is %f v\n',vls);
isph=k*iph; // phase current on secondary
isl=sqrt(3)*isph;
printf('line current on secondary is %f A\n',isl);
Kv=(3*sph*isph)/1000;
printf('Output KVA is %f KVA\n',Kv);
disp('case b:delta-star');
vph=E1; // primary phase voltage
iph=ip/sqrt(3); // phase current on primary
sph=vph/k; // secondary phase voltage
vls=sqrt(3)*sph;
printf('Line voltage on secondary is %f v\n',vls);
```

```
isph=k*iph; // phase current on secondary
isl=isph;
printf('line current on secondary is %f A\n',isl);
Kv=(3*sph*isph)/1000;
printf('Output KVA is %f KVA\n',Kv);
disp('case c:delta-delta');
vph=E1; // primary phase voltage
iph=ip/sqrt(3); // phase current on primary
sph=vph/k; // secondary phase voltage
vls=sph;
printf('Line voltage on secondary is %f v\n',vls);
isph=k*iph; // phase current on secondary
isl=sqrt(3)*isph;
printf('line current on secondary is %f A\n',isl);
Kv=(3*sph*isph)/1000;
printf('Output KVA is %f KVA\n',Kv);
disp('case d:star-star');
vph=E1/sqrt(3); // primary phase voltage
iph=ip; // phase current on primary
sph=vph/k; // secondary phase voltage
vls=sqrt(3)*sph;
printf('Line voltage on secondary is %f v\n',vls);
isph=k*iph; // phase current on secondary
isl=isph;
printf('line current on secondary is %f A\n',isl);
Kv=(3*sph*isph)/1000;
printf('Output KVA is %f KVA\n',Kv);
```

Scilab code Exa 1.67 Determining transformer rating and phase and line current on both high and low voltage sides

```
clc;
E1=11000; // line voltage of primary
E2=415; // line voltage of secondary
kw=30; // KW rating of 3 phase induction motor
```

```
5 n=0.9; // efficieny
6 pf=0.833; // power factor at which load is operating
7 Kv=kw/(n*pf); // KVA rating of transformer
8 printf('KVA rating of transformer is %f KVA\n',Kv);
9 ilv=(Kv*1000)/(sqrt(3)*E2); // line current on l v
    side
10 //secondary is star connected therefore line current
    =phase current
11 printf('Line current on l v side is %f A\n',ilv);
12 printf('Phase current on l v side is %f A\n',ilv);
13 ilp=(Kv*1000)/(sqrt(3)*E1); // line current on h v
    side
14 ipp=ilp/sqrt(3);
15 printf('Line current on h v side is %f A\n',ilp);
16 printf('Phase current on h v side is %f A\n',ipp);
```

Scilab code Exa 1.68 1 Finding power consumed by load 2 KVA rating of transformer 3 Phase and line currents on both h v and l v side

```
1 clc;
2 il=100; // load current
3 pf=0.8;
4 E1=11000; // primary line voltage
5 E2=400; // secondary line voltage
6 p=(sqrt(3)*E2*il*pf)/1000;
7 printf('power consumed by load is %f KW\n',p);
8 k=(sqrt(3)*E2*il)/1000;
9 printf('KVA rating of load is %f KVA\n',k);
10 iph=(k*1000)/(sqrt(3)*11000); // phase current on h
    v side
11 //primary is star connected therefore line current=
    phase current
12 printf('Line current on h v side is %f A\n',iph);
13 printf('Phase current on h v side is %f A\n',iph);
14 ipl=il/sqrt(3);
```

```
15 printf('Line current on l v side is %f A\n',il);
16 printf('Phase current on l v side is %f A\n',ipl);
```

Scilab code Exa 1.69 1 Determining number of primary turns 2 current power factor and power on primary side under no load

```
1  clc;
2  B=1.2; // maximum flux density in core
3  H=600; // magnetic field intensity in A/m
4  d=7.8; // gram density in g/cm^3
5  cl=2; // core loss per kg
6  e=1200; // supply voltage
7  f=50; // frequency of supply voltage
8  t=10; // thickness of core in cm
9  w=40;
10 L=30; // dimensions of core
11 s=0.9; // stacking factor
12 ga=t^2*10^-4; // gross core area in m^2
13 nga=ga*s; // net gross core area in m^2
14 q=nga*B; // maximum flux in core
15 N=(e)/(sqrt(2)*%pi*f*q);
16 printf('Number of turns in primary is %f\n',N);
17 ml=((w+t)+(L+t))*2; // mean flux path in cm
18 mmf=H*(ml/100); // mmf of the core
19 mi=mmf/N; // maximum value of magnetizing current
20 irm=mi/sqrt(2); // rms value of magnetizing current
21 cv=(ml/100)*nga; // core volume
22 wc=cv*d*10^3; // weight of core
23 pc=wc*cl; // total core loss
24 Ic=pc/e; // core loss current
25 io=sqrt(Ic^2+irm^2);
26 printf('No load current on primary side is %f A\n',
     io);
27 pf=Ic/io;
28 printf('No load power factor is %f\n',pf);
```

```
29 pf=e*io*pf;
30 printf('power input at no load is %f W',pf);
```

Scilab code Exa 1.70 Determining magnetizing current for the given figs

```
1  clc;
2  // Three core type transformers are given in fig
       1.80
3  // For first core type transformer
4  im1=4; // magnetizing core
5  e2=100; // emf induced in secondary winding
6  B=1; // maximum flux density in Tesla
7  // mmf is directly proportional maximum flux in core
       i.e im*N(no. of turns)=kq(flux), k is
       proportionality constant
8  // for fig(80(b)),qm2(flux for core transformer 1)=
       qm1(flux for core transformer 2), that is flux in
       both coils in core transformer 2 is qm1/2;
9  //for upper coil im2*N is directly proportional to
       qm1/2
10 //for lower coil Im2*N is directly proportional to
       qm2/2
11 //adding above relation we get im2+Im2=4(magnetizing
       current)
12 Im2=im1/2;
13 im2=Im2; // magnetizing current of each coil is 2 A
14 imt=Im2+im2; //total magnetizing current for
       transformer 2
15 // since flux is same for both transformer, emf
       induced is also same
16 // since flux is same for both transformer, area is
       same , therefore magnetic flux density is also
       same
17 printf('Magnetizing current for transformer 2 is %f
       A\n',imt);
```

```
18 printf('emf induced in secondary for transformer 2
      is %f v\n',e2);
19 printf('Magnetic flux density in transformer 2 is %f
      T\n',B);
20 // for fig (80(c)), qm3=qm1/2
21 // qm1~im1*N,qm3~im3*N; ~-sign of directly
      proportional (assumption)
22 // from above two relations, we get
23 im3=im1/4;
24 B3=B/2;
25 E2=e2/2;
26 printf('Magnetizing current for transformer 3 is %f
     A\n',im3);
27 printf('emf induced in secondary for transformer 3
      is %f v\n',E2);
28 printf('Magnetic flux density in transformer 3 is %f
      T\n',B3);
```

Scilab code Exa 1.71 Determining load voltage load power factor and load power

```
1 clc;
2 P=20; // Rated KVA of transformer
3 E1=250; // rated primary voltage
4 E2=125; // rated secondary voltage
5 r1=0.15; // resistance of primary side
6 x1=0.25; // leakage reactance of primary side
7 r2=0.03; // resistance of secondary side
8 x2=0.04; // leakage reactance of secondary side
9 // given E1=V1(primary terminal voltage)
10 k=E2/E1; // turns ratio
11 ip=(P*1000)/E1; // full load primary current
12 // voltage regulation=0, because E1=V1 therefore
13 pf=-atand(r1,x1); // phase angle between E1 and ip
14 // negative sign indicates that current leads
```

```
    voltage
15 re2=r2/k^2; // secondary resistance referred to
    primary
16 xe2=x2/k^2; // secondary leakage reactance referred
    to primary
17 ip=ip*(cos(pf*(%pi/180))-%i*sin(pf*(%pi/180))); //
    complex form of primary current
18 V2=E1-ip*(re2+xe2*%i);
19 pfl=-atand(imag(V2),real(V2))-pf; // phase angle by
    which primary current leads secondary terminal
    voltage referred to primary
20 PF=cos(pfl*(%pi/180));
21 vl=abs(V2)/2;
22 isl=(P*1000)/E2;
23 pl=vl*isl*PF;
24 printf('Load voltage is %f v\n',vl);
25 printf('Load power factor is %f leading\n',PF);
26 printf('Load power is %f W',pl);
```

Scilab code Exa 1.72 Calculating power delivered by each source and power dissipated in given resistor

```
1  clc;
2  // from fig 1.82
3  E1=5; // supply voltage
4  E2=20; // induced secondary voltage
5  k=E2/E1; // turns ratio
6  r1=6; // primary parameters
7  r2=16; // secondary parameters
8  r21=r2/k; // secondary parameters referred to
    primary
9  E21=(E2*2)/k; // secondary voltage referred to
    primary
10 theta=60*(%pi/180); // phase angle assocoated with
    E2
```

```
11 // after referring to primary side, with E1 as a
      reference
12 V=E21*(cos(theta)-%i*sin(theta))-E1; //resultant
      voltage
13 I=abs(V)/(r1+r21); // magnitude of current
14 pd1=I^2*r1;
15 pd2=I^2*r21;
16 printf('power dissipated in %f ohm resistor is %f W\
      n',r1,pd1);
17 printf('power dissipated in %f ohm resistor is %f W\
      n',r21,pd2);
18 // Current lags E1 by 90 degree
19 teta1=90*(%pi/180);
20 // Since E2 lags E1 by 60 degree and Current due to
      resultant voltage lags E1 by 90, therefore phase
      difference Current I and E2 is
21 teta2=(90-60)*(%pi/180);
22 Pd1=E1*I*cos(teta1);
23 Pd2=E21*I*cos(teta2);
24 printf('power delivered by %f v source is %f W\n',E1
      ,Pd1);
25 printf('power delivered by %f v source is %f W\n',E2
      ,Pd2);
```

Scilab code Exa 1.73 Calculating efficiency and regulation under given condition

```
1 clc;
2 P=1200; // rated VA of transformer
3 E1=240; // rated primary voltage
4 E2=110; // rated secondary voltage
5 xe=5; // total leakage reactance of transformer
      referred to primary
6 re=1; // total resistance of transformer referred to
      primary
```

```
7  vl=240; // rated voltage of load
8  R=2500; // core resistance
9  pf=1; // power factor
10 ip=P/E1; // full load primary current
11 // assuming E1 as a reference
12 Vin=sqrt((E1+ip*re)^2+(ip*xe)^2); // input voltage
      when load is connected
13 pi=ip^2*re; // ohmic losses
14 pc=Vin^2/R; // core loss
15 n=(P*pf*100)/(P*pf+pi+pc);
16 printf('Efficiency at full load is %f percent\n',n);
17 vr=((Vin-E1)/Vin)*100;
18 printf('Voltage regulation for full load is %f
      percent',vr);
```

Scilab code Exa 1.74 Determining current taken from source primary input impedance and input power

```
1  clc;
2  k1=4; // turns ratio for transformer 1
3  k2=3; // turns ratio for transformer 2
4  E1=120; // supply across which two transformers are
      connected in parallel
5  E21=E1/k1; // secondary voltage for transformer 1
6  E22=E1/k2; // secondary voltage for transformer 2
7  R=10; // load resistance
8  // Secondary windings are connected in series with
      the polarity such that the voltages E21 and E22
        aid each other
9  E2=E21+E22; // resultant output voltage
10 il=E2/R; // Load current
11 // for mmf balance, primary current for T1
12 ip1=il/k1;
13 // for mmf balance, primary current for T2
14 ip2=il/k2;
```

```
15 ip=ip1+ip2; // total current drawn from source
16 printf('Current drawn from source is %f A\n',ip);
17 zi=E1/ip;
18 printf('Primary input impedance is %f ohm\n',zi);
19 pi=E2*il;
20 printf('Primary input power is %f W',pi);
```

Scilab code Exa 1.75 Finding currents drawn by primary and secondary of transformer A and open circuit voltage across secondary of transformer B

```
1 clc;
2 // A and B are two transformer shown in fig 1.85
3 im=0.1; // magnetizing current
4 // Since SA(secondary winding for transformer A) is
    connected directly across 200 v supply, so the
    magnetizing current required to establish the
    flux must flow through SA, therefore current
    taken by winding PA(primary winding for
    transformer A) is zero
5 // Since voltage across SA is 200 v , voltage across
    PA has to be 200 v by transformer action
6 // As a result of it , voltage across PB is zero,
    therefore induced emf in SB is zero
7 printf('Current in secondary winding of transformer
   A is %f A',im);
8 disp('Current in primary winding of transformer A is
    zero');
9 disp('Voltage across secondary winding of
   transformer B is zero');
```

Scilab code Exa 1.76 Determining the reading of ideal voltmeter

```
1 clc;
```

```
2 // 1 and 2 subscripts are used for transformer 1 and
      transformer 2
3 // P and S are used for primary and secondary
     winding
4 E=230; // Rated primary voltage of both transformer
5 disp('case 1');
6 R=0; // load conneted across secondary of
     transformer 1
7 // R=0 means winding is short circuited, therefore
     voltage across S1 is zero, therefore whole
     voltage is applied across s2 therefore
8 printf('Reading of voltmeter for R=%f is %f v\n',R,E
     );
9 disp('case 2');
10 R=115; // load conneted across secondary of
     transformer 1
11 // A resistance of 115 ohm should cause a current of
      1 A because voltage across P1 is 115 v but this
     means that P1 and P2 carrying 1A current .
     According to this voltage across P2 is
     magnetizing impedance of transformer 2 times
     magnetizing current. But magnetizing impedance is
      very large, due to this voltage across P2 rises
     much above 115 v and voltage across P1 falls, due
      to which magnetizing    current through S1
     decreases.
12 disp('Voltmeter reading is much more than 115 v but
     less than 230 v. Let it be Vb');
13 disp('case 3');
14 R=1000; //  load conneted across secondary of
     transformer 1
15 // For R=1000 ohm , current in P1 and S1 are reduced
     . Hence current in P2 is also reduced. Therefore
     voltage across P2 is also reduced but still it is
      more than 115 v
16 disp('Voltmeter reading is more than 115 v but less
     than Vb');
17 disp('case 4');
```

```
18 // for R=infinity S1 is open circuited, therefore
      voltage across P1=115 v and P2=115 v
19 disp('Reading of voltmeter is 115 v');
```

Scilab code Exa 1.77 Finding current drawn by transformer under no load test

```
1  clc;
2  E1=200; // rated voltage of l v side
3  E2=400; // rated voltage of h v side
4  f=50; // frequency of supply
5  W=80; // open circuit input wattage=core loss
6  m=1.91; // mutual induction between h v and l v side
7  Ic=W/E2; // core loss current
8  Qmax=E1/(sqrt(2)*%pi*f); // maximum value of flux
      linkage with l v winding
9  Im=Qmax/(sqrt(2)*m);
10 Io=sqrt(Ic^2+Im^2);
11 printf('Current taken by transformer when no load
      test is conducted on h v side is %f A',Io);
```

Scilab code Exa 1.78 Determining the efficiency and voltage regulation of transformer

```
1  clc;
2  P=100000; // rated VA of transformer
3  n=0.98; // maximum possible efficiency
4  l=80000; // rated KVA of load
5  vrm=0.04; // maximum possible voltage regulation is
      equal to ze2 in p u
6  pf=0.8; // power factor at which efficiency anf
      voltage regulation has to be determined
7  pl=((1/n)-1)*l; // total losses in transformer
```

```
pc=pl/2; // core losses; at maximum efficiency ohmic
    losses = core losses
po=(1/pf)^2*pc; // ohmic losses at given power
   factor
N=(P*pf*100)/(1+po+pc);
printf('Efficiency at %f lagging power factor is %f
   percent\n',pf,N);
re2=po/P; // resistance in p u
xe2=sqrt(vrm^2-re2^2);
vr=(re2*pf+xe2*sqrt(1-pf^2))*100;
printf('Voltage regulation at %f lagging power
   factor is %f percent',pf,vr);
```

Scilab code Exa 1.79 Determining the KVA rating of different section of autotransformer

```
clc;
// after deriving the expression for both the
   transformer and auto transformer
k=0.8; // ratio of V2/V1(turns ratio)
W=100; // Power to be delivered in KW
pf=1; // unity power factor
n=0.96; // given efficiency
disp('for two winding transformer');
ks=W;
printf('KVA rating for secondary of two winding
   transformer is %f KVA\n',ks);
kp=ks/n;
printf('KVA rating for primary of two winding
   transformer is %f KVA\n',kp);
disp('for auto transformer');
kab=(W/n)*(1-k);
printf('KVA rating for section AB of autotransformer
    is %f KVA\n',kab);
kbc=W*(1-k/n);
```

```
16 printf('KVA rating for section BC of autotransformer
       is %f KVA\n',kbc);
```

Chapter 2

Electromechanical Energy Conversion Principle

Scilab code Exa 2.4 Determining magnitude of average magnetic force

```
1  clc;
2  l=0.02; // air gap length
3  i1=20; // intermediate current
4  i2=40; // current during armature movement from open
       to close position
5  // from fig 2.11
6  f1=0.04*i1; // flux linkage during open position at
       A
7  f2=1.2+0.03*(i1-20); // flux linkage during close
       position at D
8  f3=0.04*i2; // flux linkage during open position at
       B
9  f4=1.2+0.03*(i2-20); // flux linkage during close
       position at C
10 // Mechanical work done=area ODCFEO-area OABFEO
11 W=((i1*f2)/2)+(((f2+f4)*i1)/2)-((i2*f3)/2);
12 fe=W/l;
13 printf('Average electromagnetic force is %d N',fe);
```

Scilab code Exa 2.6 Determining force required for axial alignment of electromagnets

```
clc;
g=0.003; // gap length
wp=0.006; // pole width
B=0.8; // flux density in air gap
uo=4*%pi*10^-7; // free space permeability
// after the derivation of expression
fe=(B^2*wp*g)/(2*uo);
printf('Force tending to bring electromagnets into
   axial alignment is %f N',fe);
```

Scilab code Exa 2.7 Determining 1 air gap flux densities and coil inductance 2 energy stored in magnetic field 3 electromagnetic force 4 mechanical work done 5 electrical energy supplied by load

```
clc;
N=1500; // number of turns in coil
i=3; // current carried by coil
uo=4*%pi*10^-7; // free space permeability
l=0.04; // side of plunger
A=%pi*(l/2)^2; // cross section area of plunger
disp('case a');
disp('for gap length G=2 cm');
g=0.02; // air gap length in cm
x=0; // displacement of plunger
G1=g-x; // gap length
B=(uo*i*N)/G1; // air gap flux density
printf('Air gap flux density is %f Wb/m^2\n',B);
L1=(N^2*uo*A)/G1;
printf('Coil inductance is %f H',L1);
```

```
disp('for gap length G=1.5 cm');
g=0.02; // air gap length in cm
x=0.005; // displacement of plunger
G2=g-x; // gap length
B=(uo*i*N)/G2; // air gap flux density
printf('Air gap flux density is %f Wb/m^2\n',B);
L2=(N^2*uo*A)/G2;
printf('Coil inductance is %f H',L2);
disp('for gap length G=1 cm');
g=0.02; // air gap length in cm
x=0.01; // displacement of plunger
G3=g-x; // gap length
B=(uo*i*N)/G3; // air gap flux density
printf('Air gap flux density is %f Wb/m^2\n',B);
L3=(N^2*uo*A)/G3;
printf('Coil inductance is %f H',L3);
disp('for gap length G=0.5 cm');
g=0.02; // air gap length in cm
x=0.015; // displacement of plunger
G4=g-x; // gap length
B=(uo*i*N)/G4; // air gap flux density
printf('Air gap flux density is %f Wb/m^2\n',B);
L4=(N^2*uo*A)/G4;
printf('Coil inductance is %f H',L4);
disp('case b');
disp('for gap length G=2 cm');
W=(i^2*L1)/2;
printf('Energy stored is %f watt-sec\n',W);
disp('for gap length G=1.5 cm');
W=(i^2*L2)/2;
printf('Energy stored is %f watt-sec\n',W);
disp('for gap length G=1 cm');
W=(i^2*L3)/2;
printf('Energy stored is %f watt-sec\n',W);
disp('for gap length G=0.5 cm');
W=(i^2*L4)/2;
printf('Energy stored is %f watt-sec\n',W);
disp('case c');
```

```
disp('for gap length G=2 cm');
fe=round((i^2*g*L1)/(2*G1^2));
printf('Electromagnetic force is %f N\n',fe);
disp('for gap length G=1.5 cm');
fe=(i^2*g*L1)/(2*G2^2);
printf('Electromagnetic force is %f N\n',fe);
disp('for gap length G=1 cm');
fe=round((i^2*g*L1)/(2*G3^2));
printf('Electromagnetic force is %f N\n',fe);
disp('for gap length G=0.5 cm');
fe=round((i^2*g*L1)/(2*G4^2));
printf('Electromagnetic force is %f N\n',fe);
disp('case 4');
// for g=2 cm and g=0.5cm, displacement is given by
xi=0;
xf=0.015;
Wm=integrate('(i^2*g*L1)/(2*(g-x)^2)','x',xi,xf);
printf('Mechanical work done is %f watt-sec\n',Wm);
disp('case e');
We=integrate('(i^2*g*L1)/(g-x)^2','x',xi,xf);
printf('Electrical energy supplied by source is %f
   watt-sec\n',We);
```

Scilab code Exa 2.8 Determining torque

```
clc;
r=50*10^-3; // radius of rotor
g=2*10^-3; // air gap length
l=10*10^-3; // length normal to radius r
B=2.2; // maximum air gap flux density
uo=4*%pi*10^-7; // free space permeability
// after the derivation of the expression
T=(B^2*g*r*l)/uo;
printf('Magnitude of torque is %f N-m',T);
```

Scilab code Exa 2.9 Determining torque

```
clc;
r=50*10^-3; // radius of rotor
g=2*10^-3; // air gap length
l=10*10^-3; // length normal to radius r
B=2.2; // maximum air gap flux density
uo=4*%pi*10^-7; // free space permeability
// after the derivation of the expression
T=(B^2*g*(r+(g/2))*l)/uo;
printf('Magnitude of torque is %f N-m',T);
```

Scilab code Exa 2.13 Determining magnitude and direction of torque for different cases

```
clc;
f=50; // frequency
w=2*%pi*f; // angular speed
y=60; // y=angular position of rotor
Ls=0.6+0.2*cosd(2*y) // self inductance of stator
dLs=-2*0.2*sind(2*y); // derivative of Ls with y
Lr=0.75+0.3*cosd(2*y) // self inductance of rotor
dLr=-2*0.3*sind(2*y); // derivative of Lr with y
Ms=0.8*cosd(y) // mutual inductance of stator
dMs=-0.8*sind(y); // derivative of Ms with y
disp('case a');
is=20; // stator current
ir=10; // rotor current
te=(is^2*dLs)/2+(ir^2*dLr)/2+(is*ir)*dMs;
printf('Magnitude of torque is %f Nm and since it is
    negative it acts in such a direction so as to
   decrease angular position\n',-te);
```

```
is=20; // stator current
ir=-10; // rotor current
te=((is^2*dLs)/2)+((ir^2*dLr)/2)+((is*ir)*dMs);
printf('Magnitude of torque is %f Nm and it acts in
   clockwise direction\n',te);
is=20; // stator current
ir=0; // rotor current
te=((is^2*dLs)/2)+((ir^2*dLr)/2)+((is*ir)*dMs);
printf('Magnitude of torque is %f Nm and it acts in
   counter-clockwise direction\n',-te);
disp('case b');
// rotor winding is short circuited rotor voltage=0
   and is=sqrt(2)*20*sin(wt) here average torque is
   needed so for calculation we need not to worry
   about sin(wt)
is=sqrt(2)*20; // stator current
ir=(-Ms/Lr)*is; // rotor current
te=((is^2*dLs)/2)+((ir^2*dLr)/2)+((is*ir)*dMs);
printf('Magnitude of torque is %f Nm and it acts in
   clockwise direction\n',te/2);
disp('case c');
// vs=sqrt(2)*314*sin(wt) again here average torque
   is needed so for calculation we need not to worry
    about sin(wt)
vs=sqrt(2)*314; // stator winding voltage
ls1=(Ls-(Ms^2/Lr)); // short circuit inductance of
   stator winding
is=vs/(w*ls1); // stator current
ir=(-Ms/Lr)*is; // rotor current
te=((is^2*dLs)/2)+((ir^2*dLr)/2)+((is*ir)*dMs);
printf('Magnitude of torque is %f Nm and it acts in
   clockwise direction\n',te/2);
```

Scilab code Exa 2.15 Determining magnitude of exciting current for closing relay and keeping it closed

```
clc;
B=[ 0.2 0.4 0.6 0.8 1 1.2];
H=[ 50 100 160 225 300 400];
plot(H,B);
xlabel('magnetic field intensity');
ylabel('magnetic flux density');
title('B-H curve');
p=0.2; // force exerted by spring
g1=0.5*10^-2; // air gap length
g2=0.1*10^-2; // reduced gap length after coil is
   energised
n=2000; // coil turns
l=0.2; // mean length of magnetic iron path
A=0.2*10^-4; // area of cross-section
g=9.81; // acceleration due to gravity
l1=6; // gap length
l2=3; // gap length between spring and core
uo=4*%pi*10^-7; // free space permeability
disp('case a');
fe=(p*g*l2)/l1; // electromagnetic torque
Bg=sqrt((2*fe*uo)/A); // air gap flux density
printf('Air gap flux density is %f T\n',Bg);
// corresponding to value of Bg from B-H curve H is
Hg=87.7; // magnetic flux intensity
ATi=l*Hg; // total ampere turn for iron path
ATg=(Bg*g1)/uo; // ampere turn for air gap
AT=ATi+ATg; // total ampere turns
ie=AT/n;
printf('Exciting current required to close the
   armature relay is %f A\n',ie);
disp('case b');
ATg=(Bg*g2)/uo; // ampere turn for air gap
AT=ATi+ATg; // total ampere turns
ie=AT/n;
printf('Exciting current required to keep the
   armature closed is %f A\n',ie);
```

Scilab code Exa 2.16 Determining magnitude of unbalanced magnetic pull on armature

```
clc;
x=0.1*10^-3; // displacement of armature
B=0.8; // air gap flux density
A=200*10^-4; // area under pole
g=0.6*10^-2; // air gap length
uo=4*%pi*10^-7; // free space permeability
// after derived expression
p=(B^2*A*g*x)/(uo*(g^2-x^2));
printf('Unbalanced magnetic pull on armature is %f N
    ',p);
```

Scilab code Exa 2.17 Determining magnitude and direction of magnetic force

```
clc;
i=sqrt(2)*1000; // maximum current carried by
    conductors
z=2; // number of conductors in slot
l=1; // embedded length
w=0.05; // slot width
uo=4*%pi*10^-7; // free space permeability
// after derived expression
fe=(uo*z^2*l*i^2)/(2*w);
printf('Magnitude of magnetic force is %f N and its
    direction is towards the bottom of the slot\n',fe
    /2);
```

Scilab code Exa 2.19 Determining 1 mechanical work done 2 energy supplied by each electrical source 3 change in field energy

```
clc;
// L1=3+(1/(2*X)) -self inductance of coil 1
// L1=2+(1/(2*X)) -self inductance of coil 2
// M=1/(2*X) -mutual inductance
// X is displacement
i1=10; // current of coil 1
i2=-5; // current of coil 2
// from expression W=(L1*i1^2)/2 + (L2*i2^2)/2 + (i1*i2*M) where W is work done and is equal to 175+25/(4*x);
// fe=-25/(4*x^2) where fe is electromagnetic force and is equal to rate of change of work done with respect to x
disp('case a');
x1=0.5;
x2=1;
Wm=integrate('-25/(4*x^2)','x',x1,x2);
printf('Mechanical work done for given increment in displacement is %f watt-sec\n',Wm);
disp('case b')
// psi1=(3+(1/(2*x)))*i1+(1/(2*x))*i2 psi1 is flux linkage with coil 1
// psi2=(2+(1/(2*x)))*i2+(1/(2*x))*i1 psi2 is flux linkage with coil 2
We1=(((3+(1/(2*x2)))*i1+(1/(2*x2))*i2)-((3+(1/(2*x1)))*i1+(1/(2*x1))*i2))*i1;
We2=(((2+(1/(2*x2)))*i2+(1/(2*x2))*i1)-((2+(1/(2*x1)))*i2+(1/(2*x1))*i1))*i2;
printf('Electrical energy supplied by source 1 is %f watt-sec\n',We1);
printf('Electrical energy supplied by source 2 is %f watt-sec\n',We2);
disp('case c');
// W=175+(25/(4*x));
dw=175+(25/(4*x2))-(175+(25/(4*x1)));
```

```
25 printf('Change in field energy is %f Watt-sec\n',dw)
   ;
```

Scilab code Exa 2.21 Determining force between two magnetic surfaces

```
1 clc;
2 B=1.6; // flux density between magnetic surfaces
3 a=1; // area of magnetic surfaces
4 uo=4*%pi*10^-7; // free space permeability
5 f=(B^2*a)/(2*uo);
6 printf('Force between two magnetic surfaces is %f N'
   ,f);
```

Scilab code Exa 2.22 Determining force between two plates

```
1 clc;
2 A=1; // area of plates
3 E=3*10^6; // electric field intensity between plates
4 Eo=(10^-9/(36*%pi)); // vaccum permittivity
5 // after using both energy and coenergy method
   expression for force is derived
6 f=(E^2*Eo*A)/2;
7 printf('Force between two plates is %f N',f);
```

Scilab code Exa 2.23 Determining magnitude of voltage applied between two plates

```
1 clc;
2 w=5*10^-3; // counter weight
3 a=30*10^-4; // area of cross section of plates
```

```
4 d=1*10^-2; // distance between two plates
5 g=9.81; // acceleration due to gravity
6 Eo=(10^-9/(36*%pi)); // vaccum permittivity
7 l1=8*10^-2; // horizontal distance between pivot and
      plates
8 l2=10*10^-2; // horizontal distance between pivot
     and counter weight
9 // for the bar to remain horizontal electrostatic
     force is given by
10 fe=(w*l2*g)/l1;
11 v=sqrt((fe*2*d^2)/(Eo*a));
12 printf('Voltage applied between the plates is %f KV'
     ,v/1000);
```

Scilab code Exa 2.25 Determining 1 coil inductance and magnetic energy 2 electrical energy supplied by source 3 mechanical work done

```
1 clc;
2 n=1000; // number of turns in exciting coil
3 a=5*5*10^-4; // cross section area of core
4 g=1*10^-2; // length of air gap
5 uo=4*%pi*10^-7; // free space permeability
6 disp('case a');
7 i=5; // coil current
8 l=(n^2*uo*a)/(2*g);
9 printf('Inductance of coil is %f H\n',l);
10 E=(l*i^2)/2;
11 printf('Field energy stored in inductor is %f Watt-
     sec\n',E );
12 fe=(i^2*a*n^2*uo)/(4*g^2);
13 printf('Force on the armature is %f N\n',fe);
14 disp('case b');
15 g1=0.5*10^-2; // reduced length of air gap
16 We=((n^2*uo*a)/(2*g1)-(n^2*uo*a)/(2*g))*i^2;
17 printf('Electrical energy supplied by source is %f
```

```
    Watt-sec\n',We);
18 disp('case c');
19 w=integrate('(n^2*uo*a*i^2)/(4*(g-x)^2)','x',0,g1);
20 printf('Mechanical work done is %f Watt-sec',w);
```

Scilab code Exa 2.26 Determining force required for armature alignment with field structure

```
1 clc;
2 de=110*(%pi/180); // pole pitch
3 g=0.4*10^-2; // air gap length
4 B=0.5; // air gap flux density
5 d=0.3; // armature diameter
6 uo=4*%pi*10^-7; // free space permeability
7 fe=(B^2*d*de*g)/(2*uo);
8 printf('Force that tends to pull the armature into
    alignment is %f N',fe)
```

Scilab code Exa 2.28 Determining energy stored in inductor

```
1 clc;
2 r=4; // resistance of inductor
3 v=8; // maximum voltage
4 L=2; // inductance
5 t=2; // time required to reach maximum voltage value
6 disp('case a');
7 // after solving laplace equation we get expression
    for i(t) (transient current) i.e          i(t)=((
    exp^-2*t)+(2*t-1))/2
8 // for t=2 sec i(t) is given by
9 it=((exp(-2*t))+2*t-1)/2;
10 E=(L*it^2)/2;
11 printf('Energy stored during %d sec is %f J\n',t,E);
```

```
12 disp('case b');
13 i=v/r; // current when transients are over
14 E=(L*i^2)/2;
15 printf('Energy stored after transients are over is
     %d J\n',E);
```

Scilab code Exa 2.29 Determining and comparing field energy stored and field energy density in iron and air gap

```
1  clc;
2  l=1.2; // length of iron path
3  a=5*5*10^-4; // area of cross section
4  uo=4*%pi*10^-7; // permeability for free space
5  ur=1500; // relative permeability for iron
6  i=2; // exciting current
7  n=1000; // number of turns of coil
8  g=0.5*10^-2; // air gap length
9  r=(l/(uo*ur*a))+(g/(uo*a)); // net reluctance
10 f=(n*i)/r; // flux in coil
11 fe1=((f^2*l)/(uo*ur*a))/2;
12 printf('Field energy stored in iron is %f J\n',fe1);
13 fe2=((f^2*g)/(uo*a))/2;
14 printf('Field energy stored in air gap is %f J\n',
     fe2);
15 r1=fe2/fe1;
16 printf('Ratio of field energy stored in air gap to
     field energy stored in iron is %f \n',r1);
17 d1=fe1/(l*a);
18 printf('Energy density in iron is %f J/m^3\n',d1);
19 d2=fe2/(g*a);
20 printf('Energy density in air gap is %f J/m^3\n',d2)
     ;
21 r2=d2/d1;
22 printf('Ratio of energy density in air gap to energy
      density in iron is %f \n',r2);
```

Scilab code Exa 2.30 Determining 1 coil inductance field energy and force on armature 2 mechanical work done 3 magnetic force 4 mechanical work done for constant flux linkage

```
1
2
3 clc;
4 n=1200; // number of turns in exciting coil
5 a=6*5*10^-4; // area of cross section of core
6 disp('case a');
7 x=0.01; // displacement of coil
8 i=2; // exciting current
9 uo=4*%pi*10^-7; // free space permeability
10 Wf=(n^2*uo*a*i^2)/(4*x);
11 printf('Field energy stored is %f J\n',Wf);
12 F=(-n^2*uo*a*i^2)/(4*x^2);
13 printf('Force on armature is %f N\n',F);
14 disp('case b');
15 x1=0.005; // further displacement of coil
16 v1=(n^2*uo*a*i)/(2*x); // flux linkage corresponding
    to displacement 1 cm
17 v2=(n^2*uo*a*i)/(2*x1); // flux linkage
   corresponding to displacement 0.5 cm
18 M=((v2-v1)*i)/2;
19 printf('Mechanical energy output is %f J\n',M);
20 disp('case c');
21 // after deriving expression
22 Wm=integrate('(-n^2*uo*a)/x^2','x',x,x1);
23 printf('Mechanical work done is %f J\n',Wm);
24 disp('case d');
25 // for x=0.005 flux linkage is constant than current
    will change
26 i2=v1/((2*n^2*uo*a)/(2*x));
27 Wm=((i-i2)*v1)/2;
```

```
28 printf('Mechanical work done if flux linkage are
      maintained constant is %f J\n',Wm);
29 disp('case e');
30 // after the expression is derived
31 Wm=integrate('(-v1^2)/(n^2*uo*a)','x',x,x1);
32 printf('Mechanical work done if flux linkage are
      maintained constant is %f J\n',Wm);
```

Chapter 3

Basic Concepts of Rotating Electrical Machines

Scilab code Exa 3.2 Determining rating of generator for given parallel paths

```
1  clc;
2  n=24; // Number of armature conductor
3  v=2; // average voltage per conductor
4  i=5; // current carrying capacity of each conductor
5  disp('case a');
6  a=2; // number of parallel path
7  sc=n/a; // series connected conductor in each path
8  Ea=sc*v; // output voltage
9  Ia=i*a; // output current
10 p=Ea*Ia; // power rating
11 printf('Generator rating is %f W\n',p);
12 disp('case b');
13 a=4; // number of parallel path
14 sc=n/a; // series connected conductor in each path
15 Ea=sc*v; // output voltage
16 Ia=i*a; // output current
17 p=Ea*Ia; // power rating
18 printf('Generator rating is %f W\n',p);
```

```
19 disp('case c');
20 a=6; // number of parallel path
21 sc=n/a; // series connected conductor in each path
22 Ea=sc*v; // output voltage
23 Ia=i*a; // output current
24 p=Ea*Ia; // power rating
25 printf('Generator rating is %f W\n',p);
```

Scilab code Exa 3.3 Calculating generated armature voltage for different types of machine

```
1 clc;
2 p=4; // number of poles
3 s=60; // number of slots
4 c=8; // number of conductors per slot
5 f=20*10^-3; // flux per pole
6 nr=1500; // relative speed in rpm between field flux
      and armature winding
7 disp('case a');
8 // winding is lap connected
9 a=p; // for lap connected winding , number of
     parallel path=number of pole
10 z=s*c; // total number of conductors
11 n=nr/60; // speed in rps
12 E=(f*z*n*p)/a;
13 printf('Generated EMF is %f V\n',E);
14 disp('case b');
15 kw=0.96; // winding factor
16 nt=z/2; // Total number of turns
17 nph=nt/3; // number of series turns per phase
18 fg=(p*n)/2; // generated EMF frequency
19 E=sqrt(2)*%pi*fg*nph*kw*f;
20 printf('Generated EMF per phase is %f V\n',E);
21 e=round(sqrt(3)*E);
22 printf('Generated EMF between line terminal is %f V\
```

```
n',e);
```

Scilab code Exa 3.4 Determining 1 frequency of EMF 2 number of poles 3 number of synchronous motor poles

```
clc;
p1=4; // number of poles in slip ring induction
   motor
p2=6; // number of poles in synchronous  motor
f=50; // frequency of supply
ns=(120*f)/p2; // synchronous motor speed
ni=(120*f)/p1; // induction motor speed
disp('case a(1)');
// when synchronous motor is driven in direction
   opposite to the rotating field produced the
   induction motor stator
nr=ns+ni; // relative speed
F=(p1*nr)/120;
printf('Frequency of EMF at rotor slip ring
   terminals is %f Hz\n',F);
disp('case a(2)');
// when synchronous motor is driven in direction of
   the rotating field produced the induction motor
   stator
nr=ni-ns; // relative speed
F=(p1*nr)/120;
printf('Frequency of EMF at rotor slip ring
   terminals is %f Hz\n',F);
disp('case b');
fn=150; // frequency of rotor terminal voltage
   required
// let new number of pole be pn then relative speed
   is nr=ns+(120*50)/pn;
pn=((fn*120)-(120*f))/ns;
printf('Number of poles that the induction motor
```

```
    must have is %f \n',pn);
22 disp('case c');
23 pi=8; // number of poles in induction motor
24 ps=(120*f*pi)/((fn*120)-(120*f));
25 printf('Number of synchronous motor poles required
    is %f',ps);
```

Scilab code Exa 3.5 Calculating frequency and magnitude of per phase EMF for different speed of rotor

```
1  clc;
2  p=4; // number of pole
3  f=50; // frequency of supply
4  ns=420; // stator turns
5  nr=240; // rotor turns
6  F=30*10^-3; // flux per pole
7  kw=0.96; // winding factor for both stator and rotor
8  nsph=ns/3; // stator turn per phase
9  nrph=nr/3; // rotor turn per phase
10 es=sqrt(2)*%pi*f*kw*nsph*F; // stator turn per phase
11 disp('case a');
12 // rotor is stationary
13 s=1; // at standstill slip=1
14 er=sqrt(2)*%pi*f*kw*nrph*F;
15 printf('frequency of EMF in stator is %f Hz\n',f);
16 printf('frequency of EMF in rotor is %f Hz\n',f);
17 printf('Per phase stator EMF is %f V\n',es);
18 printf('Per phase rotor EMF is %f V\n',er);
19 disp('case b');
20 sr=1440; // speed of rotor in rpm in direction of
    rotating flux
21 Ns=(120*f)/p; // speed of rotating flux
22 s=(Ns-sr)/Ns; // slip
23 fr=s*f; // frequency of EMF in rotor
24 er=sqrt(2)*%pi*fr*kw*nrph*F;
```

```
25 printf('frequency of EMF in stator is %f Hz\n',f);
26 printf('frequency of EMF in rotor is %f Hz\n',fr);
27 printf('Per phase stator EMF is %f V\n',es);
28 printf('Per phase rotor EMF is %f V\n',er);
29 disp('case c');
30 sr=1440; // speed of rotor in rpm opposite to the
      direction of rotating flux
31 s=(Ns+sr)/Ns; // slip
32 fr=s*f; // frequency of EMF in rotor
33 er=sqrt(2)*%pi*fr*kw*nrph*F;
34 printf('frequency of EMF in stator is %f Hz\n',f);
35 printf('frequency of EMF in rotor is %f Hz\n',fr);
36 printf('Per phase stator EMF is %f V\n',es);
37 printf('Per phase rotor EMF is %f V\n',er);
```

Scilab code Exa 3.6 Calculating fundamental third and fifth harmonic belt factors for stator

```
1 clc;
2 disp('case a');
3 s=54; // number of slots in stator,3 phase
4 p=6; // number of poles
5 spp=s/(3*p); // slots per pole per phase
6 v=(p*180)/s; // slot angular pitch
7 k1=sin(((spp*v)/2)*(%pi/180))/(spp*sin((v/2)*(%pi
      /180))); // fundamental harmonics
8 k3=sin(((3*spp*v)/2)*(%pi/180))/(spp*sin(((3*v)/2)*(
      %pi/180))); // third harmonic
9 k5=sin(((5*spp*v)/2)*(%pi/180))/(spp*sin(((5*v)/2)*(
      %pi/180))); // fifth harmonic
10 printf('First harmonic component is %f\n',k1);
11 printf('Third harmonic component is %f\n',k3);
12 printf('Fifth harmonic component is %f\n',k5);
13 disp('case b');
14 s=48; // number of slots in stator,3 phase
```

```
15 p=6; // number of poles
16 spp=s/(3*p); // slots per pole per phase
17 sk=spp*3;
18 v=(p*180)/s; // slot angular pitch
19 ps=spp*v; // phase spread
20 k1=sin(((ps)/2)*(%pi/180))/(sk*sin(((ps)/(sk*2))*(
      %pi/180))); // fundamental harmonics
21 k3=sin(((3*ps)/2)*(%pi/180))/(sk*sin(((3*ps)/(sk*2))
      *(%pi/180))); // third harmonic
22 k5=sin(((5*ps)/2)*(%pi/180))/(sk*sin(((5*ps)/(sk*2))
      *(%pi/180))); // fifth harmonic
23 printf('First harmonic component is %f\n',k1);
24 printf('Third harmonic component is %f\n',k3);
25 printf('Fifth harmonic component is %f\n',k5);
```

Scilab code Exa 3.8 Determining distribution and winding factor

```
1  clc;
2  disp('case a');
3  cs=160*(%pi/180); // coil span in radian
4  ps=120*(%pi/180); // phase spread
5  kd=sin(ps)/(ps/2); // distribution factor for
      uniformly distributed winding
6  e=180-(cs*(180/%pi)); // chording angle
7  kp=cos((e/2)*(%pi/180)); // Coil span factor
8  wf=kd*kp; // winding factor
9  disp('Distribution factor is');
10 disp(kd);
11 disp('Winding factor is');
12 disp(wf);
13 disp('case b');
14 s=9; // number of slots per pole
15 sa=180/s; // slot angular pitch
16 // for a phase spread of 120 , 6*20=120, 6 adjacent
      slots must belong to the same phase, therefore
```

```
17 p=6; // poles belonging to same phase
18 kd=sin(ps/2)/(p*sin(ps/(2*6)));
19 wf=kd*kp;
20 disp('Distribution factor is');
21 disp(kd);
22 disp('Winding factor is');
23 disp(wf);
```

Scilab code Exa 3.10 Finding ratio of outputs and amount of copper required for different combinations

```
1  clc;
2  disp('case a');
3  f1=2/3; // fraction of slot wound
4  p1=f1*180; // phase spread , 2/3 of the slots are
       wound
5  kd1=sin((p1/2)*(%pi/180))/((p1/2)*(%pi/180)); //
       distribution factor
6  p2=180; // phase spread , All the slots are wound
7  f2=1; // fraction of slot wound
8  kd2=sin((p2/2)*(%pi/180))/((p2/2)*(%pi/180)); //
       distribution factor
9  // output is directly proportional to the product of
        fraction of slots wound and distribution factor
10 ro=(f2*kd2)/(f1*kd1); // It is assumed that
       frequency ,flux per pole and the conductor cross
       section is same
11 printf('Ratio of outputs is %f \n',ro);
12 rc=f2/f1;
13 printf('ratio of copper required is %f\n',rc);
14 disp('case b');
15 p3=60; // for 3-phase winding ,phase spread is 60
       degrees
16 kd3=sin((p3/2)*(%pi/180))/((p3/2)*(%pi/180)); //
       distribution factor
```

```
17 // since all the slots are wound for both 1-phase
     and 3-phase, fraction of the slots wound is 1
18 f3=1; // fraction of the slots wound
19 ro=kd3/kd2;
20 printf('Ratio of outputs is %f \n',ro);
21 rc=f2/f3;
22 printf('ratio of copper required is %f\n',rc);
23 disp('case c');
24 f4=1; // fraction of the slots wound
25 p4=90; // for 2-phase winding ,phase spread is 90
     degrees
26 kd4=sin((p4/2)*(%pi/180))/((p4/2)*(%pi/180)); //
     distribution factor
27 ro=kd3/kd4;
28 printf('Ratio of outputs is %f \n',ro);
29 rc=f3/f4;
30 printf('ratio of copper required is %f\n',rc);
```

Scilab code Exa 3.11 1 Estimating resultant line and phase voltage for given configurations 2 Determining circulating current for delta connected machine

```
1 clc;
2 d=0.28; // air gap diameter
3 l=0.23; // core length of alternator
4 spp=4; // slots per pole per phase
5 b1=0.87; // amplitude of flux density in fundamental
     harmonic in Tesla
6 b3=0.24; // amplitude of flux density in third
     harmonic in Tesla
7 b5=0.14; // amplitude of flux density in fifth
     harmonic in Tesla
8 p=6; // number of poles in alternator
9 np=3; // number of phases
10 c=8; // number of conductor per slot
```

```
f=50; // frequency of supply
f1=(2*d*l*b1)/p; // flux for fundamental harmonic
f3=(2*d*l*b3)/(p*3); // flux for third harmonic
f5=(2*d*l*b5)/(p*5); // flux for fifth harmonic
ap=180/(spp*np); // slot angular pitch
kd1=sin(((spp*ap)/2)*(%pi/180))/(spp*sin((ap/2)*(%pi
   /180))); // distribution factor for fundamental
   harmonic
kd3=sin(((3*spp*ap)/2)*(%pi/180))/(spp*sin(((3*ap)
   /2)*(%pi/180))); // distribution factor for third
    harmonic
kd5=sin(((5*spp*ap)/2)*(%pi/180))/(spp*sin(((5*ap)
   /2)*(%pi/180))); // distribution factor for fifth
    harmonic
// coil is short pitched by one slot, therefore
e=180/(spp*np); // chording angle
cs1=cos((e/2)*(%pi/180)); // coil span factor for
   fundamental harmonic
cs3=cos(((3*e)/2)*(%pi/180)); // coil span factor
   for third harmonic
cs5=cos(((5*e)/2)*(%pi/180)); // coil span factor
   for fifth harmonic
kw1=cs1*kd1; // winding factor for fundamental
   harmonic
kw3=cs3*kd3; // winding factor for third harmonic
kw5=cs5*kd5; // winding factor for fifth harmonic
ts=spp*np*p; // total number of slots
tt=(ts*c)/2; // total number of turns
nph=tt/np; // series turn per phase
ep1=sqrt(2)*%pi*f*kw1*nph*f1; // emf per phase for
   fundamental harmonics
ep3=(ep1*kw3*3*f3)/(kw1*f1); // emf per phase for
   third harmonics
ep5=(ep1*kw5*5*f5)/(kw1*f1); // emf per phase for
   fifth harmonics
disp('case a(1): star connected alternator');
ep=sqrt(ep1^2+ep3^2+ep5^2);
printf('Resultant EMF per phase is %f V\n',ep);
```

```
36 // third frequency line emf doesnot appear in line
   voltage
37 el=sqrt(3)*sqrt(ep1^2+ep5^2);
38 printf('Resultant line voltage is %f V\n',el);
39 disp('case a(2): Delta connected alternator');
40 // third frequency line emf doesnot appear in line
   and phase voltage as they are short circuited  by
    closed delta
41 ep=sqrt(ep1^2+ep5^2);
42 printf('Resultant EMF per phase(also line voltage)
   is %f V\n',ep);
43 disp('case b: delta connected alternator ');
44 rpp=10; // reactance per phase
45 // emf to due first and third harmonic cancels each
   other but third harmonic gives rise to
   circulating current
46 I=(3*ep3)/(3*np*rpp);
47 printf('Circulating current is %f A',I);
```

Scilab code Exa 3.12 Calculating percentage increase in per phase rms emf due to harmonic

```
1 clc;
2 spp=3; // slots per pole per phase
3 np=3; // number of phases
4 cs=8; // coil span
5 fp=0.20; // fraction of third harmonic in flux
   density wave in air gap
6 sp=spp*np; // slots per pole
7 v=180/sp; // slot angular pitch
8 kd1=sin(((spp*v)/2)*(%pi/180))/(spp*sin((v/2)*(%pi
   /180))); // distribution factor
9 // for a coil span of 8 slots the coil is short
   pitched by one slot
10 e=v; // chording angle
```

```
11 kp1=cos((e/2)*(%pi/180)); // coil span factor
12 kw1=kp1*kd1; // winding factor
13 kd3=sin(((3*spp*v)/2)*(%pi/180))/(spp*sin(((v*3)/2)
      *(%pi/180))); // distribution factor for third
      harmonic
14 kp3=cos(((3*e)/2)*(%pi/180)); // coil span factor
      for third harmonic
15 kw3=kd3*kp3; //  winding factor for third harmonic
16 er=(kw3/kw1)*fp; // ratio of third harmonic emf to
      fundamental emf
17 ep=sqrt(1+er^2); // ratio of net emf to fundamental
      emf
18 pi=((ep-1)/1)*100;
19 printf('Percentage increase in per phase rms emf is
      %f percent',pi);
```

Scilab code Exa 3.13 Determining phase and line EMF for given windings

```
1  clc;
2  p=6; // number of poles in alternator
3  s=42; // number of slots in alternator
4  f=0.012; // flux per pole
5  t=8; // number of turns in full pitch coil
6  F=50; // frequency of alternator
7  disp('case a');
8  np=2; // number of phases
9  spp=42/(p*np); // slots per pole per phase
10 // spp is not an integer, the 2-phase winding is a
      fractional slot winding, therefore Sk is given by
11 Sk=spp*2;
12 v=90; // phase spread for 2-phase winding
13 kd=sind(v/2)/(Sk*sind(v/(2*Sk))); // distribution
      factor
14 kw=kd; // winding factor as kp=1
15 nph=(s*t)/np; // per phase series turn
```

```
16 eph=sqrt(2)*F*%pi*kw*nph*f;
17 el=sqrt(2)*eph;
18 printf('Phase emf is %f V\n',eph);
19 printf('Line emf is %f V\n ',el);
20 disp('case b');
21 np=3; // number of phases
22 v=60; // phase spraed for 3-phase winding
23 kd=sind(v/2)/(Sk*sind(v/(2*Sk))); // distribution
      factor
24 kw=kd; // winding factor as kp=1
25 nph=(s*t)/np; // per phase series turn
26 eph=sqrt(2)*F*%pi*kw*nph*f;
27 el=sqrt(3)*eph;
28 printf('Phase emf is %f V\n',eph);
29 printf('Line emf is %f V\n ',el);
```

Scilab code Exa 3.14 Calculating third and fifth phase EMF in terms of fundamental phase emfs and the ratio of resultant line emf to resultant phase emf

```
1  clc;
2  s=81; // number of slots
3  p=6; // number of poles
4  np=3; // number of phases
5  cs=13; // coil span in terms of slot pitches
6  v=60; // phase spread for three phase winding
7  f3=0.4; // ratio of third harmonic flux to first
      harmonic flux
8  f5=0.25; // ratio of fifth harmonic flux to first
      harmonic flux
9  spp=s/(p*np); // // spp is not an integer, the 2-
      phase winding is a fractional slot winding,
      therefore Sk is given by
10 Sk=spp*2;
11 ap=(p*180)/s;
```

```
12 Cs=cs*ap; // coil span
13 e=180-Cs; // chording angle
14 kd1=sind(v/2)/(Sk*sind(v/(2*Sk))); // distribution
      factor for fundamental harmonic
15 kp1=cosd(e/2); // coil span factor
16 kd3=sind((3*v)/2)/(Sk*sind((3*v)/(2*Sk))); //
      distribution factor for third harmonic
17 kp3=cosd((3*e)/2); // coil span factor for third
      harmonic
18 kd5=sind((5*v)/2)/(Sk*sind((5*v)/(2*Sk))); //
      distribution factor for fifth harmonic
19 kp5=cosd((5*e)/2); // coil span factor for fifth
      harmonic
20 kw1=kd1*kp1; // winding factor for fundamental
      harmonics
21 kw3=kd3*kp3; // winding factor for third harmonic
22 kw5=kd5*kp5; // winding factor for fifth harmonic
23 ep3=(kw3*f3)/kw1;
24 printf('rms value of third harmonic emf is %f times
      the fundamental harmonic emf\n',ep3);
25 ep5=(kw5*f5)/kw1;
26 printf('rms value of fifth harmonic emf is %f times
      the fundamental harmonic emf\n',ep5);
27 ep=sqrt(1+ep3^2+ep5^2); // resultant phase emf
28 el=sqrt(3)*sqrt(1+ep5^2); // resultant line emf
29 r=el/ep;
30 printf('Ratio of resultant line emf to resultant
      phase emf is %f',r);
```

Scilab code Exa 3.15 Finding rms value of voltage in single turn coil

```
1 clc;
2 B=1; // peak flux density in Tesla
3 l=0.8; // length of armature conductor
4 v=20; // velocity of coil
```

```
// for 0< theta <30 coil aa' is moving in zero B-wave, emf for this range is zero
// for 30< theta < 60 coil side a is cutting through B-wave and coil side a' is cutting zero B-wave, therefore
e1=B*l*v; // emf at given position of coil
// for 60< theta < 150 both coil sides are cutting through B-wave
e2=2*B*l*v; // net emf at given position of coil
rms=sqrt((1/%pi)*(((e1^2*%pi*2)/6)+((e2^2*%pi)/2)));
printf('RMS value of generated emf in one single turn coil is %f V',rms);
```

Scilab code Exa 3.16 Calculating rms value of fundamental emf per phase

```
clc;
f=50; // frequency of alternator
B=1; // peak flux density
t=360; // total turns
v=60; // phase spread
pi=0.6; // pole pitch
l=0.8; // stator length
cs=180; // coil span in electrical degrees
nph=t/3; // series turn per phase
Bp=(4*B*cosd(v/2))/%pi; // fundamental value of peak flux density
F=(2*l*pi*Bp)/%pi; // Fundamental air-gap flux per pole
kd=sind(v/2)/((v/2)*(%pi/180)); // distribution factor
kw=kd; // winding factor , as kp=1
eph=sqrt(2)*%pi*f*F*kw*nph;
printf('RMS value of fundamental emf per phase is %f V',eph);
```

Scilab code Exa 3.18 Determining resultant emf for given combination of series coil

```
clc;
p=6; // number of poles
s=54; // number of slots
n=1000; // speed of alternator in rpm
t=80; // number of turn in coils A and B
f=0.015; // flux per pole
F=50; // given frequency of alternator
// Coil A is over pitched by one slot and coil B is
   short pitched by one slot
pp=s/p; // pole pitch
sap=(p*180)/s; // slot angular pitch
e1=(%pi*F*f*t)/sqrt(2); // EMF generated in one coil
    side of coil A or B
// same EMF is generated in col side 11 but with a
   phase of (180+sap) degrees. Resultant of emf in
   coil side 1 and 11 is given by
Ea=2*e1*cosd(sap/2); // net emf in coil side 1
Eb=Ea; // net emf in coil side 2
//Ea and Eb are in phase with each other from phasor
    diagram (fig. 3.26)
disp('case a');
en=Ea+Eb;
printf('Resultant e.m.f when coils A and B are
   connected in series aiding is %f V\n',en);
disp('case b');
en=Ea-Eb;
printf('Resultant e.m.f when coils A and B are
   connected in series opposing is %f V\n',en);
```

Scilab code Exa 3.19 Determining maximum and rms value of peak of fundamental mmf wave

```
clc;
np=3; // number of phases
p=2; // number of poles
spp=5; // slots per pole per phase
n=4; // number of turns in coil
i=20; // per phase current
v=(spp*180)/(spp*np); // phase spread
imax=sqrt(2)*i; // maximum value of current
mmf=spp*n*imax; // resultant amplitude of mmf
kd=sind(v/2)/((v/2)*(%pi/180)); // distribution
    factor
fp=(4*mmf*kd)/%pi; // peak value of fundamental
    component
fr=(4*3*spp*n*i)/%pi^2; // rms value of fundamental
    component
printf('Maximum value of the peak of fundamental m.m
    .f wave is %f AT/pole\n',fp);
printf('RMS value of the peak of fundamental m.m.f
    wave is %f AT/pole\n',fr);
```

Scilab code Exa 3.20 Calculating peak amplitude of mmf wave peak and rms value of fundamental mmf wave

```
clc;
p=2; // number of pole
i=24; // phase current
t=300; // full pitched turns
v=60; // phase spread
np=3; // number of phases
nph=t/np; // series turn per phase
j=(nph*sqrt(2)*i*180)/(v*%pi); // peak value of
    uniform current density
```

```
disp('case a');
A=(j*v*%pi)/(2*180); // peak amplitude of
   trapezoidal m.m.f wave
printf('Peak amplitude of trapezoidal m.m.f wave is
   %f ATs/pole\n',A);
disp('case b');
kd=sind(v/2)/((v/2)*(%pi/180)); // distribution
   factor
fp=(4*kd*A)/%pi;
printf('Peak value of fundamental mmf wave is %f AT/
   pole\n',fp);
fr=(4*3*A)/(%pi^2*sqrt(2));
printf('RMS value of fundamental mmf wave is %f AT/
   pole\n',fr);
```

Scilab code Exa 3.30 Finding linear velocity of travelling mmf wave

```
clc;
p=6; // number of poles in induction motor
f=50; // frequency of motor
d=1.2; // stator bore diameter
// in one revolution peripheral distance of Pi*
   diameter is transversed
v=(2*f*%pi*d)/p;
printf('Linear velocity of travelling mmf wave is %f
    m/sec',v);
```

Scilab code Exa 3.32 Calculating resultant peak gap mmf peak gap flux density total gap energy electromagnetic torque and electromagnetic power

```
clc;
p=2; // number of poles
f=50; // frequency of machine
```

```
D=1.6; // diameter of cylindrical rotor
l=1.8; // length of cylindrical rotor
g=0.012; // air gap length
rm=4000; // peak value of rotor mmf
rs=6000; // peak value of stator mmf
ph=140; // phase difference between stator mmf and
   rotor mmf
uo=4*%pi*10^-7; // free space permeability0
disp('a');
rp=sqrt(rm^2+rs^2+2*rm*rs*cosd(ph));
printf('Resultant peak gap mmf is %f AT/pole\n',rp);
disp('b');
Bp=(uo*rp)/g;
printf('Peak gap flux density is %f T\n',Bp);
disp('c');
ge=(uo*%pi*D*l*rp^2)/(4*g);
printf('Total gap energy is %f Joules\n',ge);
disp('d');
T=(p*uo*%pi*D*l*rs*rm*sind(ph))/(4*g);
printf('Electromagnetic torque is %f Nm\n',T);
disp('e');
wm=(4*%pi*f)/2; // synchronous speed
P=(T*wm)/1000
printf('Electromagnetic power is %f KW',P);
```

Scilab code Exa 3.33 Determining torque for given pole fields

```
clc;
d=0.8; // diameter of rotor machine
l=0.5; // length of rotor machine
g=0.005; // air gap length
as=10000; // peak current density for stator
ar=6000; // peak current density for rotor
t=60; // torque angle
disp('case a');
```

```
p=2; // number of pole
uo=4*%pi*10^-7; // free space permeability
Fs=(as*d)/p; // peak stator mmf per pole
Fr=(ar*d)/p; // peak rotor mmf per pole
Te=(p*uo*%pi*d*l*Fs*Fr*sind(t))/(4*g);
printf('Torque for given number of poles is %f Nm\n'
   ,Te);
disp('case b');
p=6; // number of pole
uo=4*%pi*10^-7; // free space permeability
Fs=(as*d)/p; // peak stator mmf per pole
Fr=(ar*d)/p; // peak rotor mmf per pole
Te=(p*uo*%pi*d*l*Fs*Fr*sind(t))/(4*g);
printf('Torque for given number of poles is %f Nm\n'
   ,Te);
```

Scilab code Exa 3.35 Finding peak value of fundamental mmf peak value of fundamental air gap flux density wave fundamental value of flux per pole and rms value of phase and line emfs at no load and rated speed

```
clc;
p=4; // number of poles
np=3; // number of phases
f=50; // frequency of alternator
sap=8; // slot angular pitch
c=12; // number of concentric coils in field winding
tf=6; // turns per field coil
ta=28; // series armature turn per phase
ar=0.6; // armature radius
la=4; // armature length
g=0.06; // gap length
w=0.96; // winding factor for armature winding
fc=1000; // field current
disp('case a');
kd=sind((np*sap)/2)/(np*sind(sap/2)); //
```

```
    distribution factor
kp=1; // coil span factor
kf=kd*kp; // winding factor for field winding
nf=tf*c; // number of field turn
F=(4*kf*nf*fc)/(%pi*p);
printf('Peak value of fundamental mmf produced by
    field winding is %f AT/pole\n',F);
disp('case b');
uo=4*%pi*10^-7; // free space permeability
B=(uo*F)/g;
printf('Peak value of fundamental flux density wave
    is %f T\n',B);
disp('case c');
v=(4*B*la*ar)/p;
printf('Fundamental value of air gap flux per pole
    is %f W\n',v);
disp('case d');
eph=sqrt(2)*%pi*f*v*ta*w;
printf('EMF per phase is %f V\n',eph);
el=sqrt(3)*round(eph);
printf('Line EMF is %f V',el);
```

Scilab code Exa 3.36 Calculating 1 peak value of fundamental air gap flux density 2 peak value of fundamental mmf wave 3 peak value of armature mmf wave and resultant mmf wave per pole 4 rms value of armature current and its power factor

```
clc;
np=3; // number of phases
p=6; // number of poles
f=50; // frequency of alternator
e=415; // open circuit emf;
s=36; // number of slots in armature
t=4; // number of turns per coil
g=0.18; // air gap diameter
```

```
l=0.4; // core length
G=0.002; // gap length
T=42; // number of turns in field winding
kf=0.96; // winding factor
uo=4*%pi*10^-7; // free space permeability
disp('case a');
nph=(s*t)/np; // series turn per phase
spp=s/(p*np); // slots per pole per phase
v=180/p; // slot angular pitch
kd=sind((spp*v)/2)/(spp*sind(v/2)); // distribution
   factor
Flu=e/(sqrt(2)*sqrt(3)*%pi*f*nph*kd); // flux per
   pole
B=(p*Flu*2)/(4*l*g);
printf('Peak value of fundamental flux density wave
   is %f T\n',B);
disp('case b');
Fl=(G*B)/uo; // peak fundamental field mmf wave
printf('Peak value of fundamental mmf wave is %f AT/
   pole\n',Fl);
If=(%pi*Fl*p)/(4*kf*T);
printf('DC field current is %f A\n',If);
disp('case c');
Te=114; // given torque
Ta=146; // torque angle
Fm=floor((Te*4*G)/(p*uo*%pi*g*l*Fl*sind(Ta)));
printf('Peak value of fundamental armature mmf is %f
    AT/pole\n',Fm);
Fr=sqrt(Fl^2+Fm^2+2*Fl*Fm*cosd(Ta));
printf('Resultant mmf per pole is %f AT/pole\n',Fr);
disp('case d')
ia=(Fm*2*%pi*p)/(12*kd*nph*sqrt(2));
printf('RMS value of armature current is %f A\n',ia)
   ;
ns=1000; // speed in rpm
wm=(2*%pi*ns)/60; // angular speed in rps
pf=(Te*wm)/(sqrt(3)*e*ia);
printf('Power factor is %f lagging',pf);
```

Scilab code Exa 3.37 Determining full load efficiency of given transformer

```
clc;
n1=0.95; // efficiency of transformer 1
lo=((1/n1)-1); // fraction of output lost
d=2; // Linear dimension of transformer B is two
   times the Linear dimension of transformer A
nb=(1/(1+((1*lo)/d)))*100;
printf('Full load efficiency of transformer B is %f
   percent',nb);
```

Scilab code Exa 3.39 Determining KW rating of motor

```
clc;
t0=0; // accelerating period
t1=30; // decelerating period
l1=2000; // maximum load during accelerating period
lf=600; // maximum load during decelerating period
l=1000; // load during full load
tf=60; // full load duration
td=10; // decelerating duration
tde=20; // decting period
sa=l1/t1; // slope during accelerating
sd=lf/td; // slope during decelerating
e1=integrate('(sa*t)^2','t',t0,t1); // term 1 for
   finding motor rating
e2=l^2*tf; // term 2 for finding motor rating
e3=integrate('(sd*t)^2','t',t0,td); // term 3 for
   finding motor rating
T=t1+tf+td+tde; // total duration
R=sqrt((1/120)*(e1+e2+e3));
```

```
17 printf('KW rating of motor is %f KW',R);
18 disp('Choose a motor of rating above the calculated
     rating');
```

Scilab code Exa 3.40 Determining continuous KW rating of motor

```
1  clc;
2  T=80; // total duration
3  t1=5-0; // duration of first increasing loading
     period
4  t2=36-5; // duration of second increasing loading
     period
5  t3=39-36; // duration of first decreasing loading
     period
6  t4=55-39; // duration of second decreasing loading
     period
7  t5=80-55; // duration of uniform loading
8  l1=150; // initial load
9  l2=1000; // load at 5th sec
10 l3=1400; // load at 36th sec
11 l4=300; // load at 39th sec
12 l5=150; // load during uniform loading
13 T1=(t1/3)*(l1^2+l2^2+l1*l2); // term 1 for
     evaluating rms power
14 T2=(t2/3)*(l2^2+l3^2+l2*l3); // term 2 for
     evaluating rms power
15 T3=(t3/3)*(l3^2+l4^2+l3*l4); // term 3 for
     evaluating rms power
16 T4=(t4/3)*(l4^2+l5^2+l4*l5); // term 4 for
     evaluating rms power
17 T5=t5*l5^2; // term 5 for evaluating rms power
18 R=sqrt((1/T)*(T1+T2+T3+T4+T5));
19 printf('As per the load time graph rating is %f KW',
     R);
20 disp('Choose a motor of rating above the calculated
```

```
rating');
```

Scilab code Exa 3.41 Determining final steady temperature rise and new KVA rating of transformer

```
clc;
p=200; // rated KVA of transformer
n=0.98; // efficiency
t1=20; // temperature after one hour of operation
t2=34; // temperature after two hour of operation
r=1/3; // ratio of full load core losses to ohmic
   loss
disp('case a');
t=[(t2/t1)-1];
th=-1/log(t); // heating time constant in hours
theta=t1/(1-exp(-1/th));
printf('Final steady temperature rise of the
   transformer on rated load is %f degree celsius\n'
   ,theta);
disp('case b');
f=1.2; //with increased heat dissipation ,ratio of
   new loss to old loss
Pn=sqrt((f*(1+r))-r)*p;
printf('New KVA rating of transformer is %f KVA\n',
   Pn);
// for a temperature rise of 78 degree
t3=78;
f=(t3/theta)*f; // ratio of new loss to old loss
Pn=sqrt((f*(1+r))-r)*p;
printf('New KVA rating of transformer is %f KVA\n',
   Pn);
```

Scilab code Exa 3.42 Determining one hour rating of induction motor

```
clc;
p=100; // KW rating of transformer
al=1; // ratio of core loss to ohmic loss
th=3; // heating time constant in hours
h=1; // duration in hour for which KVA rating has to
    be determined
disp('case a');
// constant losses are equal to variable losses
pn=p*sqrt(((1+al)/(1-exp(-h/th)))-al);
printf('One hour rating is %f KW\n',pn);
disp('case b');
// consatant losses are neglected
al=0;  // ratio of core loss to ohmic loss
pn=p*sqrt(((1+al)/(1-exp(-h/th)))-al);
printf('One hour rating is %f KW\n',pn);
```

Scilab code Exa 3.43 Calculating ratio of core loss to ohmic loss

```
clc;
t=1/2; //ratio of continuous rating to one hour
   rating
p=2; // ratio of new KVA rating to old KVA rating
al=2*(p*t);
printf('Ratio of core loss to ohmic loss is %f ',al)
   ;
```

Chapter 4

DC machines

Scilab code Exa 4.2 Determining electromagnetic power and internal torque

```
1  clc;
2  l=0.3;//core length
3  r=0.2;//radius
4  n=20;//speed in r.p.s.
5  Ia=20;//armature current
6  Z=500;//total conductors
7  Bav=0.5;//avg. flux density
8  a=4;//lap-wound
9  P=4;//no of poles
10 Wm=2*%pi*n
11 phi=((0.5*2*%pi*0.2*0.3)/4);
12 Ea=((P*n*Z*phi)/a);//generated emf
13 Pm=Ea*Ia;//gross mechanical power developed
14 Te=((Ea*Ia)/Wm);//internal torque
15 printf('Generated E.M.F. is %f V.\n',Ea);
16 printf('Gross mechanical power developed is %f W.\n'
      ,Pm);
17 printf('Internal Torque is %f Nm.',Te);
```

Scilab code Exa 4.3 Determining total current emf power developed in armature and electromagnetic torque

```
clc;
P=6;//no of poles
Z=300;//no of conductors
phi=0.015;//flux per pole in webers
n=30;//speed in r.p.s.
Ic=80;//current per conductor
Wm=2*%pi*n;
Eav=P*n*phi;//avg. emf per conductor
//when conductors are wave connected
disp('Wave Connected')
a1=2;//no of parallel paths
Ia=Ic*a1;//total current
Ea=Eav*(Z/a1);//E.M.F.
Pa=Ea*Ia;//power developed in armature
Te=Ea*Ia/Wm;//Electromagnetic torque
printf('Generated E.M.F. is %f V.\n',Ea);
printf('Power developed in armature is %f W.\n',Pa);
printf('Electromagnetic Torque is %f Nm.\n',Te);
//when conductors are lap connected
disp('Lap Connected')
a2=4;//no of parallel paths
Ia2=Ic*a2;//total current
Ea2=Eav*(Z/a2);//E.M.F.
Pa2=Ea2*Ia2;//power developed in armature
Te2=Ea2*Ia2/Wm;//Electromagnetic torque
printf('Generated E.M.F. is %f V.\n',Ea2);
printf('Power developed in armature is %f W.\n',Pa2)
   ;
printf('Electromagnetic Torque is %f Nm.',Te2);
```

Scilab code Exa 4.4 Determining 1 generated emf at no load 2 terminal voltage at full load

```
clc;
p=6; // number of poles
c=240; // number of coils
t=2; // number of turns per coil
rt=0.03; // resistance of one turn
l=0.5; // length of armature
d=0.4; // diameter of armature
B=0.6; // air gap flux density
a=p; // number of parallel paths is same as number
   of poles foe lap winding
an=40; // mechanical angle subtended by pole
n=1200; //  armature speed
th=an*(p/2); // electrical angle subtended by pole
f=(2*%pi*(d/2)*l*th*B)/(p*180); // flux per pole
Z=2*c*t; // total conductors
disp('case a');
Ea=(f*Z*n*p)/(60*a);
printf('Generated EMF at no load is %f V\n',ceil(Ea)
   );
disp('case b');
ia=40; // armature current
at=(c*t)/a; // number of armature turns per path
r=at*rt; // resistance of one path
Ra=r/a; // resistance of armature circuit
vt=Ea-ia*Ra;
printf('Terminal voltage at full load is %f V\n',
   ceil(vt));
```

Scilab code Exa 4.5 Determining terminal voltage of generator

```
clc
Pout=24000;//rated output power in watts
Et=250;//rated terminal voltage
Ra=0.1;//armature resistance
N=1600;//speed in rpm
```

```
6 //Ea(terminal voltage)= k*(N*phi),where k is
    constant & phi is flux per pole
7 //At no load, 260=k*1600*phi ....(1)
8 Ia=Pout/Et;
9 //if the generated voltage under rated load is Ea1,
    then
10 //Ea=k*1500*phi ....(2)
11 //From equation (1)&(2), (Ea1/260)=((1500*phi)
    /(1600*phi))
12 Ea1=(1500*260)/1600;
13 Vt=Ea1-Ia*Ra//terminal voltage at rated load
14 printf('The terminal voltage of generator under
    given conditions is %f V.',Vt)
```

Scilab code Exa 4.6 Determining ratio of speed as a generator to speed as a motor

```
1 clc;
2 Vt=230;//terminal voltage of dc shunt machine
3 Il=40;//Line current
4 Ra=0.5;//Armature circuit resistance
5 Rf=115;//Field circuit resistance
6 //GENERATOR OPERATION
7 If=Vt/Rf;//field current
8 Ia1=If+Il;//armature current
9 Ea1=Vt+Ia1*Ra;//generated emf
10 //Ea1=k*Ng*phi ....(1), where Ng is the generator
    speed & phi is flux per pole proportional to If
11 //MOTOR OPERATION
12 Ia2=Il-If;//armature current
13 Ea2=Vt-Ia2*Ra;//generated emf
14 //Ea2=k*Nm*phi ....(2), where Nm is the motor speed
    & phi is flux per pole proportional to If
15 //From equation (1)&(2), (Ea1/Ea2)=((Ng*phi)/(Nm*phi
    ))
```

```
16 N=Ea1/Ea2;//ratio of speed of generator to motor,N=
     Ng/Nm
17 printf('The ratio of speed as a generator to the
     speed as a motor is %f.',N)
```

Scilab code Exa 4.9 Determining demagnetizing and cross magnetizing ampere turns per pole for different positions of brushes

```
1  clc;
2  A=2;//No of parallel paths for armature conductors
3  P=6;//No. of poles
4  If=2;//Field current
5  Il=148;//Line current
6  Ia=If+Il;//Armature current
7  Z=480;//No of conductors
8  //brushes on GNA, theta=0
9  ATd1=0//demagnetizing ampere turns
10 ATc1=((Ia*Z)/(2*A*P))//Cross magnetizing ampere
     turns
11 printf('When brushes are on GNA the demagnetizing
     ampere turns & Cross magnetizing ampere turns are
      equal to %f & %f ATs/pole respectively.\n',ATd1,
     ATc1);
12 //brushes are shifted from GNA by 5 degrees
     electrical, theta=5
13 theta=5;
14 ATd2=((2*theta*Ia*Z)/(180*2*A*P))//demagnetizing
     ampere turns
15 ATc2=3000-ATd2;//Cross magnetizing ampere turns
16 printf('When the brushes are shifted from GNA by 5
     degrees electrical the demagnetizing ampere turns
      & Cross magnetizing ampere turns are equal to %f
      & %f ATs/pole respectively.\n',ATd2,ATc2);
17 //brushes are shifted from GNA by 5 degrees
     mechanical, theta_m=5
```

```
18 theta_m=5;//mechanical angle
19 theta_e=(P/2)*theta_m;//electrical angle
20 ATd3=((2*theta_e*Ia*Z)/(180*2*A*P))//demagnetizing
      ampere turns
21 ATc3=3000-ATd3;//Cross magnetizing ampere turns
22 printf('When the brushes are shifted from GNA by 5
      degrees mechnical the demagnetizing ampere turns
      & Cross magnetizing ampere turns are equal to %f
      & %f ATs/pole respectively',ATd3,ATc3);
```

Scilab code Exa 4.11 Determining number of turns required on each pole

```
1 clc;
2 P=4;//No of poles
3 Pout=100000;//Output power in watts
4 Vt=200;//terminal voltage
5 Z=256;//No of conductors
6 A=4;//no of parallel paths of armature conductors
7 Ia=Pout/Vt;//armature current
8 Bcp=0.25;//interpolar flux density in tesla
9 gcp=0.01;//interpolar air gap length
10 U=4*%pi*0.0000001;//permeability of air
11 Fcp=((Ia*Z)/(2*A*P))+((Bcp/U)*(gcp));//The
      interpolar m.m.f. per pole
12 Ncp=Fcp/Ia;
13 printf('The turns on each interpoles should be equal
      to %f.',round(Ncp));
```

Scilab code Exa 4.12 Determining time of commutation

```
1 clc;
2 D=50;//diameter of commutator
3 N=1000;//speed of rotation of commutator in rpm
```

```
4 Wb=1.5;//brush width
5 V=%pi*D*N/60;//peripheral velocity of commutator
6 Tc=(Wb*1000)/V;//time of commutation in ms
7 printf('Time of commutation is %f ms.',Tc);
```

Scilab code Exa 4.13 Determining value of commutating field

```
1 //The answer given in book for this question is
    wrong.
2
3 clc;
4 P=4;//No of poles
5 Ia=120;//armature current
6 A=4;//No of parallel paths for armature conductor
7 L=0.02//inductance in mH
8 //Et=L*(di/dt),Transformer emf in coil
9 //di=2*Ia/A,change of current during commutation
10 //dt=Tc,time of commutation
11 //Et=0.02*0.001*(60/Tc) ....(1)
12 //Er=2*(Bav*l*v),rotational emf in single turn coil
13 //Er=2*(phi_c/Tc) ....(2),phi_c is the avg value of
    flux in the commutating zone
14 //For linear commutation, Er=Et, from equation (1)
    &(2)
15 phi_c=60*0.02*0.001/2;//phi_c is the avg value of
    flux in the commutating zone
16 printf('THE AVG. VALUE OF FLUX IN THE COMMUTATING
    ZONE IS %f Wb.',phi_c)
```

Scilab code Exa 4.14 Determining number of pole face conductors of compensating winding in each pole

```
1 clc;
```

```
Pout=2000000;//output power in watts
Vt=400;//output voltage
P=14;//No of poles
A=14;//No of parallel paths of conductor
Pr=0.7;//pole arc to pole pitch ratio
Z=1100;//total armature conductors
Ia=Pout/Vt;//armature current
A_z=(Ia*Z)/(A*P);//armature ampere conductors per
   pole
A_z1=Pr*A_z;//armature ampere conductors per pole to
    be compensated by pole face winding
//The compensating winding carries the entire
   armature current of 5000 A.
Wc=A_z1/Ia;//compensating winding conductors per
   pole
printf('Total compensating winding conductors per
   pole are %f.',round(Wc));
```

Scilab code Exa 4.15 Determining 1 compensating winding conductors per pole 2 number of turns on each interpole

```
clc;
ATp=15000;//armture ampere turns per pole
Pr=0.68;//ratio of pole arc to pole pitch
Ia=850;//rated armature current
Bcp=0.25;//interpolar flux density in tesla
gcp=0.01;//interpolar air gap length
U=4*%pi*0.0000001;//permeability of air
ATc=Pr*ATp;//compensating winding ampere turns per
   pole
C=2*(ATc/Ia);//compensating winding conductors per
   pole
MMF_ag=(Bcp/U)*gcp;//M.M.F. required for the air gap
    under the interpole
MMF=MMF_ag+ATp;//interpole M.M.F. without
```

```
    compensating winding
12 MMF_c=MMF-ATc;//ampere turns furnished by each
    interpole
13 N=MMF_c/Ia;//No. of turns on each interpole
14 printf('Number of turns on each interpole is %f.',
    round(N));
```

Scilab code Exa 4.16 Determining number of series field turns per pole

```
1  clc;
2  Pout=10000;//output power of dc generator in watts
3  Vt=250;//terminal voltage in volts
4  If=2;//field current in ampere at no load
5  If1=2.2;//field current in ampere at rated load
6  Tp=1400;//turns on each pole
7  Ia=Pout/Vt;//armature current
8  MMF_rl=If1*Tp;//M.M.F. required at rated load
9  MMF_nl=If*Tp;//M.M.F. required at no load
10 MMF_s=MMF_rl-MMF_nl;//M.M.F. supplied by series
    winding
11 Is=Ia;//series current at full load
12 Ts=MMF_s/Is;//series field turns
13 printf('Series field turns are equal to %f.',Ts);
```

Scilab code Exa 4.17 Determining demagnetizing effect of armature reaction at rated load and speed

```
1 clc;
2 // table is given in question for plotting
    magnetising curve
3 if1=[ 0 0.2 0.4 0.6 1 1.4 1.8 2 ];
4 Ea=[ 6 40 80 120 194 246 269 274];
5 plot(if1,Ea);
```

```
6  xlabel('If');
7  ylabel('Ea');
8  title('magnetising curve')
9  v=230; // rated voltage of generator
10 p=10000; // rated power of generator
11 n=1500; // rated speed of generator
12 rf=184; // shunt field resistance
13 ra=0.443; // armature resistance
14 ifl=1.7; // rated field current
15 il=p/v; // full load current
16 printf('Total armature current is %f A\n',il+ifl);
17 printf('Armature resistance drop is %f ohms\n',(il+
     ifl)*ra);
18 disp('In fig 4.17(textbook),AB is made equal to
     armature resistance drop then through B a
     horizontal line is made meeting curve at c');
19 disp('Demagnetising effect is given by BC which is
     equal to 0.25 A');
```

Scilab code Exa 4.18 Determining terminal voltage at given speed

```
1  clc;
2  vt1=50; // terminal voltage
3  rf=100; // resistance of field circuit
4  n1=1000; // speed corresponding to vt1=50
5  vt2=225; // terminal voltage
6  n2=2000; // speed corresponding to vt2=225
7  vt3=405; // terminal voltage
8  n3=3000; // speed corresponding to vt3=405
9  disp('case a');
10 ifl1=vt1/rf; // field current for n=1000 rpm
11 ifl2=vt2/rf; // field current for n=2000 rpm
12 ifl3=vt3/rf; // field current for n=3000 rpm
13 printf('Field current for speed=%f rpm is %f A\n',n1
     ,ifl1);
```

```
14 printf('Field current for speed=%f rpm is %f A\n',n2
   ,if12);
15 printf('Field current for speed=%f rpm is %f A\n',n3
   ,if13);
16 vt11=vt1*(n2/n1);
17 printf('Terminal voltage=%f V at %f rpm is
   equivalent to %f V at %f rpm\n',vt1,n1,vt11,n2);
18 vt33=vt3*(n2/n3);
19 printf('Terminal voltage=%f V at %f rpm is
   equivalent to %f V at %f rpm\n',vt3,n3,vt33,n2);
20 disp('Using above data, magnetising curve is drawn
   for n=2000 rpm');
21 // from fig 4.37
22 disp('For field resistance=80 ohms terminal voltage
   is given by BC');
23 disp('BC=253, hence terminal voltage corresponding
   to field resistance of 80 ohms is 253 V');
24 disp('For field resistance=70 ohms terminal voltage
   is given by QP');
25 disp('QP=268, hence terminal voltage corresponding
   to field resistance of 70 ohms is 268 V');
```

Scilab code Exa 4.19 Determining 1 open circuit voltage 2 critical value of shunt field resistance 3 critical speed 4 open circuit voltage for given field resistance 5 terminal voltage

```
1 clc;
2 n=1500; // speed of generator
3 // data is given in question for magnetising curve
   at n=1500 rpm
4 If=[ 0 0.4 0.8 1.2 1.6 2 2.4 2.8 3];
5 Ea=[6 60 120 172.5 202.5 221 231 237 240];
6 subplot(221);
7 plot(If,Ea);
8 xlabel('field current');
```

```
 9 ylabel('generated EMF');
10 title('Magnetising curve for n=1500');
11 disp('case a')
12 rf=100; // field resistance
13 // rf=100 lets say voltage=240 and field current=2.4
       which is shown by point A, straight line passing
       through A and origin meets magnetising current
     at B which is no load voltage
14 Eo=230;
15 printf('No load voltage is %f V\n',Eo);
16 disp('case b');
17 // a line OF is drawn passing through origin slope
     of this line gives critical resistance
18 vt=180; // terminal voltage
19 ifl=1.2; // field current corresponding to terminal
     voltage
20 rfl=vt/ifl;
21 printf('Critical value of shunt field resistance is
     %f ohms\n',rfl);
22 disp('case c');
23 // Choose S (any point) on linear part of
     magnetising curve.A vertical line from S meets
     field resistance line at t and horizontal line at
       y. Now
24 e1=90; // terminal voltage corresponding to point s
25 e2=60; // terminal voltage corresponding to point t
26 n2=(e2/e1)*n;
27 printf('Critical speed for given shunt field
     resistance is %f rpm\n',n2);
28 disp('case d');
29 n3=1200; // speed at which magnetising curve is
     drawn
30 // data for magnetising curve at n=1200 can be
     obtained by multiplying voltage of magnetising
     curve at n=1500 by factor 1200/1500 and at point
     C field resistance line for 100 ohms meet at
     magnetising curve .This point gives no load EMF
31 EAn=Ea*(n3/n);
```

```
32 subplot(222);
33 plot(If,EAn);
34 xlabel('field current');
35 ylabel('generated EMF');
36 title('Magnetising curve for n=1200');
37 Eo=165;
38 printf('No load EMF is %f V\n',Eo);
39 disp('case e');
40 ia=50; // armature current
41 ra=0.3; // armature resistance
42 vd=ia*ra; // armature resistance drop
43 // To obtain terminal voltage cut OD equal to vd and
       draw DG parallel to field resistance line. From
     G draw vertical line  meeting field resistance
     line at H. Point corresponding to H gives
     terminal voltage which is
44 vt=207;
45 printf('Terminal voltage is %f V\n',vt);
```

Scilab code Exa 4.20 Determining 1 no load emf 2 output current and shunt field current 3 maximum output current and terminal voltage 4 steady state short circuit current 5 additional resistance that must be inserted in field circuit

```
1 clc;
2 ra=0.5; // armature resistance
3 rf=180; // shunt field resistance
4 n=1100; // speed at which generator is being driven
5 n1=1000; // speed for which data is given
6 disp('case a');
7 // from the data given in question magnetising curve
      is drawn (fig 4.46)
8 If=[ 0 0.2 0.4 0.6 0.8 1 1.2 1.4 ];
9 Ea=[5 50 100 140 170 190 200 205];
10 Ean=(n/n1)*Ea
```

```
11 plot(If,Ean);
12 xlabel('field current');
13 ylabel('generated EMF');
14 title('Magnetising curve for n=1100');
15 // line corresponding to rf=180 ohms to meet
      saturation curve at 221 V which is no load EMF
16 Eo=221;
17 printf('No load EMF is %f V\n',Eo);
18 disp('case b');
19 vt=190; // terminal voltage
20 // from curve armature resistance drop is given by
      line BC
21 vd=22.5; // armature resistance drop
22 ia=vd/ra; // armature current
23 ifl=vt/rf; // field current
24 printf('Shunt field current is %f A\n',ifl);
25 printf('Output current is %f A\n',ia-ifl);
26 disp('case c');
27 // OP represents maximum armature resistance drop i.
      e OP=46.5 V
28 vd=46.5;
29 ia=vd/ra; // armature resistance
30 // tangent point at R gives field current which is
31 ifl=0.635;
32 printf('Maximum output current is %f A',ia-ifl);
33 disp('case d');
34 // under steady state short circuit terminal voltage
     =0 V and residual flux EMF is
35 E=5.5; // residual flux EMF
36 printf('Steady state short circuit current is %f A\n
     ',E/ra);
37 disp('case e');
38 Eo=210; // no load voltage
39 // for Eo OD represents field resistance field
      current is 1.015
40 ifl=1.015; // field current
41 rfn=Eo/ifl; // field resistance
42 printf('Additional resistance required is %f ohms\n'
```

```
   ,rfn-rf);
43 disp('case f');
44 rf=150; // shunt field resistance
45 vt=180; // terminal voltage
46 p=0.04; // reduction in flux due to armature
   reaction
47 ifl=vt/rf; // field current
48 Ea=220*(1-p); // generated voltage
49 ia=(Ea-vt)/ra; // armature current
50 il=ia-ifl; // load current
51 printf('Load power is %f KW',(vt*il)/1000);
```

Scilab code Exa 4.21 Determining range of external rheostat and dissipating power

```
1  clc;
2  Vrated=30;//rated output voltage of generater
3  Irated=200;//rated output current of generator
4  Ra=0.03;//armature resistance(including brushes)
5  Rf=2.4;//field winding resistance
6  //No-load saturation curve at 2200rpm
7  If=[2 4 6 8 10 12];
8  Ea=[15 27 35 40 43 45];
9  plot(If,Ea);//magnetization curve at 2200 rpm
10
11
12 //(1)AT 2200 rpm
13 //at no load
14 Ea1=28;//induced voltage in armature
15 //for this voltage, the field current required, from
       magnetization curve is-
16 If1=4.23;//field current in ampere
17 Rt1=Ea1/If1;//total shunt field resistance
18 Re=Rt1-Rf;//external resistance
19
```

```
20 //at full load
21 Ea1_=28+Irated*Ra;//induced voltage in armature
22 //for this voltage, the field current required, from
       magnetization curve is-
23 If1_=5.67;//field current
24 Rt1_=Ea1/If1_;//total shunt field resistance
25 Re_=Rt1_-Rf;//external resistance
26
27
28 //(2)AT 4500 rpm
29 //at no load
30 Ea2__=28;//induced voltage in armature at 4500 rpm
31 Ea2=28*(2200/4500);//Ea at 2200 rpm
32 //for this voltage, the field current required, from
       magnetization curve is-
33 If2=1.833;//field current in ampere
34 Rt2=Ea2__/If2;//total shunt field resistance
35 Re__=Rt2-Rf;//external resistance
36
37 //at full load
38 Ea2___=28+Irated*Ra;//induced voltage in armature at
       4500 rpm
39 Ea2_=34*(2200/4500);//Ea at 4500 rpm
40 //for this voltage, the field current required, from
       magnetization curve is-
41 If2_=2.17;//field current
42 Rt2_=Ea2__/If2_;//total shunt field resistance
43 Re___=Rt2_-Rf;//external resistance
44 Pmax=If1_*If1_*min(Re,Re_,Re__,Re___);
45 printf('The minimum & maximum value of external
     resistance is %f & %fohm respectively.\nMaximum
     power dissipated through rheostat is %f ohm.',min
     (Re,Re_,Re__,Re___),max(Re,Re_,Re__,Re___),Pmax);
```

Scilab code Exa 4.22 Determining field circuit resistance and flux per pole

```
clc;
Vt=100;//terminnal voltage
P=2;//no of poles
Z=1000;//no of conductors
A=2;//no of parallel paths for armature conductors
Ra_=2*10e-3;//resistance of each armature
Ra=500*Ra_*(1/2);//total armature resistance
//Let If be field current
//Ea=Vt+(Il+If)*0.5
//Ea1=100+(10+If)*0.5,because at 1055 rpm Il=10.
//Ea2=100+(20+If)*0.5,because at 1105 rpm Il=20.
//But, Ea=k1*If*speed
//Therefore,((If*1055)/(If*1105))=((100+(10+If)*0.5)
   /(100+(20+If)*0.5)),which gives-
If=1;//field current
Ea1=100+(10+1)*0.5;//at 1055 rpm
N=1055;//speed of rotor
phi=(Ea1*60*A)/(Z*N*P);
Rf=Vt/If;//field circuit resistance
printf('Field circuit resistance is %f ohm.\n',Rf);
printf('Flux per pole is %f Wb.',phi);
```

Scilab code Exa 4.23 Determining 1 value of regulator resistance 2 no load terminal voltage for given speeds

```
clc;
disp('case a');
v=90; // voltage build up by regulating resistance
rs=(v*v)/(2*v); // shunt winding resistance
IF=[500 1000 1500 2000 2500 3000];
VA=[154 302 396 458 505 538 ];
subplot(313);
plot(IF,VA);
xlabel('Field ATs/pole');
ylabel('Generated e.m.f E,(V)');
```

```
11 title('Magnetizing curve for n=500 r.p.m.');
12 // from magnetizing curve for v=90, field current is
       0.89 A
13 ifl=0.89; // field current
14 re=(v/(2*ifl))-rs;
15 printf('Value of the resistance in the regulator is
      %f ohms\n',re);
16 disp('case b');
17 t1=800; // turns per pole of separately excited
      winding
18 r1=160; // resistance of winding
19 vc=220; // constant supply voltage
20 t2=500; // turns per pole of shunt winding
21 r2=200; // resistance of winding
22 AT1=(vc*t1)/r1; // Ampere turns of separately
      excited winding
23 // AT2=(t2/r2)*E is Ampere turns of shunt winding
      and E is generated EMF
24 AT3=AT1+(t2/r2)*VA
25 n1=500;
26 n2=600; // given speeds
27 VA2=(n2/n1)*VA; // generated EMF for n=600 rpm
28 subplot(323);
29 plot(IF,VA2);
30 xlabel('Field ATs/pole');
31 ylabel('Generated e.m.f E,(V)');
32 title('Magnetizing curve for n=600 r.p.m.');
33 subplot(333);
34 plot(AT3,VA);
35 ylabel('Generated e.m.f E,(V)');
36 xlabel('Total ATs/pole due to both field winding');
37 title('Generated e.m.f E,(V) vs total Ampere turns/
      pole ');
38 // plot of variation of generated e.m.f with total
      Ampere turns per pole intersects magnetizing
      curve for n=500 rpm at P and  magnetizing curve
      for n=600 rpm at Q. (refer fig. 4.48)
39 // Point P gives no-load terminal voltage at 500 rpm
```

```
    and Q gives no-load terminal voltage at 600 rpm
40 disp('No load voltage at 500 rpm is 490 V and at 600
    rpm is 621 V');
```

Scilab code Exa 4.24 Determining terminal voltage and number of series field turns per pole

```
1  clc;
2  //magnetization curve at 1200 rpm
3  If=[0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8];//field
     current in rpm
4  Ea=[6 53 106 160 209 241 258 272 282 288];//induced
     voltage in armature
5  plot(If,Ea);xlabel('If');ylabel('Ea');//
     magnetization curve at 1200 rpm
6  Pout=10000;//genertor output in watts
7  Vt=230;//Terminal Voltage
8  Ra=0.5;//armature resistance with brushes
9  Ns=1000;//turns of shunt winding
10 Nf=4;//turns of field winding
11 Z=1000;//No of conductors
12
13 //PART (A)
14 //At rated output current the speed is 1150 rpm &
     shunt field current is 1 A
15 If_=1;//field current at rated o/p current
16 Il=Pout/Vt;//rated output current
17 Ia=Il+If;//armature current at rated load
18 Is=Ia;//for long shunt compound generator the series
     field current is equal to armature current
19 //Since the compound geenerator is cumulatively
     compounded ,the total pole per m.m.f. is (Nf*If+
     Ns*Is)ampere turns
20 //Thus the equivalent shunt field current is given
     by 1/Nf*(Nf*If+Ns*Is)=1+(4*44.5/1000)=1.18 A. The
```

```
    generated emf for this field currenr from the
    magnetization curve is 257 volts.
//For speed of 1150 rpm the generated emf is-
Ea_=257*(1150/1200);
Vt_=Ea_-Ia*Ra;//terminal voltage

//PART(B)
Eg=Vt+Ia*Ra;//generated emf in the armature at 1150
    rpm
//By using the magnetization curve, the generated
    emf at 1200 rpm will be 252.25*(1200/1500)=263.3
    volts.
//From the open circuit characteristics, the field
    current corresponding to 263.3 volts is 1.26 A.
MMFt=1.26*1000;//Total MMF
//Total MMF must be produced by the combined action
    of shunt & series windings.
//1.26*1000=1.00*1000+Ns*(44.5);
Ns_=(0.26*1000)/44.5;//series field turns
printf('The number of series field turns should be
    %f.',round(Ns_));
```

Scilab code Exa 4.25 Determining series field turns and resistance of diverter for achieving desired performance

```
clc;
//repeat part (b) of example 4.21

//PART(a)-
//When the demagnetizing effect is accounted for,
    then from equation :-Net mmf = Nf*If+Ns*Is-ATd
    ....(1)
//1.26*1000=1.00*1000+10Is-0.022Is*1000
Ns=round(0.3578*1000/44.5);//no of turns in series
    field winding
```

```
8
9  //PART(b)-
10 //If there are 10 series field turns, then from
       equation (1),
11 //1.26*1000=1.00*1000+10Is-0.0022Is*1000
12 Is=0.26/0.0078
13 //Out of the total armature current of 44.5 A, only
       Is(33.3) should flow through the series field.
14 //This can be achieved by putting a resistor in
       parallel with the series field winding.
15 //33.3=(44.5*Rdi)/(0.05+Rdi)
16 Rdi=0.05/0.3363;
17 printf('NO OF TURNS IN SERIES FIELD WINDING ARE %f.'
       ,Ns);
18 printf('\nTHE RESISTANCE OF DIVERTER Rdi SHOULD BE
       %f OHMS.',Rdi);
```

Scilab code Exa 4.26 Determining emf generated in armature and percentage change in series field ampere turns due to diverter

```
1  clc;
2  Vt=250;//rated o/p voltage of generator
3  Pout=10000;//o/p of generator in watts
4  Ra=0.4;//armature resistance
5  Rse=0.2;//series field resistance
6  Rs=125;//shunt field reesistance
7  Vb=2;//total brush cotact drop
8  Il=Pout/Vt;//load current
9
10 //PART(a)-LONG SHUNT CONNECTION
11 If=Vt/Rs;//shunt field current
12 Ia=Il+If;//armature current
13 //series field winding also carries Ia.
14 Eal=Vt+Ia*(Rse+Ra)+Vb;//generated emf in armature
15 printf('The generated EMF in armature when the
```

```
    generated is connected as long shunt machine is
    %f.\n',Eal);
16
17 //PART(b)-SHORT SHUNT CONNECTION
18 V=Vt+Il*Rse;//voltage across shunt field and
    armature terminals
19 If_=V/Rs;//shunt field current
20 Ia_=Il+If_;//armature current
21 Eas=V+Ia*Ra+Vb;//generated emf in armature
22 printf('The generated EMF in armature when the
    generated is connected as short shunt machine is
    %f.',Eas);
23
24 //PART(c)-
25 //Series field ampere turns are proportional to
    series-field current I
26 //Is=0.3/0.5*I, where , Is is series field current
    with diverter.
27 //series field ampere-turns with dvider = K*0.6*Is,
    where K is a constant.
28 //percentage reduction in series field ampere turns
    is - ((I-0.6I)/I)*100.
29 disp('Percentage reduction in series field ampere
    turns is 40%.');
```

Scilab code Exa 4.27 Determining speed and developed torque at full load

```
1 clc;
2 Vt=230;//output voltage
3 Ra=0.3;//armature circuit resistance
4 Rf=160;//field circuit resistance
5 Il=40;//line current at full load & rated voltage
6 Ia1=3.33//armature current at rated voltage & no
    load speed of 1000 rpm
```

```
7 //No load counter emf is-
8 Ea1=Vt-Ia1*Ra;
9 If=Vt/Rf;//field current
10 //At full load armature current is-
11 Ia2=Il-If;
12 Ea2=Vt-Ia2*Ra;//Counter emf at full load
13 //At full load, the field flux is-
14 //Phi_2=0.96*phi_1
15 //The conter emf Ea, is given by- Ea=Ka*phi*Wm
16 //Ea1/Ea2=(Ka*phi_1*Wm1)/(Ka*phi_2*Wm2)=(phi_1*n1)/(
   phi_2*n2) or 229/218.43=(1000*phi_1)/n2*(0.96*
   phi_1)...(1)
17 //from equation (1)
18 n2=995;//full load speed
19 //At full load, Ea2=Ka*phi_2*Wm
20 //Ka*phi_2=Ea2/Wm
21 //Electromagnetic or developed, torque at full load
   is, Te=Ka*phi_2*Ia2
22 Te=(Ea2*60)/(2*%pi*n2)*Ia2;//Electromagnetic torque
   developed.
23 printf('Electromagnetic or developed, torque at full
    load is %f.',Te);
```

Scilab code Exa 4.28 Determining motor speed and rated shaft torque

```
1 clc;
2 //Armature reaction is neglected
3 Vt=220;//output voltage
4 Ra=0.2;//armature circuit resistance
5 Rf=110;//field circuit resistance
6 n1=1500;//speed of rotor at no load
7 Il1=5;//curent drawn by motor in ampere at no load &
    1500 rpm
8 Il2=52;//curent drawn by motor in ampere at rated
   load & rated voltage
```

```
If=Vt/Rf;//shunt field current
Ia1=Il1-If;//armature current at no load
Ea1=Vt-Ia1*Ra;//counter emf at no load
Pr=Ea1*Ia1;//rotational losses at no load
//Rotational losses at full load & no load are same
Ia2=Il2-If;//armature current at full load
Ea2=Vt-Ia2*Ra;//counter emf at full load
Pem=Ia2*Ea2;//electromagnetic power
//Here phi_1(no load flux)=phi_2(full load flux),
   because the field current is constant & effect of
    AR is neglected.
//Ea1/Ea2=(n1*phi_1)/(n2*phi_2);where n1 & n2 are
   speed of rotor at no load & full load
   respectively.
n2=fix((n1*Ea2)/(Ea1));
Psh=Pem-Pr;//shaft power
Wm=(2*%pi*n2)/60;//angular velocity of shaft at full
    load
Tsh=Psh/Wm//shaft torque
printf('The motor speed is %f rpm.\n',n2);
printf('Rated shaft torque is %f Nm.',Tsh);
```

Scilab code Exa 4.29 Determining external resistance inserted in field circuit

```

clc;
Ra=0.4;//armature resistance in ohm
Rf=200;//field circuit resistance in ohm
Vt=230;//terminal voltage for dc motor
If_1=1.1;//field current for dc generator at open
   circuit voltage of 210 V.
If_2=0.9;//field current for dc generator at open
   circuit voltage of 230 V.
Ia=24;//armature current for dc shunt motor at 1500
```

```
    rpm
Ea=Vt-Ia*Ra;//counter e.m.f. for dc motor at 1500
    rpm and full load
//For generated e.m.f., Ea=230 V, field current is
    1.1 A & for Ea=210 V, field current is 0.9 A
//The change in generated e.m.f. is 20 V for field
    variation of 0.2 A & this change is linear.
//Therefore for a generated e.m.f. of Ea=220.4 V at
    1500 rpm, the field current would be-
If=0.9+(0.2/20)*10.4;//0.9 A for 210 V & (0.2/20)
    *10.4 for remaining 10.4 V.
Rsh=Vt/If;//Shunt field resistance required for a
    field current(If) with terminal voltage(Vt).
Rext=Rsh-Rf;//External resistance that must be
    inserted in shunt field circuit
printf('The external resistance that must be
    inserted in shunt field circuit = %f ohm.',Rext);
```

Scilab code Exa 4.30 Determining 1 speed and internal torque developed 2 shaft power shaft torque and efficiency

```
clc;
//Armature reaction is neglected.
Vt=250;//Supply voltage
P=4;//No of poles
A=2;//No of parallel paths for armature conductors
Z=500;//No of armature conductors
Ra=0.25;//armature circuit resistance in ohm
Rf=125;//field resistance in ohm
phi=0.02;//flux per pole in weber
Il=14;//current drawn by motor from supply mains
Ish=Vt/Rf;//constant shunt field current
Pr=300;//rotational losses in watts
Pi=Vt*Il;//power input in watts

```

```
15 //PART(a)-
16 Ia=Il-Ish;//armature current
17 Ea=Vt-Ia*Ra;//counter/back emf
18 //Ea=(P*phi*Z*N)/(60*A)
19 N=(60*A*Ea)/(P*phi*Z);//speed of rotation of motor
      in rpm
20 Wm=(2*%pi*N)/60;//angular velocity of motor
21 Pe=Ea*Ia;//electromagnetic power
22 Ti=Pe/Wm;//Internal torque developed in Nm.
23 printf('Speed of rotation of motor is %f rpm.',N);
24 printf('\nInternal torque developed = %f Nm.',Ti);
25
26 //PART(b)-
27 Psh=Pe-Pr;//shaft power
28 Tsh=Psh/Wm;//shaft torque
29 %n=(Psh/Pi)*100;//percentage eficiency
30 printf('\nShaft power = %f watts.',Psh);
31 printf('\nShaft torque = %f Nm.',Tsh);
32 printf('\nEfficiency of motor is %f percent.',%n);
```

Scilab code Exa 4.31 Determining shaft power operating speed armature current and motor efficiency

```
1 clc;
2 Vt=230;//Supply voltage
3 P=4;//No of poles
4 A=2;//No of parallel paths for armature conductors
5 Z=600;//No of armature conductors
6 Ra=0.25;//armature circuit resistance in ohm
7 phi=0.01;//flux per pole in weber
8 Pr=500;//rotational losses in watts
9 //generated emf in armature, Ea=(phi*Z*P*n)/(60*A)
     if n is speed in armature
10 //Counter emf is Ea=(0.01*600*4*n)/(60*2)=0.2n volts
11 //Vt=Ea+Ia*Ra
```

```
12 //Ia=(Vt-Ea)/Ra/
13 //Shaft o/p in watts, Psh=Ea*Ia-Pr, Psh=(0.2n)
     *(920-0.8n)-500 ....(1)
14 n=[700 800 900 1000 1100];//different speeds of
     motor for which the shaft o/p power is to be
     measured
15 //Psh=(0.184*n)-(1.6*(10e-4)*n*n)-0.5, Shaft o/p
     power in KW.
16 Psh1=49.1;//Shaft o/p power in KW at n=700 rpm
17 Psh2=44.3;//Shaft o/p power in KW at n=800 rpm
18 Psh3=33.5;//Shaft o/p power in KW at n=900 rpm
          *Psh1,Psh2,Psh3,Psh4,Psh5 are calclulated
     from equation (1)*
19 Psh4=23.5;//Shaft o/p power in KW at n=1000 rpm
20 Psh5=8.3;//Shaft o/p power in KW at n=1100 rpm
21 Psh=[Psh1 Psh2 Psh3 Psh4 Psh5];
22 Pi=[4.5 8.5 14 21.1 30];//i/p power supplied to fan
     in KW.
23 plot(n,Psh,n,Pi);xlabel('RPM');ylabel('KW');//Shaft
     o/p power versus speed of motor and power i/p
     versus speed of fan are plotted on the same graph
24 //For plot :-*blue line- motor characteristic,green
     line- fan charactestic*
25 //The intesecton of these two curves is called as
     OPERATING POINT.
26 //At operating point the speed is 1012 rpm & pwer o/
     p of motor or power i/p to the fan is 22 KW ....(
     from the intersection point of two curves)
27 n_=1012;//speed at operating point
28 P_o=22000;//Power output loss
29 Ia=920-(0.8*n_);//armature current
30 Parm=Ia*Ia*Ra;//armature loss
31 P_ip=P_o+Pr+Parm;//Power input
32 %n=(P_o/P_ip)*100;//motor efficiency
33 printf('Armature current is %f A\n.',Ia);
34 printf('Operating speed is %f rpm\n.',n_)
35 printf('Motor efficiency is %f percent.',%n);
```

Scilab code Exa 4.32 Determining speed of motor

```
clc;
Vt=230;//Supply voltage
P=4;//No of poles
A=2;//No of parallel paths for armature conductors
Z=500;//No of armature conductors
Ra=0.2;//armature circuit resistance in ohm
Rs=0.1;//field resistance in ohm
Il=40;//line current
N=1000;//rated speed in rpm
Ia1=40;//armature current for dc series motor at 40 A line current
Ia2=20;//armature current for dc series motor at 20 A line current
//For 40A line current
Ea1=Vt-Ia1*(Ra+Rs);//counter emf
//For 20A line current
Ea2=Vt-Ia2*(Ra+Rs);//counter emf
//Let, phi_1=flux at 40 A, phi_2=flux at 20 A line current
//phi_2=0.6*(phi_1)
//(Ea1/Ea2)=(n1*phi_1)/(n2*phi_2)
//(218/224)=(1000*(phi_1))/(n2*(0.6*(phi_1))
n2=(1000*224)/(218*0.6);//speed of motor at line current of 20 A at 230 V
printf('Speed of motor at line current of 20 A at 230 V is %f rpm.',round(n2));
```

Scilab code Exa 4.33 Determining 1 speed in rpm 2 shaft power output

```
1  //ANSWER GIVEN IN THE BOOK FOR THIS QUESTION IS
     INCORRECT.
2
3  clc;
4  //Neglecting armature reaction & magnetic saturation
5  //Assuming rotational losses to remain constant
6  V=230;//Supply voltage
7  P=15000;//power rating of dc series motor in watts
8  Il_1=80;//line current rated
9  Il_2=40;//line current assuming that motor draws
     half the rated current at rated voltage
10 Ia_1=Il_1;//armature current at line current equal
     to 80 A.
11 Ia_2=Il_2;//armature current at line current equal
     to 40 A.
12 n1=1000;//rated speed in rpm
13 //Full load losses expressed as percentage of motor
     input:-
14 //Armature ohmic loss=2.8%(including brush loss)
15 //Field ohmic loss=2.2%
16 //Rotational loss=2.2%
17 P_ip=V*Il_1;//full load input
18 P_ohmic=P_ip*(5.4/100)//As percent of total ohmic
     losses=2.2+2.8=5.4%
19 //But P_ohmic=Il*Il*(Ra+Rs); where (Ra+Rs)=(armature
     + series field) resistance
20 //(Ra+Rs)=P_ohmic/(Il*Il)=0.115 ohms
21 //Let, r=(Ra+Rs)
22 r=0.115;
23
24 //PART(a)-
25 Ea1=V-(Ia_1*r);//counter emf at line current = 80 A
26 Ea2=V-(Ia_2*r);//counter emf at line current = 40 A
27 //Since the magnetic saturation is neglected, phi_1=
     k*80 & phi_2=k*40; where k=constant & phi_1 &
     phi_2 are flux per pole at line currents 80 & 40
     A respectively.
28 //(Ea1/Ea2)=(n1*phi_1)/(n2*phi_2) or (220.8/225.4)
```

```
    =(1000*80)/(n2*40); where Ea1=220.8 V Ea2=225.4 V
    .
29 n2=(1000*80*225.4)/(40*220.8);//speed in rpm
30 printf('The speed of rotation of motor when the
    motor draws half the rated current at rated
    voltage is %f rpm.',round(n2));
31
32 //PART(b)-
33 Pr=P_ip*(2.2/100);//rotational losses
34 Psh=Ea2*Ia_2-Pr;
35 printf('\nThe shaft output power is %f W.',Psh);
```

Scilab code Exa 4.34 Determining operating speed and current drawn from source

```
1
2 clc;
3 Pout=40000;//output power
4 V=250;//supply voltage in volts
5 r=0.2;//sum of armature circuit resistance & series
    field circuit resistance
6 n=1500;//speed of dc series motor at rated current
7
8 //PART(a)-
9
10 Ir=Pout/V;//rated current
11 Ea=V-Ir*r;//counter emf at rated load
12 Wm=(2*%pi*n)/60;//angular speed of rotation of motor
13 Te=round((Ea*Ir)/Wm);//rated electromagnetic torque
    in Nm.
14 //Now the relation giving the torque speed
    characteristics of series motor must be developed
    .
15 //Since the magnetic saturation is neglected
16 //Te=Ka*phi*I
```

```
17 //Te=K1*Ia^2
18 K1=Te/(Ir^2);//Ia=rated current
19 //Ea=K2*phi*n=K2*Ia*n
20 K2=Ea/(Ir*n);// values of constant of
      proportionality
21 //The values of constants k1 & K2 are obtained from
      rated conditions
22 //Ia=(V-Ea)/r & Ea=K2*Ia*n ; Ia=1250-0.00454*Ia*n
23 //Ia=1250/(1+0.00454n) ....(1); Ia=armature current
      at any speed
24 //Te=K1*Ia^2
25 n=[1400 1450 1500 1550 1600 1650 1700];
26 Te=K1.*(((V/r)^2)./(1+(K2/r).*n).^2); //
      Electromagnetic torque
27 Tl=5.*sqrt(n); // load torque
28 plot(Te,n,Tl,n);
29 xlabel('T(Nm)');
30 ylabel('Speed(rpm)');
31 title('Speed-torque characteristics for Series-motor
       and for load');
32
33 //THE INTERSECTION OF SERIES MOTOR & LOAD
      CHARACTERISTICS GIVES THE OPERATING POINT
34
35 //From the curve the operating point is obtained at
      1591 rpm & torque is 199.5 Nm
36 disp('The operating speed of motor is 1591 rpm.');
37
38 //PART(b)-
39 //Current drawn from the source is -
40 Ia=(V/r)/(1+(K2/r)*1591);//From equation (1)
41 printf('Current drawn from the source is %f A.',Ia);
```

Scilab code Exa 4.35 Determining number of series field turns

```
clc;
V=230;//supply current
Pout=15000;//output voltage
Ra=0.2;//armature circuit resistance
Rse=0.1;//resistance of series field winding
Nf=1000;//shunt field turns per pole
//Data for magnetization curve at 1500 rpm
If_=[0 0.2 0.4 0.6 0.8 1.02 1.15 1.32 1.56 1.92
   2.4];//field current at 1500 rpm
Ea=[6 40 80 120 160 200 220 240 260 280 300];//
   counter emf at 1500 rpm and respective field
   current
plot(If_,Ea);//Magnetization curve at 1500 rpm
Ia_1=4;//armature current at rated voltage and rated
    load
Ia_2=70;//armature current at 1200rpm

//At no load
Ea_=V-Ia_1*Ra;//counter emf
//field current required for Ea_(ie.229.2 V),from O.
   C.C. is 1.23 A.

//At load
Ea__=V-Ia_2*(Ra+Rse);//counter emf at 1200 rpm
Ea___=209*(1500/1200);//Ea at speed of 1500 rpm
//Field current corresponding to Ea___(ie.261.25 V),
   from O.C.C. is 1.575 A.
//Total D-axis mmf per pole=Nf*If+Ns*Is
If=1.23;//field current at 229.2 V is 1.23 A
If1=1.23;//field current at 261.25 V is 1.575 A
//1.575*1000=1.23*1000+Ns*(70)
Ns=(0.345*1000)/70;//series field turns
printf('For long-shunt connection, series field
   turns is equal to %f.',round(Ns));
```

Scilab code Exa 4.36 Determining 1 shunt field current 2 effective armature reaction 3 number of series field turns 4 speed at rated armature current and at rated voltage 5 internal starting torque

```
1 //Answer for part(e) in book is incorrect.
2 clc;
3 //Magnetization curve is same as that of example
    4.33
4 Ra=0.2;//armature resistance (including brushes)
5 Nf=2000;//shunt field turns
6 N=1500;//motor speed in rpm at no load as well as
    rated load.
7 Ia=36;//motor armature current in Amperes at rated
    load
8
9 //PART(a)-At no load,
10 Vt=230;//supply mains in volts
11 Ea_a=Vt;//counter emf, neglecting armature circuit
    resistance
12 If_a=1.23;//field current in amperes
13 printf('(a) Shunt field current is %f A.\n',If_a);
14 //Thus constant shunt field current If from O.C.C.
    is 1.23 A corresponding to 230V.
15
16 //PART(b)-At full load,
17 Ea_b=Vt-Ia*Ra;//counter emf
18 //A point is drawn on magnetization curve with
    coordinates A(If,Ea_b).
19 //The horizontal distance between Pt. A & the
    magnetization curve, gives the effective armature
     reaction in terms of shunt field current, its
    value is 0.06 A.
20 AT_arm=Nf*0.06;//armature reaction in amopere turns
    per pole
21 printf('(b) Effective armature reaction is %f ampere
     turns per pole.\n',AT_arm);
22
23 //PART(c)-At rated load, with series winding in
```

```
    circuit & motor is cumulatively compounded,
Rse=0.05;//series field resistance in ohm
Ea__c=Vt-Ia*(Ra+Rse);//counter emf at 1350 rpm
Ea_c=Ea__c*(1500/1350);//Ea at 1500 rpm
//From magnetization curve, Ea=245.5 V requires If_c
    =1.365 A.
//From equation - Net MMF =Nf*If+Ns*Is-ATd ....(1)
//1.365*2000=1.23*2000+Ns*(36)-120
Ns=round(65/6);//Series field current
printf('(c) Required no of series field turns are %f
    .\n',Ns);

//PART(d)-If the series field winding has 20 turns -
Ns_=20;//no of turns of series field winding
//Net mmf = Nf*If+Ns_*Is-AT_arm ....(formula)
mmf_net=If_a*Nf+Ns_*Ia-AT_arm;//Net field mmf in
    terms of ATs
If_d=(If_a*Nf+Ns_*Ia-AT_arm)/Nf;//Net field mmf in
    terms of the equivalent shunt field current(A).
//From the magnetization curve, the value of Ea
    corresponding to If=1.53A is 258V at 1500rpm.
//But the counter emf,Ea corresponding to rated
    current is 230-36(0.2+0.05)=221 V.
//Therefore the motor speed n corresponding to Ea
    =221V is-
//(221/258)=(n/1500)
n=(221/258)*1500;
printf('(d) Speed at rated voltage rated armature
    current is %f rpm.\n',round(n));

//PART(e)-Assuming demagnetizing effect of armature
    reaction to be 200 ampere turns per pole.
ATarm=200;//demagnetizing effect of armature
    reaction in ampere turns per pole.
Ia_e=50;//armature current in amperes ....(given)
mmfnet=If_a*Nf+Ns_*Ia_e-ATarm;//from equation no
    ....(1)
If_e=mmfnet/Nf;//Net field mmf in terms of the
```

```
    equivalent shunt field current(A).
50 //From the magnetizing curve, corresponding to field
    current If_e(1.63 A), Ea at 1500 rpm is 264 V.
51 //But, Ea=Ka*phi*Wm ; where, phi = flux per pole
52 //Thus, Ka*phi=(264*60)/(2*%pi*1500)
53 Kaphi=264/(50*%pi);//Ka*phi
54 Test=Kaphi*Ia_e;//starting torque
55 printf('(e) When the armature current is limited to
    50 A the starting torque is %f Nm.',Test);
```

Scilab code Exa 4.37 Determining steady state speed and armature current drawn from source

```
1
2 clc;
3 V=230;//supply voltage in volts
4 Ra=0.5;//armature resistance in ohm
5 N=250;//rated speed of motor
6 I=100;//rated current in ampere
7 //For the separately excited dc motor torque-speed
    characteristics is given by Tl=500-W, where W is
    rotational speed in rad/sec & Tl is load torque
    in Nm.
8 //At rated load, motor counter emf is -
9 Ea=V-I*Ra;
10 //Ea=Km*Wr; Km = motor constant, Wr = rated motor
    speed in rad/sec
11 Wr=(2*%pi*250)/60;//rated motor speed in rad/sec
12 Km=Ea/Wr;//motor constant in V-s/rad
13 //Armature current at any speed W is given by-
14 Ia=(V-Ea)/Ra;// ie. Ia=(230-Km*W)/0.5
15 //Motor torque, Te=Km*Ia=(Km/0.5)*(230-Km*W)
16 //Under steady state, motor torque ,Te=load torque,
    Tl
17 //Thus, (Km/0.5)*(230-Km*W)=500-10*W
```

```
18 W=(((V*Km)/Ra)-500)/((Km^2/Ra)-10);//angular speed
      in rpm
19 N_=(W*60)/(2*%pi);//Speed in rpm
20 Ia_=(230-Km*W)/0.5//armature current
21 printf('Steady state speed of motor is %f rpm\n.',N_
      );
22 printf('Armature current drawn by motor at steady
      state is %f A.',Ia_);
```

Scilab code Exa 4.38 Determining 1 external resistance 2 value of first resistance element 3 external resistance cut out in second step 4 total number of steps

```
1  clc;
2  v=230; // rated voltage of dc motor
3  p=10000; // rated power of dc motor
4  rf=115; // field resistance
5  ra=0.348; // net armature resistance
6  ifs=v/rf; // shunt field current
7  ia=(p/v)-ifs; // rated armature current
8  disp('case a');
9  rx1=(v/(2*ia))-ra;
10 printf('External resistance required at the time of
      starting is %f ohms\n',rx1);
11 disp('case b');
12 Ea1=v-ia*(rx1+ra); // counter emf at stud 1
13 r2=(v-Ea1)/(2*ia); // resistance when handle is
      moved to 2nd stud
14 rx2=r2-ra; // external resistance
15 rc=rx1-rx2;
16 printf('Resistance that must be cut out in first
      step is %f ohms\n',rc);
17 disp('case c');
18 Ea2=v-ia*rc; // counter emf at stud 2
19 r3=(v-Ea2)/(2*ia); // resistance when handle is
```

```
    moved to 3rd stud
rc=rc-r3;
printf('Resistance that must be cut out in second
    step is %f ohms\n',rc);
disp('case d');
Ea3=v-ia*rc; // counter emf at stud 3
r4=(v-Ea3)/(2*ia); // resistance when handle is
    moved to 4th stud
rc=rc-r4;
printf('Resistance that must be cut out in third
    step is %f ohms\n',rc);
disp('Total number of steps is 3');
```

Scilab code Exa 4.39 Calculating 1 resistance of each step 2 voltage at which contactors should be close

```
clc;
v=240; // rated voltage of dc shunt motor
i=50; // rated current of dc shunt motor
ra=0.2; // armature resistance
n=4; // number of resistance element
N=1500; // rated speed of motor
vb=1; // pu base voltage
ia=1; // pu base current
rb=v/i; // pu base resistance
ra=ra/rb; // per unit armature resistance
disp('case a');
ia1=1.4; // pu maximum allowable armature current
R=vb/ia1; // net resistance
al=(ra/R)^(1/n); // ratio of total resistances on
    two adjacent studs
r1=R*(1-al);
printf('Resistance cut out when handle is at stud 2
    is %f pu or %f ohms\n',r1,r1*rb);
r2=al*r1;
```

```
18 printf('Resistance cut out when handle is at stud 3
      is %f pu or %f ohms\n',r2,r2*rb);
19 r3=al*r2;
20 printf('Resistance cut out when handle is at stud 4
      is %f pu or %f ohms\n',r3,r3*rb);
21 r4=al*r3;
22 printf('Resistance cut out when handle is at stud 5
      is %f pu or %f ohms\n',r4,r4*rb);
23 disp('case b');
24 ia2=al*ia1; // pu minimum armature current
25 // at stud 1 armature current=ia2 after t1 where t
      is time reckoned from the instant motor is
      switched on
26 Ea1=vb-ia2*R; // counter EMF at stud 1
27 Va1=Ea1+ia2*ra; // voltage across at armature
      terminal at instant t1
28 printf('The first contactor should close at %f pu or
       %f V\n',Va1,Va1*v);
29 // at stud 2 armature current=ia2 after t2 where t
      is time reckoned from the instant motor is
      switched on
30 Ea2=vb-ia2*(R-r1); // counter EMF at stud 2
31 Va2=Ea2+ia2*ra; // voltage across at armature
      terminal at instant t2
32 printf('The second contactor should close at %f pu
      or %f V\n',Va2,Va2*v);
33 // at stud 3 armature current=ia2 after t3 where t
      is time reckoned from the instant motor is
      switched on
34 Ea3=vb-ia2*(R-r1-r2); // counter EMF at stud 3
35 Va3=Ea3+ia2*ra; // voltage across at armature
      terminal at instant t3
36 printf('The third contactor should close at %f pu or
       %f V\n',Va3,Va3*v);
37 // at stud 4 armature current=ia2 after t4 where t
      is time reckoned from the instant motor is
      switched on
38 Ea4=vb-ia2*(R-r1-r2-r3); // counter EMF at stud 4
```

```
39 Va4=Ea4+ia2*ra; // voltage across at armature
     terminal at instant t4
40 printf('The fourth contactor should close at %f pu
     or %f V\n',Va4,Va4*v);
41 disp('case c');
42 Ea=vb-ia*ra; // pu full load counter EMF
43 n1=Ea1/Ea; // pu speed when handle is at stud 1
44 printf('Speed of dc shunt motor when handle is at
     stud 1 is %f pu or %f rpm\n',n1,n1*N);
45 n2=Ea2/Ea; // pu speed when handle is at stud 2
46 printf('Speed of dc shunt motor when handle is at
     stud 2 is %f pu or %f rpm\n',n2,n2*N);
47 n3=Ea3/Ea; // pu speed when handle is at stud 3
48 printf('Speed of dc shunt motor when handle is at
     stud 3 is %f pu or %f rpm\n',n3,n3*N);
49 n4=Ea4/Ea; // pu speed when handle is at stud 4
50 printf('Speed of dc shunt motor when handle is at
     stud 4 is %f pu or %f rpm\n',n4,n4*N);
51 disp('Using above data sketch of variation of
     armature current and speed can be obtained with
     time');
```

Scilab code Exa 4.40 Determining load torque for different cases

```
1 clc;
2 v=200; // rated voltage of shunt motor
3 i=22; // rated current of dc shunt motor
4 n1=1000; // speed at which motor is running
5 rf=100; // field resistance
6 ra=0.1; // armature resistance
7 n2=800; // reduced speed at which motor is to run
8 iF=v/rf; // field current
9 ia=i-iF; // armature current
10 disp('case a');
11 // load torque is independent of speed
```

```
12 Ea1=v-ia*ra; // counter EMF at 1000 rpm
13 rg=(v-ia*ra-(n2*Ea1)/n1)/ia;
14 printf('Additional resistance inserted in armature
      circuit is %f ohms\n',rg);
15 printf('Loss in additional resistance is %f W\n',ia
      ^2*rg);
16 disp('case b');
17 // load torque is directly proportional to speed
18 ia2=(n2/n1)*ia; // armature current at 800 rpm
19 rg=(v-ia2*ra-(n2*Ea1)/n1)/ia2;
20 printf('Additional resistance inserted in armature
      circuit is %f ohms\n',rg);
21 printf('Loss in additional resistance is %f W\n',ia2
      ^2*rg);
22 disp('case c');
23 // load torque varies as the square of speed
24 ia2=(n2/n1)^2*ia; // armature current at 800 rpm
25 rg=(v-ia2*ra-(n2*Ea1)/n1)/ia2;
26 printf('Additional resistance inserted in armature
      circuit is %f ohms\n',rg);
27 printf('Loss in additional resistance is %f W\n',ia2
      ^2*rg);
28 disp('case d');
29 // load torque varies as the cube of speed
30 ia2=(n2/n1)^3*ia; // armature current at 800 rpm
31 rg=(v-ia2*ra-(n2*Ea1)/n1)/ia2;
32 printf('Additional resistance inserted in armature
      circuit is %f ohms\n',rg);
33 printf('Loss in additional resistance is %f W\n',ia2
      ^2*rg);
```

Scilab code Exa 4.41 Finding motor speed

```
1 clc;
2 V=240; // rated voltage of dc shunt motor
```

```
n=800; // rated speed of dc shunt motor
i=50; // rated current of dc shunt motor
ra=0.2; // armature resistance
pr=0.6; // reduction in load torque as a fraction of
    full load torque
rg=2; // series resistance in armature circuit
fr1=0.04; // weakening of field flux at full load
fr2=0.02; // weakening of field flux at 60% of full
   load
Ea1=V-(i*ra); // counter EMF at rated load
ia2=(i*pr)*((1-fr1)/(1-fr2)); // armature current at
    reduced load torque
Ea2=V-ia2*(rg+ra); // counter EMF at reduced load
   torque
n2=(n*Ea2*(1-fr1))/(Ea1*(1-fr2));
printf('Motor speed at reduced load torque is %f rpm
   ',n2);
```

Scilab code Exa 4.42 Finding motor speed

```
clc;
N=1000; // speed of dc series motor
v=250; // supply from mains
i=50; // current drawn from mains
r=0.6; // armature + field resistance
rg=4.4; // additional resistance
// field flux is proportional to armature current
Ea1=v-i*r; // counter EMF at 1000 rpm
// Ea2=v-(n2/20)*(r+rg) where Ea2 is counter EMf at
   speed n2 . taking ratio of Ea2/Ea1 we obtain a
   quadratic equation in n2 whose terms are given by
t1=(Ea1*i)/N;
t2=(N*i)*((r+rg)/(N/i));
t3=-(N*i*v);
p=[ t1 t2 t3];
```

```
14 n=roots(p);
15 printf('New speed of motor is %f rpm',ceil(n(2)));
```

Scilab code Exa 4.43 Finding speed regulation

```
1  clc;
2  v=230; // rated voltage of dc shunt motor
3  n1=900; // speed at which motor is running
4  ia1=2; // armature current at n=900 rpm
5  ra=0.5; // armature resistance
6  ia2=20; // armature current at rated load and rated
      voltage
7  Ea=v-ia1*ra; // counter EMF at no load
8  k=(Ea*60)/(2*%pi*n1); // constant term used for
      calculating back EMF
9  disp('case a');
10 rs=2; // resistance in series with armature
11 rp=3; // resistace in parallel with series
      combination of rs and ra
12 A=rp/(rp+rs);
13 wmo=(1/k)*(A*v-ia1*(A*rs+ra)); // no-load speed
14 wml=(1/k)*(A*v-ia2*(A*rs+ra)); // full-load speed
15 sr=((wmo-wml)/wml)*100; // percent speed regulation
16 printf('Speed regulation for first case is %f
      percent\n',sr);
17 disp('case b');
18 rs=3; // resistance in series with armature
19 wmo=(1/k)*(v-ia1*(rs+ra)); // no-load speed
20 wml=(1/k)*(v-ia2*(rs+ra)); // full-load speed
21 sr=((wmo-wml)/wml)*100; // percent speed regulation
22 printf('Speed regulation for second case is %f
      percent\n',sr);
```

Scilab code Exa 4.44 Determining 1 maximum value of current and corresponding torque 2 ultimate speed and armature current

```
clc;
v=200; // rated voltage of dc shunt motor
ra=0.1; // armature resistance
n=1000; // running speed of motor
ia=50; // armature current at n=1000 rpm
re=0.1; // reduction in field flux
disp('case a');
Ea1=v-ia*ra; // initial counter EMF
Ea2=Ea1*(1-re); // counter EMF after reduced field
   flux
iam=(v-Ea2)/ra;
printf('Maximum value of armature current is %f A\n'
   ,iam);
T=(iam/ia)*(1-re);
printf('Torque corresponding to maximum armature
   current is %f times initial torque\n',T);
disp('case b');
ia2=(1/(1-re))*ia;
printf('Armature current when transients are over is
    %f A\n',ia2);
Ea2=v-ia2*ra; // counter EMF when transients are
   over
n2=(Ea2*n)/(Ea1*(1-re));
printf('Ultimate speed after transients are over is
   %f rpm',ceil(n2));
```

Scilab code Exa 4.45 Determining armature current

```
clc;
clc;
v=200; // rated voltage of dc shunt motor
ra=0.1; // armature resistance
```

```
5 n=1000; // running speed of motor
6 ia=50; // armature current at n=1000 rpm
7 re=0.1; // reduction in field flux
8 ia2=(1/(1-re))*ia; // armature current when
     transients are over
9 Ea1=v-ia2*ra; // counter EMF when transients are
     over
10 // with sudden increase from 0.9*f to f (f=flux),
     counter EMF rises to
11 Ea2=Ea1*(1/(1-re));
12 i=(v-Ea2)/ra;
13 printf('Armature current is %f A',i);
14 disp('Since armature current is negative, machine
     acts as a generator. Speed reduces till counter
     EMF becomes less than supply voltage,so that
     motor action takes place and torque balance is
     obtained')
```

Scilab code Exa 4.46 Determining new speed and armature current

```
1 clc;
2 v=220; // supply voltage
3 n1=2000; // speed of fan motor
4 ia1=60; // current corresponding to n=2000 rpm
5 // flux is directly proportional to exciting current
     and load torque increase as square of speed
6 // four field coils are connected in two parallel
     groups also n^2 is directly proportional to
     armature current therefore
7 r=sqrt((2*ia1^2)/n1^2); // ratio of armature current
     corresponding to n2 and n2 where n2=new speed
8 //  counter EMF are directly proportional to product
     n*ia and ra(armature resistance) and rs(series)
     resistance are not given, therefore takig ratio
     of n1*ia1 and n2*ia2 we can determine value of n2
```

```
n2=sqrt((ia1*n1*2)/r);
printf('New speed is %f rpm\n',n2);
ia2=n2*r;
printf('New armature current is %f A\n',ia2);
```

Scilab code Exa 4.48 Determining resistance inserted in shunt field

```
clc;
v=230; // rated voltage of dc shunt motor
ra=0.4; // armature circuit resistance
rf=115; // field resistance
n1=800; // initial speed
n2=1000; // final speed
ia1=20; // armature current at n=800 rpm
// torque at both speed is same therefore f1*ia1=f2*
   ia2 where f=field flux therefore
Ea1=v-ia1*ra; // counter EMF at 800rpm
// ia2=ia1*k where k=f1/f2 now writing Ea2(counter
   EMF at 1000rpm) in terms of k and finding value
   of k by solving quadratic equation in k whose
   terms are
t1=ia1*ra*n1;
t2=-v*n1;
t3=Ea1*n2;
p=[ t1 t2 t3];
k=roots(p);
if1=v/rf; // initial field current
if2=if1/k(2); // final field current correponding to
    n=1000rpm
rs=v/if2; // new shunt field circuit resistance
re=rs-rf;
printf('Resistance that must be inserted in shunt
   field circuit is %f ohms\n',floor(re));
```

Scilab code Exa 4.49 Determining new speed of motor

```
clc;
v=250; // rated voltage of dc shunt motor
ra=0.5; // armature resistance
rf=250; // field resistance
n1=600; // speed of motor
i=21; // current drawn by motor when n=600 rpm
re=250; // additional resistance in field circuit
if1=v/rf; // field current
ia=i-if1; // armature current
Ea1=v-ia*ra; // counter EMF at n=600 rpm
if2=v/(rf+re); // field current after addition of
   external resistance
ia2=ia*(if1/if2); // armature current after addition
    of external resistance
Ea2=v-ia2*ra; // counter EMF at new speed
n2=(n1*Ea2*if1)/(Ea1*if2);
printf('New speed of motor is %f rpm',n2);
```

Scilab code Exa 4.50 Determining percentage change in field flux

```
clc;
v=250; // supply voltage
i=50; // current drawn from supply
ic=0.4; // percentage increase in speed
T=1.2; // ratio of final and initial torque
n=1.4;// ratio of final and initial speed
ra=0.5; // armature resistance
Ea1=v-i*ra; // counter EMF at initial speed
// ia2=(T2/T1)*ia1*k where k=f1/f2 and T1 is initial
    torque and T2 is final torque now writing Ea2(
```

```
    counter EMF at 1000rpm) in terms of k and finding
     value of k by solving quadratic equation in k
    whose  terms are
t1=T*ra*i;
t2=-v;
t3=n*Ea1;
p=[ t1 t2 t3 ];
k=roots(p);
fr=(1-(1/k(2)))*100;
printf('Percentage reduction in field flux is %f
    percent',fr);
```

Scilab code Exa 4.51 Determining number of series turns per pole to reduce speed

```
clc;
v=250; // rated voltage of dc shunt motor
n1=1200; // no load speed
N=1000; // turns per pole in shunt field winding
n2=900; // reduced speed
ia=100; // full load armature current
rf=0.2; // series field resistance
ra=0.1; // armature resistance
ar=0.04; // armature reaction as afraction of main
    field m.m.f
// At no load counter EMF=v therefore from
    magnetization curve given in fig 4.76 field
    current is
IF=[ 0.38 0.58 0.8 1.1 1.36 1.76];
EA=[125 180 215 250 275 300];
plot(IF,EA);
xlabel('field current');
ylabel('counter EMF');
title('Magnetising curve');
ifs1=1.1; // field current
```

```
18 Ats1=ifs1*N; // ampere turns for field current
19 Ea2=v-ia*(ra+rf); // counter EMF at full load
20 // magnetization curve is for 1200 rpm, therefore
      full load counter EMF corresponding to it is
21 Ea2=Ea2*(n1/n2);
22 // corresponding to above counter EMF field current
      from magnetization curve is
23 ifs2=1.62;
24 Ats2=(ifs2*N)/(1-ar); // ampere turns for field
      current at full load
25 at=Ats2-Ats1; // series field
26 t=at/ia;
27 printf('Number of series turns per pole to reduce
      speed to %f rpm is %f ',n2,ceil(t));
```

Scilab code Exa 4.52 Determining motor speed

```
1 clc;
2 v=240; // supply voltage
3 n=1000; // speed of motor
4 i=40; // current drawn from supply
5 rf=0.2; // field resistance
6 ra=0.25; // armture resistance
7 rd=0.3; // diverter resistance
8 // torque is constant for different speeds
9 // when diverter is put in parallel with series
      resistance then some fraction of armature current
       flows through series circuit this current for
      constant torque is given by
10 ia2=sqrt(i^2/(rd/(rf+rd)));
11 Ea1=v-i*(ra+rf); // counter EMf at n=1000 rpm
12 Ea2=v-ia2*(ra+((rf*rd)/(rf+rd))); // counter EMF at
      new speed
13 n2=(Ea2*n*i)/(Ea1*(rd/(rf+rd))*ia2);
14 printf('Motor speed after diverter is put in
```

```
parallel with series field winding is %f rpm',
ceil(n2));
```

Scilab code Exa 4.53 Determining motor speed and current

```
clc;
v=230; // rated voltage of motor
p=6; // number of poles
f=4*10^-3; // flux per pole in Wb/A
T=20; // load torque
n=800; // speed at T=20 N-m
a=2; // for wave connected conductors number of
   parallel path
z=432; // number of conductors
r=1; // total resistance of motor
// it is given that T=kn^2, therefore
k=T/n^2; // proportionality of constant
r1=(f*z*p)/(60*a); // ratio of back EMF to product
   of speed and armature current
t=(r1*60)/(2*%pi); // ratio of full load torque to
   square of armature current
// also Ea(back EMf)=v-ia*ra and r1=Ea/(n*ia)
   compairing both we get ia=v/(1+r1*n);
// Also k*n2^2=t*ia^2 , in this expression putting
   value of ia and solving quadratic equation in n2
t1=sqrt(k)*r1;
t2=sqrt(k);
t3=-sqrt(t)*v;
p=[ t1 t2 t3 ];
n2=roots(p);
printf('Speed of motor is %f rpm\n',n2(2));
ia=v/(1+r1*n2(2));
printf('Armature current when motor is connected to
   rated supply is %f A',ia);
```

Scilab code Exa 4.54 Determining 1 armature current and speed of motor 2 value of external resistance inserted in field winding

```
clc;
v=230; // rated voltage of dc shunt motor
n=1000; // rated speed of motor
rf=115; // field resistance
ra=0.5; // armature resistance
ia=4; // no load armature current
k=(v-ia*ra)/(2*%pi*n/60); // constant term in
   formula of back EMF
disp('case a');
t=80; // load torque
ia2=t/k; // armature load current
Ea2=v-ia2*ra; // counter EMF corresponding to load
   armature current
printf('Armature current for given load is %f A\n',
   ia2);
n2=(Ea2*60)/(k*2*%pi);
printf('Speed of motor at given load is %f rpm\n',n2
   );
disp('case b');
pd=8000; // power developed by motor
n3=1250; // speed at power is developed
// determining value of armature current
   corresponding to power by solving quadratic
   equation whose terms are
t1=ra;
t2=-v;
t3=pd;
p=[ t1 t2 t3];
ia3=roots(p);
Ea3=v-ia3(2)*ra; // counter EMF for load armature
   current
```

```
25 k1=k/(v/rf); // constant term in formula of back EMF
       for field current = 1 A
26 ifn=(Ea3*60)/(2*%pi*n3*k1);
27 rfn=v/ifn;
28 printf('External resistance that must be inserted in
       series with field winding is %f ohms',rfn-rf);
```

Scilab code Exa 4.55 Determining current and percentage in flux

```
1  clc;
2  v=250; // rated voltage of dc series motor
3  ra=0.25; // armature resistance
4  rf=0.15; // series field resistance
5  disp('case a');
6  t=80; // developed torque
7  n1=1200; // speed at developed torque
8  // solving quadratic equation in ia
9  t1=ra+rf;
10 t2=-v;
11 t3=(t*2*%pi*n1)/60;
12 p=[ t1 t2 t3];
13 ia=roots(p);
14 printf('Current for developing given torque is %f A\
       n',ia(2));
15 disp('case b');
16 n2=1800;
17 ia2=ia(2)/2;
18 Ea1=v-ia(2)*(ra+rf); // counter EMF corresponding to
       armature current of case 1
19 Ea2=v-ia2*(ra+rf); // counter EMF corresponding to
       armature current ia2
20 fr=(n1*Ea2)/(n2*Ea1); // ratio of fluxes for two
       armatures current
21 pr=(1-fr)*100;
22 printf('Percentage reduction in flux is %f pecent',
```

```
pr);
```

Scilab code Exa 4.56 Determining additional resistance to obtain rated torque

```
clc;
v=230; // rated voltage of dc series motor
n=1500; // speed at rated output
i=20; // current drawn at rated output
ra=0.3; // armature resistance
rf=0.2; // field resistance
disp('case a');
// At starting Ea=0, therefore
re=(v/i)-(ra+rf);
printf('External resistance to be added in motor
   armature circuit to develop rated torque is %f
   ohms\n',re);
disp('case b');
n2=1000; // speed at rated torque has to be
   developed
Ea2=(n2/n)*(v-i*(ra+rf)); // counter EMF at n=1000
   rpm
re=(v-Ea2-i*(ra+rf))/i;
printf('External resistance to be added in motor
   armature circuit to develop rated torque is %f
   ohms\n',re);
```

Scilab code Exa 4.57 Determining voltage and current in magnetic circuit

```
clc;
// in book voltages are calculated for r=0.5 not for
    r=0.4(as asked in question) that is why answer
   is differing
```

```
3 v=230; // supply voltage
4 n1=800; // speed at supply voltage
5 i=20; // current drawn from supply
6 r=0.4; // dc series motor resistance
7 n2=1000; // raised speed
8 Ea1=v-i*r; // counter EMF at 800 rpm
9 disp('case a');
10 // when magnetic circuit is saturated flux is
     constant.Under steady state condition full load
     torque=torque at any load therefore
11 i2=i*(n2/n1)^2; // new current drawn from supply
12 Ea2=Ea1*(n2/n1); // counter EMF at 1000 rpm
13 vt=Ea2+i2*r;
14 printf('Current for saturated magnetic circuit is %f
     A\n',i2);
15 printf('Voltage for saturated magnetic circuit is %f
     V\n',vt);
16 disp('case b');
17 // when magnetic circuit is not saturated flux is
     directly proportional to armature current and
     torque is directly proportional to square of
     armature current
18 i3=(n2/n1)*i;
19 Ea3=(n2*Ea1*i3)/(n1*i); // counter EMF at 1000 rpm
20 vt=Ea3+i3*r;
21 printf('Current for unsaturated magnetic circuit is
     %f A\n',i3);
22 printf('Voltage for unsaturated magnetic circuit is
     %f V\n',vt);
```

Scilab code Exa 4.58 Calculating armature current for different control methods

```
1 clc;
2 s=4; // speed range
```

```
3 ia=60; // armature current at speed n
4 disp('Field flux control');
5 // For constant power load  Ea*Ia is constant
    therefore ia is conatant at 4*n
6 printf('The armature current at required speed is %f
    A\n',ia);
7 // For constant torque load, speed is 4 times of
    initial speed therefore flux changes by 1/4 times
     and hence to maintain torque constant armature
    current should be four times
8 printf('The armature current at required speed is %f
    A\n',4*ia);
9 disp('Armature voltage control');
10 // For constant power load  Ea*Ia is constant
    therefore at 4 times speed armature voltage is 4
    times and the armature current gets reduced by
    1/4 times
11 printf('The armature current at required speed is %f
    A\n',ia/4);
12 // For constant power load  Ea*Ia is constant
    therefore at 4 times speed ,flux is constant
    therefore
13 // armature current is constant
14 printf('The armature current at required speed is %f
    A\n',ia);
```

Scilab code Exa 4.59 Determining speed range for full load and no load 2 minimum motor field current

```
1 clc;
2 v=220; // rated voltage of motor
3 i=15; // rated current of motor
4 ra=0.4; // net armature resistance
5 n=1500; // speed for which magnetization curve is
    given
```

```
IF=[ 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.2 1.45];
EA=[120 160 197 210 220 228 232 236 243 248];
plot(IF,EA);
xlabel('field current');
ylabel('voltage');
title('magnetising curve');
disp('case a');
ifg1=0.15; // initial generator field current
ifg2=1.4; //  final generator field current
ifm=0.6; // motor field current
// corresponding ifg1 counter EMF of generator from
   magnetization curve is
Ea1=60;
vd=i*(ra+ra); // voltage drop in two armature
   resistance
Ea2=Ea1-vd; // counter EMF of motor
// but motor counter EMF for 0.6 A field current at
   1500 rpm is
Ea3=210;
nmin1=(Ea2/Ea3)*n; // minimum motor speed
// corresponding ifg2 counter EMF of generator from
   magnetization curve is
Ea4=247;
Ea5=Ea4-vd; // counter EMF of motor
nmax1=(Ea5/Ea3)*n; // maximum motor speed
sr=nmax1/nmin1; // speed range
printf('Speed range for full load armature current
   is %f:1\n',sr);
// for no load generator counter EMF= motor counter
   EMf
nmin2=(Ea1/Ea3)*n; // minimum motor speed
pr=((nmin2-nmin1)/nmin2)*100;
printf('Percent speed drop from no load to full load
    for condition of minimum speed is %f percent\n',
   pr);
// for maximum generator field current generator
   counter EMF= motor counter EMf at no load
nmax2=(Ea4/Ea3)*n; // maximum motor speed
```

```
35 sr=nmax2/nmin2; // speed range
36 printf('Speed range for full load armature current
      is %f:1\n',sr);
37 pr=((nmax2-nmax1)/nmax2)*100;
38 printf('Percent speed drop from no load to full load
       for condition of maximum speed is %f percent\n',
      pr);
39 disp('case b')
40 // for generator field current=1 A counter EMF from
      magnetization curve is
41 Ea6=236;
42 Ea7=Ea6-vd; // motor counter EMF at full load
43 Ea8=(Ea7/(2*nmax1))*n;
44 printf('Motor counter EMF for %f rpm is %f V\n',n,
      Ea8);
45 // Corresponding to Ea8, field current is
46 ifmi=0.25;
47 printf('Minimum motor field current is %f A\n',ifmi)
      ;
```

Scilab code Exa 4.60 Determining motor torque and motor speed

```
1 clc;
2 p=4000; // rated power of separately excited dc
      series motor
3 v=230; // rated voltage of motor
4 n=1000; // rated speed of motor
5 e=260; // ac voltage supplied to motor through
      converter
6 i=2; // current drawn at no load
7 no=1100; // speed at no load
8 ra=0.5; // armature resistance
9 vd=2; // voltage drop in thyristor
10 de=30; // firing angle delay
11 ia=20; // rated armature current
```

```
12 k=((((2*sqrt(2)*e)/%pi)-(i*ra)-vd)*60)/(2*%pi*no);
     // conatant term in formula of back EMf
13 disp('case a');
14 printf('Motor torque is %f Nm\n',k*ia);
15 disp('case b');
16 wm=((((2*sqrt(2)*e*cosd(de))/%pi)-vd)/k)-((ra*ia)/k)
     ;
17 printf('Motor speed is %f rpm',ceil((wm*60)/(2*%pi))
     );
```

Scilab code Exa 4.61 Determining 1 speed and current for torque 2 speed and torque for given armature current 3 speed and torque for given armature current

```
1  clc;
2  n=800; // speed at which magnetization curve is
     given
3  // case a
4  v=600; // dc voltage source
5  ra=0.3; // armature resistance
6  rf=0.25; // field resistance
7  T=300; // given torque
8  VT=[ 200 375 443 485 510 518]; // terminal voltage
9  IF=[ 15 30 45 60 75 90 ]; // field current
10 EA1=VT+IF*ra; // generated EMF
11 EA2=v-IF*(ra+rf); // generated EMF for v=600 V
12 N2=n*(EA2./EA1); // speed for v= 600 V
13 TE=(EA2.*IF.*EA1*60)./(2*%pi*n*EA2); //torque
14 subplot(221);
15 plot(TE,N2);
16 xlabel('Torque(Nm)');
17 ylabel('speed(rpm)');
18 title('speed-torque');
19 subplot(222);
20 plot(TE,IF);
```

```
21 xlabel('Torque(Nm)');
22 ylabel('current(A)');
23 title('current-torque');
24 disp('from curves, for a torque of 300 Nm, speed is
     940 rpm and current is 52.5 A');
25 disp('case b');
26 rd=0.25; // diverter resistance put in parallel with
     series combination of armature and field
     resistance
27 ia1=30;
28 ia2=60; // armature currents
29 if1=ia1*(rd/(rd+rf)); // field current corresponding
     to ia1
30 Ea1=204.5; // given counter EMF for field current
31 Ea2=v-ia1*(ra+((rd*rf)/(rd+rf))); // counter EMF for
     voltage supply of 600 V
32 n2=n*(Ea2/Ea1);
33 printf('Speed at %f A armature current is %f rpm\n',
     ia1,n2);
34 T=(Ea1*60*ia1)/(2*%pi*n);
35 printf('Torque at %f A armature current is %f Nm\n',
     ia1,T);
36 if1=ia2*(rd/(rd+rf)); // field current corresponding
     to ia1
37 Ea1=384; // given counter EMF for field current
38 Ea2=v-ia2*(ra+((rd*rf)/(rd+rf))); // counter EMF for
     voltage supply of 600 V
39 n2=n*(Ea2/Ea1);
40 printf('Speed at %f A armature current is %f rpm\n',
     ia2,n2);
41 T=(Ea1*60*ia2)/(2*%pi*n);
42 printf('Torque at %f A armature current is %f Nm\n',
     ia2,T);
43 disp('case c');
44 ia3=75; // armature current
45 t=0.8; // tapping percentage of field winding as a
     fration of full series turn
46 ifl=t*ia3; // corresponding field current
```

```
47 Ea=503; // given counter EMF for field current
48 Ea2=v-ia3*(ra+t*rf); // counter EMF for voltage
      supply of 600 V
49 n2=n*(Ea2/Ea);
50 printf('Speed at %f A armature current is %f rpm\n',
      ia3,n2);
51 T=(Ea*60*ia3)/(2*%pi*n);
52 printf('Torque at %f A armature current is %f Nm\n',
      ia3,T);
```

Scilab code Exa 4.62 Determining size of DC motor and hoist speed

```
1 clc;
2 ra=0.3; // armature resistance
3 n=0.7; // efficiency of dc shunt motor
4 l=800; // weight of load
5 v=3; // speed of raising a load
6 vi=230; // initial value of supply voltage
7 vf=190; // final value of supply voltage
8 g=9.81; // acceleration due to gravity
9 f=l*g; // resisting force due to gravitational pull
10 p=f*v; // power required for lifting the load
11 P=p/n; // power rating of dc machine
12 printf('Required rating of power is %f KW\n',P/1000)
      ;
13 // for supply voltage of 230 V  Ea=230-ia*ra finding
      quadratic equation in ia whose terms are
14 t1=ra;
15 t2=-vi;
16 t3=P;
17 p=[ t1 t2 t3 ] ;
18 ia=roots(p);
19 Ea=vf-ia(2)*ra; // counter EMF for supply voltage of
      190 V
20 v=(Ea*ia(2)*n)/(l*g);
```

```
21 printf('New hoist speed is %f m/s',v);
```

Scilab code Exa 4.63 Determining additional resistance inserted in motor circuit

```
1  clc;
2  v1=6; // hoist speed
3  i=60; // series current
4  v=600; // supply voltage
5  r=0.5; // net resistance
6  g=9.81; // acceleration due to gravity
7  v2=4; // reduced hoist speed
8  Ea1=v-i*r; // counter EMf corresponding to v1
9  rx=((v-((v2/v1)*Ea1))/i)-r;
10 printf('External resistance to be added is %f ohms',
      rx);
```

Scilab code Exa 4.64 Determining speed of motor for given condition

```
1  clc;
2  v=450; // supply voltage
3  i=25; // current drawn from supply
4  n=600; // full load speed
5  z=500; // number of conductors
6  f=1.7*10^-2*sqrt(i); // flux per pole
7  p=4; // number of poles
8  a=p; // number of parallel paths for wave wound
      winding is same as number of poles
9  Ea1=(f*n*z*p)/(60*a); // counter EMF
10 ra=(v-Ea1)/i; // armature resistance
11 // T=k*f*ia   where f is flux and ia is armature
      current As per question new torque is half of
      initial torque
```

```
12 i2=((i^1.5)/2)^(1/1.5); // new armature current
13 Ea2=(v/2)-i2*ra; // counter EMF for new armature
      current
14 n2=(Ea2*f*sqrt(i)*n)/(Ea1*f*sqrt(i2));
15 printf('New speed at which motor will run is %f rpm'
      ,floor(n2));
```

Scilab code Exa 4.66 Determining motor speed and armature current

```
1  clc;
2  // answer is calculated for torque=30 but it is
      asked for torque=40 i.e why answer varies
3  p=4; // number of dc series motor
4  f=4*10^-3; // ratio of flux per pole to armature
      current
5  T=40; // torque of fan
6  n=1000; // speed of motor
7  a=2; // number of parallel path for waave winding
8  z=480; // number of conductors
9  ra=1; // armature resistance
10 v=230; // supply voltage
11 re=sqrt((T*2*%pi*a)/(p*z*f*n^2)); // ratio of
      armature current and new speed
12 // Ea=vt-ia*ra writing ia in terms of n solving for
      n (n is new speed)
13 n2=v/(re+((p*f*z)/(60*a)));
14 printf('Motor speed is %f rpm\n',n2);
15 ia=re*n2;
16 printf('Armature current is %f A',ia);
```

Scilab code Exa 4.67 Determining shaft power input efficiency at rated load maximum efficiency and power output

```
clc;
p=10000; // rated power of generator
v=250; // rated voltage of generator
l1=400; // rotationl losses
ra=0.5; // armature resistance
rf=250; // shunt field resistance
ifl=v/rf; // constant field current
lc=ifl*rf+l1; // constant losses
io=p/v; // output current of generator
ia=io+ifl; // armature current
la=ia^2*ra; // armature circuit loss
ps=p+lc+la; // generator shaft power input
printf('Generator shaft power input is %f W\n',ps);
ng=(1-((lc+la)/ps))*100;
printf('Efficiency at rated load is %f percent\n',ng
   );
// at maximum efficiency variable losses= constant
   losses
ia=sqrt(lc/ra); // armature current at maximum
   efficiency
io=floor(ia)-ifl; // output current of generator
po=v*io; // output power
printf('Generator output at maximum efficiency is %f
    W\n',po);
pi=po+2*lc;
nm=(1-((lc+lc)/pi))*100;
printf('Maximum efficiency is %f percent\n',nm);
```

Scilab code Exa 4.68 Determining efficiency and speed of motor

```
clc;
v=250; // rated voltage of shunt motor
p=15000; // rated power of motor
nm=0.88; // maximumu efficiency of motor
n=700; // speed of motor
```

```
6 rf=100; // resistance of shunt field
7 i=78; // current drawn by mains
8 f=0.8; // fraction of rated output being delivered
9 l=((1/nm)-1)*f*p; // total losses
10 // at maximum losses constant losses= variable
     losses
11 lc=l/2; // constant losses
12 pi=f*p+l; // input to motor at maximum efficiency
13 il=pi/v; // input line current
14 ia=il-(v/rf); // armature current
15 ra=lc/ia^2; // armature resistance
16 ia2=i-(v/rf); // armature current at given load
17 pi=i*v; // total power input
18 tl=ia2^2*ra+lc; // total losses
19 n1=(1-(tl/pi))*100; // efficiency at line current of
     75 A
20 Ea1=v-ia*ra; // counter EMF
21 Ea2=v-ia2*ra; // counter EMF corresponding to line
     current of 75 A
22 // field current is constant so flux is constant
23 n2=(Ea2/Ea1)*n;
24 printf('Efficiency at line current of %d A is %f
     percent\n',i,ceil(n1));
25 printf('Speed at line current of %d A is %f rpm',i,
     floor(n2));
```

Scilab code Exa 4.69 Determining 1 no load current 2 speed 3 armature current

```
1 clc;
2 p=10000; // rated power of transformer
3 n=900; // speed of motor
4 v=400; // rated voltage of motor
5 ra=1; // armatyre resistance
6 rf=400; // field resistance
```

```
ne=0.85; // efficiency at rated load
l=((1/ne)-1)*p; // total losses
disp('case a');
pi=p+l; // power input
il=pi/v; // line current
ia=il-(v/rf); // armature current
la=ia^2*ra; // armature circuit losses
lf=v*(v/rf); // shunt field losses
wo=l-la-lf; // no load losses
iao=wo/v; // no load current neglecting armature
   losses at no load
printf('No load armature current is %f A\n',iao);
disp('case b');
Ea1=v-ia*ra; // counter EMF at rated load
il=20; // current drawn by motor
ia=il-(v/rf); // armature current
Ea2=v-ia*ra; // counter EMF at line current of 20 A
n2=(Ea2/Ea1)*n;
printf('Speed of motor while drawing current of %d A
    from mains is %f rpm\n',il,ceil(n2));
disp('case c');
k=(Ea1*60)/(2*%pi*n); // constant term in counter
   EMF formula
T=98.5; // electromagnetic torque
ia=T/k;
printf('Armature current at given torque is %f A',
   ceil(ia));
```

Scilab code Exa 4.70 Determining efficiency of motor

```
clc;
v=240; // rated voltage of motor and supply voltage
i=5.2; // line current
p=10000; // rated power of motor
no=1200; // no load speed
```

```
ra=0.25; // armature resistance
rf=160; // field resistance
ifl=v/rf; // constant field current
iao=i-ifl; // no load armature current
wo=v*iao-iao^2*ra; // no load rotational losses
//  by using equation of electromagnetic power
   solving quadratic equation in armature current
   whose terms are
t1=ra;
t2=-v;
t3=p+wo;
P=[ t1 t2 t3 ];
ia=roots(P);
pi=(v-ia(2)*ra)*ia(2)+ia(2)^2*ra+ifl*v; // motor
   input
nm=(p/pi)*100;
printf('Motor efficiency at rated load is %f percent
   ',nm);
```

Scilab code Exa 4.71 Determining armature voltage drop

```
clc;
v=440; // rated voltage of mootor
no=2000; // no load speed
n1=1000; // speed at full load torque
Tl=0.5; // load torque as a fraction of rated torque
n2=1050; // increased speed due to redued torque
// field current is constant so flux is constant
// since torqu gets reduced by half new armature
   current also gets reduced half i.e ia2=ia1/2;
vd=(v*(n2-n1))/(n2-(n1/2));
printf('Armature voltage drop at full load is %d V',
   vd);
```

Scilab code Exa 4.72 Determining shaft torque and efficiency of motor

```
clc;
v=230; // source voltage
ra=0.1; // resistance of armature
ia=100; // armature current
n=1600; // speed of dc shunt motor
wl=300; // friction and windage losses
lo=1200; // no load core loss
lc=2500; // copper losses
Ls=0.01; // stray losses as a fraction of output
Ea=v-ia*ra; // counter EMF
pe=Ea*ia; // electromagnetic power
wo=wl+lo; // no load rotational losses
po=pe-wo; // shaft power + stray load losses
psh=po/(1+Ls);
Tsh=(psh*60)/(2*%pi*n);
printf('Shaft torque is %f Nm\n',Tsh);
pi=pe+lc; // power input to motor
nm=(psh/pi)*100;
printf('Motor efficiency is %f percent',nm);
```

Scilab code Exa 4.73 Determining shaft torque shaft power and motor efficiency

```
clc;
// shaft power is given little bit more than actual
   value in question
w1=25;
w2=9; // spring balance readings in kg
d=19.5*10^-2; // outside pulley diameter
t=0.5*10^-2; // belt thickness
```

```
g=9.81; // acceleration due to gravity
n=1500; // motor speed
v=230; // applied voltage
il=12.5; // line current
Ts=(w1-w2)*((d/2)+(t/2))*g;
printf('Shaft torque is %f Nm\n',Ts);
psh=(2*%pi*n*Ts)/60;
printf('Shaft power is %f W\n',psh);
pi=v*il; // motor input
nm=(psh/pi)*100;
printf('Motor efficiency at rated load is %f percent
   ',nm);
```

Scilab code Exa 4.74 Determining KW output efficiency and percentage change in speed from no load to full load

```
clc;
v=400; // rated voltage of dc shunt motor
io=5; // current at no load
ra=0.5; // armature resistance
rf=200; // field resistance
i=50; // current at full load
ifl=v/rf; // constant shunt field current
iao=io-ifl; // no load armature current
wo=v*iao-iao^2*ra; // no load rotational losses
ia=i-ifl; // full load armature current
la=ia^2*ra; // full load armature circuit losses
lf=v*ifl; // constant shunt feld losses
tl=la+lf+wo; // total field losses
pi=i*v; // motor input at full load
nm=(1-(tl/pi))*100;
printf('Output power is %f KW\n',(pi-tl)/1000);
printf('Efficiency on full load is %f percent\n',nm)
   ;
Ea1=v-iao*ra; // no load counter EMF
```

```
19 Ea2=v-ia*ra; // full load counter EMF
20 pr=((Ea1-Ea2)/Ea1)*100; // Ea is directly
      proportioal to speed so percentage change in Ea
      is same as percentage in speed;
21
22 printf('Percentage change in speed from no load to
      full load is %f percent',pr);
```

Scilab code Exa 4.75 Determining full load efficiency of motor

```
1  clc;
2  v=400; // rated voltage of dc shunt motor
3  p=20000; // rated power of motor
4  i=2.5; // no load current
5  ra=0.5; // armature resistance
6  rf=800; // field current
7  vb=2; // voltage drop in brush
8  ifl=v/rf; // constant shunt field current
9  iao=i-ifl; // no load armature current
10 wo=v*iao-iao^2*ra; // no load rotational losses
11 tl=wo+v*ifl; // total losses
12 //  by using equation of power input= output power +
       losses, solving quadratic equation in armature
      current whose terms are
13 t1=ra;
14 t2=vb-v;
15 t3=p+tl-v*(v/rf);
16 P=[ t1 t2 t3];
17 ia=roots(P);
18 lo=ia(2)^2*ra; // armature ohmic losses
19 lb=ia(2)*vb; // brush drop loss
20 tl=tl+lo+lb; // total losses at rated load
21 pi=p+tl; // input power
22 nm=(p/pi)*100;
23 printf('Full load efficiency is %f percent',nm);
```

Scilab code Exa 4.77 Determining efficiency of both machines

```
clc;
// Hopkinson's method gave following result for two
   identical dc shunt machines
v=230; // line voltage
il=30; // line current excluding both field currents
ia=230; // motor armature current
ifl1=4; ifl2=5;  // field currents
ra=0.025; // armature current
// from fig 4.85
ig=ia-il; // generator armature current
la1=ig^2*ra; // armature circuit losses in generator
la2=ia^2*ra; // armature circuit losses in motor
pd=v*il; // power drawn from supply (excluding field
    loss)
wo=pd-la1-la2; // no load rotational losses for both
    machines
pg=v*ig; // generator outputk
tl=(wo/2)+v*ifl2+la1; // total losses for generator
ng=(1-(tl/(tl+pg)))*100;
pi=v*(ia+ifl1); // input power for motor
tl=(wo/2)+v*ifl1+la2; // total losses for motor
nm=(1-(tl/pi))*100;
printf('Motor efficiency is %f percent\n',nm);
printf('Generator efficiency is %f percent\n',ng);
// If both machine are assumed to have same
   efficiency then
n=sqrt(ig/ia)*100;
printf('Efficiency of machine is %d percent',n);
```

Scilab code Exa 4.78 Determining efficiency of both machines

```
clc;
// fields test on two similar machine gave following
    test
iam=60; // motor armature current
vam=500; // voltage across armature
vfm=40; // voltage across field
vt=450; // terminal voltage for generator
io=46; // output current for generator
vfg=40; // voltage across field
ra=0.25; // armture resistance
pi=(vam+vfm+vfg)*iam; // power input to whole set
pog=vt*io; // generator output
tl=pi-pog; // total loss in whole set
poh=iam^2*ra+iam*(vfm+vfg)+io^2*ra; // total ohmic
   losses
wo=(tl-poh)/2; // no load roational losses for each
   machines
pim=(vam+vfm)*iam; // motor power input
plm=iam^2*ra+iam*vfm+wo; // total motor loss
nm=(1-(plm/pim))*100;
printf('Motor efficiency is %f percent\n',nm);
plg=io^2*ra+iam*vfm+wo; // total motor loss
pgm=pog+plg; // generator input
ng=(1-(plg/pgm))*100;
printf('Generator efficiency is %f percent',ng);
```

Scilab code Exa 4.81 Determining field current and power gain at rated output and when compensation is zero

```
clc;
p=3000; //  power of amplidyne
v=300; // voltage of amplidyne
w=200; // angular velocity of amplidyne
rf=50; // field resistance
ra=5; // armature resistance
```

```
rc=1; // compensating winding resistance
kqf=250;
kdq=100;
kqd=80; // voltage constants
A=(kdq*kqf)/(ra*rf); // voltage amplification factor
id=p/v; // rated current
vf=(v+id*(ra+rc))/A; // field voltage
ifl=vf/rf; // field current
pk=(v*id)/(vf*ifl); // power gain
printf('Field current is %f A\n',ifl);
printf('Power gain at rated output is %f \n',pk);
// when compensation is zero
vf=(v+id*(((kdq*kqd)/ra)+ra))/A; // field voltage
ifl=vf/rf;
printf('Field current at zero compensation is %f A\n
   ',ifl);
pk=(v*id)/(vf*ifl); // power gain
printf('Power gain at rated output at zero
   compensation is %f \n',pk);
```

Scilab code Exa 4.82 To plot the external characteristics for given field current

```
clc;
// plot for open circuit characteristics is given in
    fig 4.10
IF=[ 0 11.5 23 36.5 59.5 79 110 160];
EA=[0 40 80 120 160 180 200 220 ];
subplot(221);
plot(IF,EA);
xlabel('field ATs');
ylabel('voltage');
title('magnetising curve');
nf=800; // field winding turns
rd=0.5; // total armature resistance along d-axis
```

```
12 ifl=0.2; // field winding current
13 d=10; // product of (difference between mmf of
      compensating winding and armature mmf along d-
      circuit)and load current
14 nf1=nf*ifl; // field winding turns for field current
       of 200mA
15 il=nf1/d; // maximum load current
16 printf('Maximum field current is %d A\n',il);
17 IL=[0 2 4 6 8 10 12 14 16]; // load currents
18 ATD=nf1-d*IL; // net d-axis ATs
19 disp('Net d-axis ATs is');
20 disp(ATD);
21 // corresponding to each ATD open circuit EMF is
      obtained from magnetising curve
22 EO=[220 213 204.7 194 180.5 161.4 128 70 0 ]; //
      open circuit EMF
23 VRD=rd*IL; // d-axis resistance drop
24 VO=EO-VRD;
25 disp('Output voltage(V) is ');
26 disp(VO);
27 subplot(222);
28 plot(IL,VO);
29 xlabel('load current(A)');
30 ylabel('Output voltage(v)');
31 title('Output voltage vs Load current');
```

Scilab code Exa 4.83 Determining field winding current

```
1 clc;
2 // from fig 4.79
3 vo=206; // output voltage
4 il=8; // load current
5 ifl=0.2; // field current
6 Eo=280; // open circuit voltage for which field
      winding current is to be determined
```

```
r=0.5; // net resistance
n=800; // d-axis ampere turns
// with saturation ignored output voltage vd is
   given by vd=(n*if-10*il)K-il*r
K=(vo+il*r)/(800*ifl-10*il); // slope of straight
   line in curve
ifl=Eo/(K*n);
printf('For given open circuit voltage field current
    is %f mA',ifl*1000);
```

Scilab code Exa 4.84 Determining output voltage of generator and reference voltage of potentiometer

```
clc;
A=100; // amplidyne voltage amplification
vo=200; // DC generator output voltage
rf=125; // field winding resistance
vfb=0.1; // ratio of feedback voltage to output
   voltage of generator
vr=50; // reference voltage
// amplidyne output voltage,Va =(vr-vfb*vt)*A
// ig=va/rf ig is generator field current
// vog=ig*vo vog is generator output voltage-1
// simplifying 1 we get
vt=(vr*A)/((vfb*A)+(rf/vo));
printf('Output voltage of generator is %f V\n',vt);
// now feedback voltage is reduced to zero
vr=(vt*rf)/(A*vo);
printf('Reference voltage to obtain required output
   generator voltage is %f V ',vr);
```

Scilab code Exa 4.85 Determining reference voltage of potentiometer

```
clc;
g1=1.5; // gain factor of amplifier
g2=80; // gain factor of generator
vo=250; // output voltage at no load
s=0.2; // feedback potentiometer setting
// for generated voltage= 80V field current is 1 A
ifl=vo/g2; // field current for generated voltage=
   250V
vi=ifl/g1; // amplifier input voltage for field
   current corresponding to generated voltage= 250V
vfb=s*vo; // feedback voltage
vr=vfb+vi;
printf('Reference voltage for given potentiometer
   setting is %f V\n',vr);
printf('When feedback setting is zero, reference
   voltage is %f V',vi);
```

Scilab code Exa 4.86 Determining amplifier gain

```
clc;
p=4000; // rated power of generator
v=250; // rated voltage of generator
ra=0.25; // armature resistance
rf=100; // fiel resistance
vr=20; // improving factor for voltage regulation
g1=120; // generator gain
// after deriving required expression
il=p/v; // load current
vgr=((il*ra)/v)*(1/vr); // pu full load generator
   regulation
dvt=-vgr*v; // decrease in terminal voltage of
   generator from no load to full load
disp('case a');
s=0.1; // feedback potentiometer setting
A=(-dvt*rf-il*ra*rf)/(dvt*s*g1);
```

```
15 printf('Amplifier gain is %f\n',A);
16 disp('case b');
17 s=1; // feedback potentiometer setting
18 A=(-dvt*rf-il*ra*rf)/(dvt*s*g1);
19 printf('Amplifier gain is %f\n',A);
```

Scilab code Exa 4.87 Determining 1 no load rotational losses 2 motor output 3 stall torque

```
1  clc;
2  v=48; // supply voltage
3  n=2400; // speed of permanent magnet DC motor
4  i=0.8; // current drawn by motor
5  ra=1; // armature resistance of motor
6  disp('case a');
7  Ea=v-i*ra; // generated EMF
8  l=Ea*i;
9  printf('No load rotational losses is %f W\n',l);
10 disp('case b');
11 km=(Ea*60)/(2*%pi*n); // speed voltage constant
12 v=40; // supply voltage
13 n1=1600; // speed at supply voltage
14 Ea=(km*2*%pi*n1)/60; // generated EMF
15 ia=(v-Ea)/ra; // new armature current
16 pe=Ea*ia; // Electromagnetic power developed
17 po=pe-l;
18 printf('Output power is %f W\n',po);
19 disp('case c');
20 v=20; // supply voltage
21 // when motor stalls Ea=0
22 ia=v/ra; // stall current
23 T=km*ia;
24 printf('Stall torque is %f Nm',T);
```

Chapter 5

Polyphase synchronous machine

Scilab code Exa 5.1 Determining percentage voltage regulation of alternator by different methods

```
1  clc;
2  v=220; // rated voltage of alternator
3  f=50; // frequency of supply
4  r=0.06; // resistance per phase
5  p=6; // number of poles
6  i=40; // full load current
7  pf=0.8; // lagging power factor
8  vt=v/sqrt(3); // rated per phase voltage
9  IF=[ 0.2 0.4 0.6 0.8 1 1.2 1.4 1.8 2.2 2.6 3 3.4];
10 EA=[ 29 58 87 116 146 172 194 232 261.5 284 300
     310];
11 subplot(313);
12 plot(IF,EA/sqrt(3));
13 xlabel('Field current');
14 ylabel('open circuit voltage');
15 title('open circuit characteristics');
16 IF1=[ 0.2 0.4 0.6 0.8 1 1.2 1.4 1.8 ];
17 ISC=[ 6.6 13.2 20 26.5 32.4 40 46.3 59 ];
```

```
subplot(323);
plot(IF1,ISC);
xlabel('Field current');
ylabel('short circuit current');
title('short circuit characteristics');
ZPF=[ 0 0 0 0 0 0 29 88 140 177 208 230];
subplot(333);
plot(IF,ZPF);
xlabel('Field current');
ylabel('terminal voltage');
title('full load zero power factor characteristics')
   ;
disp('EMF method');
// value of synchronous reactance is taken from
   given table
EA1=[ 29 58 87 116 146 172 194 232]
ZS=EA1./(ISC*sqrt(3));
disp('synchronous impedance (ohms) is');
disp(ZS);
XS=ZS; // RS^2 is negligible
disp('synchronous reactance (ohms) is');
disp(XS);
xs=2.27;
ia=i*(pf-%i*sqrt(1-pf^2)); // full load current in
   complex form
E=vt+ia*(r+%i*xs); // Excitation voltage
vr=floor(((abs(E)-vt)/vt)*100);
printf('Voltage regulation is %f percent\n',vr);
disp('Mmf method');
// with ia as reference
E=vt*(pf+%i*sqrt(1-pf^2))+i*r; // Excitation voltage
// from fig 5.30 ,E=127 V
oc=1.69; // current for given excitation voltage
   obtained from open circuit characteristics
sc=1.2; // field current required to circulate full
   load short circuit current
al=atand(imag(E),real(E)); // angle between ia and E
Ff=(oc*(-sind(al)+%i*cosd(al)))-sc; // field mmf
```

```
printf('field mmf is %f A\n',abs(Ff));
// corresponding to Ff,E=163.5 v from O.C.C
Ef=163.5;
vr=((Ef-vt)/vt)*100;
printf('Voltage regulation is %f percent\n',vr);
disp('Zero power factor method');
// As per the description given in method
vd=30; // voltage drop armature leakage reactance
xa=vd/i; // armature leakage reactance
// with ia as reference
Er=vt*(pf+%i*sqrt(1-pf^2))+i*(r+%i*xa); //
   Excitation voltage
// from fig 5.30 ,E=148.6 V
oc=2.134; // current for given excitation voltage
   obtained from open circuit characteristics
Fa=0.84; // armature mmf from potier triangle
be=atand(imag(Er),real(Er)); // angle between ia and
    E
Ff=(oc*(-sind(be)+%i*cosd(be)))-Fa; // field mmf
printf('field mmf is %f A\n',abs(Ff));
// corresponding to Ff=2.797 A,E=169 v from O.C.C
Ef=169;
vr=((Ef-vt)/vt)*100;
printf('Voltage regulation is %f percent\n',vr);
disp('New A.S.A method');
// parameters needed in this method are calculated
   in part c
id=0.366; // difference in field current between OCC
    and air gap line from fig 5.30
th=acosd(pf);
ig=1.507; // field current corresponding to rated
   rated per phase voltage
Ff=ig+sc*(%i*pf+sqrt(1-pf^2)); // field mmf without
   saturation
Ff=abs(Ff)+id; // ield mmf with saturation
printf('field mmf is %f A\n',Ff);
// corresponding to Ff=2.791 A,E=169 v from O.C.C
Ef=169;
```

```
vr=((Ef-vt)/vt)*100;
printf('Voltage regulation is %f percent\n',vr);
disp('Saturated synchronous reactance method');
// for E=148.5 v (from part c),
Era=179.5; // air line gap voltage
k=Era/abs(Er); // saturation factor
vdg=100.5; // voltage drop in unsaturated
   synchronous reactance
xag=vdg/i; // unsaturated synchronous reactance
xas=xa+((xag-xa)/k); // saturated synchronous
   reactance
// with vt as reference
Ef=vt+ia*(r+%i*xas);
ok=2.15; // resultant mmf from fig 5.30
Ff=(abs(Ef)/abs(Er))*ok;
printf('field mmf is %f A\n',Ff);
// corresponding to Ff=2.78 A,E=169 v from O.C.C
Ef=169;
vr=((Ef-vt)/vt)*100;
printf('Voltage regulation is %f percent\n',vr);
```

Scilab code Exa 5.3 Determining shaft power line current pf and efficiency for maximum power output and maximum power input

```
clc;
e=400; // rated voltage of motor
E=510; // excitation emf
zs=0.5+%i*4; // synchronous impedance per phase
l=900; // net loss
al=90-atand(imag(zs),real(zs));
disp('case a');
Pmax=((e*E)/abs(zs))-((E^2*real(zs))/abs(zs)^2); //
   maximum output power
sp=Pmax*3-l;
printf('Shaft power is %f W\n',sp);
```

```
ia=(sqrt(e^2+E^2-2*e*E*cosd(atand(imag(zs),real(zs))
   )))/abs(zs);
il=sqrt(3)*ia; // line current
printf('Line current is %f A\n',il);
di=acosd((e*abs(zs)-E*real(zs))/(ia*abs(zs)^2));
pf=cosd(atand(imag(zs),real(zs))-di);
printf('Power factor is %f lagging\n',pf);
disp('case b');
Pmax=((e*E)/abs(zs))+((e^2*real(zs))/abs(zs)^2); //
   maximum input power
ia=(sqrt(e^2+E^2-2*e*E*cosd(90+al)))/abs(zs);
sp=floor(Pmax*3-ia^2*real(zs)*3-900);
printf('Shaft power is %f W\n',sp);
il=sqrt(3)*ia; // line current
printf('Line current is %f A\n',il);
di=acosd((e+E*cosd(atand(imag(zs),real(zs))))/(ia*
   abs(zs)));
pf=cosd(atand(imag(zs),real(zs))-di);
printf('Power factor is %f lagging\n',pf);
```

Scilab code Exa 5.4 Determining line current and pf for synchronous motor

```
clc;
v=3300; // rated voltage of motor
zs=0.4+%i*5; // synchronous impedance per phase
E=4000; // excitation EMF
pi=1000; // input power
vp=v/sqrt(3); // per phase rated voltage
ep=E/sqrt(3); // per phase excitation EMF
al=atand(real(zs),imag(zs));
t1=(pi*1000)/3;
t2=(vp^2/abs(zs)^2)*real(zs);
t3=abs(zs)/(vp*ep); // terms needed to evaluate load
    angle
```

```
12 di=asind((t1-t2)*t3)+al; // load angle
13 ia=(sqrt(vp^2+ep^2-2*ep*vp*cosd(di)))/abs(zs);
14 pf=(pi*1000)/(3*ia*vp);
15 // here ep*cos(di)+ia*ra*pf> vp; hence leading power
       factor
16 printf('Line current is %f A\n',ia);
17 printf('Power factor is %f leading',pf);
```

Scilab code Exa 5.5 Determining torque developed and new pf

```
1  clc;
2  v=230; // rated voltage of motor
3  f=50; // frequency
4  p=4; // number of poles
5  zs=0.6+3*%i; // synchronous impedance
6  ia1=10; // current drawn by motor at upf
7  ia2=40; // final current after load is inceased to
       certain value
8  vt=v/sqrt(3); // per phase voltage
9  al=atand(real(zs),imag(zs));
10 Ef=sqrt((vt-ia1*real(zs))^2+(ia1*imag(zs))^2); //
       excitation EMF
11 t1=(ia2*abs(zs))^2;
12 t2=Ef^2+vt^2;
13 t3=-2*Ef*vt; // terms needed to evaluate load angle
14 de=acosd((t1-t2)/t3); // load angle
15 pi=(Ef*vt*sind(de-al))/abs(zs)+(vt^2*real(zs))/abs(
       zs)^2; // input power
16 pf=pi/(vt*ia2);
17 printf('Power factor is %f lagging\n',pf);
18 pd=3*(pi-ia2^2*real(zs)); // developed power
19 ns=(120*f)/p; // synchronous speed
20 T=(pd*60)/(2*%pi*ns);
21 printf('Torque developed is %f N-m',T);
```

Scilab code Exa 5.6 Determining pf for increased input power

```
clc;
v=6600; // rated voltage of motor
zs=1.5+12*%i ; // per phase synchronous impedance
pi1=1000; // input power
pf=0.8; // power factor
pi2=1500; // power at which power factor is to be
   found out
vt=v/sqrt(3); // per phase voltage
al=atand(real(zs),imag(zs));
ia=(pi1*1000)/(sqrt(3)*v*pf);
Ef=sqrt((vt*pf-ia*real(zs))^2+(vt*sqrt(1-pf^2)+ia*
   imag(zs))^2); // excitation EMF
t1=(pi2*1000)/3;
t2=(vt^2/abs(zs)^2)*real(zs);
t3=abs(zs)/(vt*Ef); // terms needed to evaluate load
    angle
di=asind((t1-t2)*t3)+al; // load angle
ia=(sqrt(vt^2+Ef^2-2*Ef*vt*cosd(di)))/abs(zs); //
   new armature current
pfn=((pi2-pi1)*1000)/(ia*vt);
// as Ef*cos(di)+ia*ra> vt hence leading power
   factor
printf('New power factor is %f leading',pfn);
```

Scilab code Exa 5.7 Determining new value of armature current and power factor

```
clc;
v=2300; // rated voltage of motor
xs=12 ; // per phase synchronous reactance
```

```
4 p=200000; // VA rating of motor
5 l1=120000; // initial load
6 l2=60000; // final load
7 vt=v/sqrt(3); // rated per phase voltage
8 ia=l1/(3*vt); // minimum armature current
9 ia1=1.5*ia; // armature current at reduced load (50%
    increment)
10 pf=1/1.5; // power factor
11 Ef=sqrt((vt*pf)^2+(vt*sqrt(1-pf^2)+ia1*xs)^2); //
    excitation EMF
12 de=asind((l2*xs)/(3*vt*Ef)); // new load angle
13 ia2=(sqrt(vt^2+Ef^2-2*Ef*vt*cosd(de)))/xs; // new
    armature current
14 printf('New value of armature current is %f A\n',ia2
    );
15 pfn=l2/(3*vt*ia2);
16 printf('Power factor at new armature current is %f
    leading',pfn);
```

Scilab code Exa 5.8 Determining power factor at which machine is operating

```
1 clc;
2 ef=1.2; // ratio of excitation voltage to rated per
    phase voltage
3 i=0.7; // ratio of armature current to rated current
4 r=0.01; // percentage resistance of motor
5 x=0.5; //  percentage reactance of motor
6 // as per the expression given in book
7 t1=ef^2-(r*i)^2-(x*i)^2-1;
8 t2=sqrt((2*i*r)^2+(2*i*x)^2);
9 t3=atand((2*i*r)/(2*i*x)); // terms needed to find
    out power factor
10 pf=cosd(asind(t1/t2)-t3);
11 printf('Power factor is %f lagging',pf);
```

Scilab code Exa 5.9 Calculating 1 pf efficiency excitation emfs input current and 2 load angle and maximum output

```
clc;
v=400; // rated voltage of motor
zs=0.13+%i*1.3 ; // per phase synchronous impedance
p=100000; // VA rating of motor
l=4000; // stray losses
pl=75000; // power delivered to load
disp('case a');
il=p/(sqrt(3)*v); // line current
vt=v/sqrt(3); // per phase rated voltage
pd=pl+l ; // power developed
poh=3*il^2*real(zs);
lt=poh+l; // total losses
pi=pl+lt; // input power
pf=pi/p; // power factor
n=(1-(lt/pi))*100; // efficiency
printf('Power factor is %f\n',pf);
printf('Efficiency is %f percent\n',n);
Ef1=round(sqrt((vt*pf-il*real(zs))^2+(-vt*sqrt(1-pf
    ^2)+il*imag(zs))^2)); // excitation EMF
de=atand((-vt*sqrt(1-pf^2)+il*imag(zs))/(vt*pf-il*
    real(zs)))+acosd(pf); // load angle
printf('Excitation EMf at under excitation is %f v\n
    ',Ef1);
printf('Load angle at under excitation is %f degrees
     \n',de);
Ef2=round(sqrt((vt*pf-il*real(zs))^2+(vt*sqrt(1-pf
    ^2)+il*imag(zs))^2)); // excitation EMF
de=atand((vt*sqrt(1-pf^2)+il*imag(zs))/(vt*pf-il*
    real(zs)))-acosd(pf); // load angle
printf('Excitation EMf at over excitation is %f v\n'
    ,Ef2);
```

```
25 printf('Load angle at over excitation is %f degrees\
   n',de);
26 i=pi/(sqrt(3)*v);
27 printf('Input current is %f A\n',i);
28 disp('caes b');
29 de=acosd(real(zs)/abs(zs)); // load angle
30 pmax=((vt*Ef1)/abs(zs))-((Ef1^2*real(zs))/abs(zs)^2)
   ;
31 pt=pmax*3;
32 printf('Load angle for maximum power output is %f
   degrees\n',de);
33 printf('Maximum output per phase is %f W\n',pmax);
34 printf('Total maximum output is %f W\n',pt);
```

Scilab code Exa 5.10 Determining 1 excitation emfs 2 mechanical power developed and pf 3 minimum excitation voltage

```
1 clc;
2 v=6600; // rated voltage of motor
3 xs=20 ; // per phase synchronous reactance
4 p=500000; // VA rating of motor
5 il=p/(sqrt(3)*v); // rated armature current
6 vt=v/sqrt(3); // per phase rated voltage
7 disp('case a');
8 de=10; // load angle
9 c1=1;
10 c2=-2*vt*cosd(de);
11 c3=vt^2-(il*xs)^2; // coefficients of quadratic
   equation in Ef
12 p= [ c1 c2 c3 ];
13 Ef=roots(p);
14 printf('Per phase excitation EMF at lagging pf is %f
    v\n',Ef(2));
15 printf('Excitation line EMF at lagging pf is %f v\n'
   ,sqrt(3)*Ef(2));
```

```
16 printf('Per phase excitation EMF at leading pf is %f
       v\n',Ef(1));
17 printf('Excitation line EMF at leading pf is %f v\n'
      ,sqrt(3)*Ef(1));
18 disp('case b');
19 disp('For lagging pf');
20 pd=(3*vt*Ef(2)*sind(de))/xs;
21 pf=pd/(sqrt(3)*v*il);
22 printf('Mechanical power developed is %f W\n',pd);
23 printf('Power factor is %f lagging\n',pf);
24 disp('For leading pf');
25 pd=(3*vt*Ef(1)*sind(de))/xs;
26 pf=pd/(sqrt(3)*v*il);
27 printf('Mechanical power developed is %f W\n',pd);
28 printf('Power factor is %f leading\n',pf);
29 disp('case c');
30 p=200000; // delivered power
31 de=90; // load angle for falling out of step
32 // motor falls out of step at de= 90 degrees
33 Ef=(p*xs)/(3*sind(de)*vt);
34 printf('Minimum excitation voltage per phase is %f v
      ',Ef);
```

Scilab code Exa 5.11 Calculating current drawn from supply and pf

```
1 clc;
2 v=415; // rated voltage of motor
3 f=50; // frequency of motor
4 ef=520; // line to line excitation emf
5 p=6; // number of poles
6 xs=2; // per phase synchronous reactance
7 t=220; // torque developed
8 vt=v/sqrt(3); // rated per phase voltage
9 eft=ef/sqrt(3); // per phase excitation emf
10 ws=(4*%pi*f)/p; // synchronous speed
```

```
de=asind((t*ws*xs)/(3*vt*eft)); //  load angle
ia=(sqrt(vt^2+eft^2-2*eft*vt*cosd(de)))/xs; //  from
    phasor diagram(fig 5.48),armature current
pf=(ef*sind(de))/(xs*ia*sqrt(3));
printf('Current drawn from supply is %f A\n',ia);
printf('Power factor is %f leading',pf);
```

Scilab code Exa 5.12 Determining synchronous reactance

```
clc;
v=415; // rated volatge of motor
pf=0.9; // leading power factor
ps=15000; // shaft power
E=400; // excitation emf
r=0.5; // per phase resistance
vt=v/sqrt(3); // rated per phase voltage
e=E/sqrt(3); // per phase excitation emf
c1=1.5;
c2=-sqrt(3)*v*pf;
c3=ps; // coefficients of quadratic equation in
   armature current
p= [ c1 c2 c3 ];
ia=roots(p);
// higher value of armature current is neglected
xs=((vt*sqrt(1-pf^2))-(sqrt(e^2-(vt*pf+ia(2)*r)^2)))
   /ia(2);
printf('Synchronous reactance is %f ohm',xs);
```

Scilab code Exa 5.13 Finding mechanical power delivered by motor and input KVA

```
clc;
e=1.2; // pu excitation emf
```

```
xs=0.8; // pu synchronous reactance
vt=1; // pu rated voltage
ia=1; // pu armature current for KVA=100 %, vt*ia=1
   therefore ia=1;
pf=cosd(asind((e^2-xs^2-1)/(-2*xs))); // leading
   power factor
pd=vt*ia*pf;
printf('Mechanical power developed by motor is %f pu
   \n',pd);
e=1; // pu excitation emf reduced to generate 100%
   emf
de=asind((pf*xs)/(vt*e)); // load angle
ia=(sqrt(vt^2+e^2-2*e*vt*cosd(de)))/xs; // new
   armature current
p=(vt*ia)*100;
printf('New KVA rating is %f percent ',p);
```

Scilab code Exa 5.14 Determining 1 load angle pu armature current and pf 2 excitation voltage load angle and pf

```
clc;
xs=0.8; // pu reactance
Ef=1.3; // pu excitation EMF
p=0.5; // pu output power
vt=1; // rated per phase voltage
disp('case a');
de=asind((p*xs)/(vt*Ef));
printf('Load angle is %f degrees\n',de);
ia=(sqrt(vt^2+Ef^2-2*vt*Ef*cosd(de)))/xs; // from
   phasor diagram (fig5.49)
printf('Armature current is %f p.u.\n',ia);
pf=p/(vt*ia);
printf('Power factor is %f lagging\n',pf);
disp('case b');
// Under given condition magnitude of power factor
```

```
    remains same but it becomes leading
15 Ef=sqrt((vt*pf)^2+(vt*sqrt(1-pf^2)-ia*xs)^2); //
    excitation EMF
16 printf('Excitation EMF is %f p.u.\n',Ef);
17 de=asind((p*xs)/(vt*Ef));
18 printf('Load angle is %f degrees\n',de);
```

Scilab code Exa 5.15 Determining 1 new value of armature current load angle and pf 2 armature current load angle and power delivered

```
1  clc;
2  v=11000; // rated voltage of motor
3  zs=1+10*%i; // per phase synchronous impedance
4  ia=100; // armature current at unity power factor
5  vt=v/sqrt(3); // per phase voltage
6  Ef=sqrt((vt+ia*real(zs))^2+(ia*imag(zs))^2); //
    excitation EMF from phasor diagram
7  al=atand(real(zs),imag(zs));
8  de=atand((ia*imag(zs))/(vt+ia)); // load angle
9  p=(Ef*vt*sind(de+al)/abs(zs))-((vt^2*real(zs))/abs(
    zs)^2); // per phase power delivered
10 disp('case a');
11 Ef1=1.15*Ef; // Excitation EMF after an increment of
    15%
12 t1=p;
13 t2=(vt^2/abs(zs)^2)*real(zs);
14 t3=abs(zs)/(vt*Ef1); // terms needed to evaluate
    load angle
15 di=asind((t1+t2)*t3)-al; // load angle
16 ia1=(sqrt(vt^2+Ef1^2-2*Ef1*vt*cosd(di)))/abs(zs); //
    armature current
17 pf=p/(vt*ia1);
18 printf('New value of armature current is %f A\n',ia1
    );
19 printf('New value of load angle is %f degrees\n',di)
```

```
    ;
20 printf('New power factor is %f lagging\n',pf);
21 disp('case b');
22 // at unity pf
23 pf=1;
24 c1=1+imag(zs)^2;
25 c2=2*vt;
26 c3=vt^2-Ef1^2; // coefficients of quadratic equation
       in armature current
27 p= [ c1 c2 c3 ];
28 ia=roots(p);
29 printf('Armature current under given condition is %f
       A\n',ia(2));
30 P=(vt*ia(2)*pf)/1000;
31 Pt=P*3;
32 printf('Per phase power delivered is %f KW\n',P);
33 printf('Net power delivered is %f KW\n',Pt);
```

Scilab code Exa 5.16 Determining operating pf and load angle

```
1  clc;
2  vt=1; // rated per phase voltage
3  zs=0.02+0.8*%i; // per phase p.u synchronous
      impedance
4  // At the time of synchronization excitation EMF=
      rated per phase voltage and load angle=0
5  ef=1; // pu excitation EMF
6  ia=1; // pu armature current
7  // from phasor diagram 5.51
8  t1=ef^2-real(zs)^2-imag(zs)^2-1;
9  t2=sqrt((2*real(zs))^2+(2*imag(zs))^2);
10 t3=atand(-real(zs)/imag(zs)); // terms needed to
      find out power factor
11 pf=cosd(asind(t1/t2)+ t3);
12 printf('Operating power factor is %f leading\n',pf);
```

```
al=atand(real(zs),imag(zs));
t1=vt*ia*pf;
t2=(vt^2/abs(zs)^2)*real(zs);
t3=abs(zs)/(vt*ef); // terms needed to evaluate load
    angle
de=floor(asind((t1+t2)*t3))-al; // load angle
printf('Load angle of generator is %f degrees',de);
```

Scilab code Exa 5.17 Determining armature current power factor and excitation emf

```
clc;
p=40*10^6; // rated power of turbogenerator
v=11000; // rated voltage of generator
xs=0.8; // p.u. synchronous reactance
ra=0.5; // series reactance of infinite bus
vt=v/sqrt(3); // rated per phase voltage
disp('case b');
ia=p/(v*sqrt(3)); // armature current
printf('Armature current is %f A\n',ia);
xs=xs*(vt/ia); // xs in ohms
vd=ia*ra; // voltage drop in series resistance
pf=cosd(asind((vd/2)/vt));
printf('Alternate power factor is %f lagging\n',pf);
disp('case c');
Ef=sqrt((vt*pf)^2+((vd/2)+(ia*xs))^2);
printf('Excitation EMF line to neutral is %f V\n',Ef
   );
printf('Excitation EMF line to line is %f V\n',sqrt
   (3)*Ef);
```

Scilab code Exa 5.18 Determining load angle power factor and armature current

```
clc;
v=400; // rated voltage of motor
pi=5472; // input power
np=3; // number of phases
xs=10; // synchronous reactance
ef=v; // excitation voltage
vt=v/sqrt(3); // rated per phase voltage
de=round(asind((pi*xs*np)/(np*v^2)));
printf('Load angle is %f degrees\n',de);
// from fig. 5.53, vt=ef(excitation voltage per
   phase) armature resistance=0
pf=cosd(de/2);
printf('Power factor is %f lagging\n',pf);
// from fig. 5.53
ia=floor((2*vt*sind(de/2))/xs);
printf('Armature current is %f A',ia);
```

Scilab code Exa 5.19 Determining 1 excitation emf 2 power transfer and 3 maximum power transfer armature current terminal voltage and power factor

```
clc;
v=2000; // rated voltage of motor
xsm=2; // synchronous reactance of motor
xsg=3; // synchronous reactance of generator
xt=1.5; // transmission line reactance
ia=100; // current drawn by motor
pf=1; // power factor
disp('case a');
vt=v/sqrt(3); // rated per phase voltage
Efm=floor(sqrt(vt^2+(ia*xsm)^2)); // excitation EMF
printf('Excitation EMF for motor is %f V\n',Efm);
Efg=sqrt(vt^2+(ia*(xsg+xt))^2); // excitation EMF
printf('Excitation EMF for alternator is %f V\n',Efg
   );
```

```
disp('case b');
de1=acosd(vt/Efm); // load angle for motor
de2=acosd(vt/Efg); // load angle for alternator
de=de1+de2; // power angle between Efm and Efg
pt=(Efg*Efm*sind(de))/(xsm+xsg+xt);
P=pt*3;
printf('Per phase power transfer between alternator
   and motor is %f KW\n',pt/1000);
printf('Net power transfer between alternator and
   motor is %f KW\n',P/1000);
disp('case c');
// from phasor diagram fig 5.54
ia=sqrt(Efm^2+Efg^2)/(xsm+xsg+xt);
// for maximum transfer of power , power angle=90
   degrees
de=90
pmax=(Efg*Efm*sind(de))/(xsm+xsg+xt);
P=pmax*3;
printf('Per phase maximum power transfer between
   alternator and motor is %f KW\n',pmax/1000);
printf('Net maximum power transfer between
   alternator and motor is %f KW\n',P/1000);
// from phasor diagrams determining various
   parameters needed to find power factor
be=acosd(Efm/(ia*(xsm+xsg+xt)));
Vp=sqrt((Efm-ia*xsm*cosd(be))^2+(ia*xsm*sind(be))^2)
   ; // phase voltage
Vl=sqrt(3)*Vp; // line voltage
printf('Armature current for given condition is %f A
   \n',ia);
printf('Terminal voltage of synchronous motor is %f
   V\n',Vp);
// from phasor diagram
aoc=asind((ia*xsm*sind(be))/Vp);
pf=cosd(90-be-aoc);
printf('Power factor angle of motor is %f leading',
   pf);
```

Scilab code Exa 5.20 Determining 1 maximum power output 2 armature current and power factor

```
clc;
p=20*10^6; // VA rating of alternator
z=5; // impedance of alternator
r=0.5; // resistance of alternator
v=11000; // voltage rating of bus bars
e=12000; // excitation voltage
vt=v/sqrt(3); // alternator per phase voltage
Ef=e/sqrt(3); // alternator per phase excitation
   voltage
pmax=round((((Ef*vt)/z)-((vt^2*r)/z^2))/10^6);
P=round(pmax*3);
printf('Per phase maximum output power from
   alternator is %f MW\n',pmax);
printf('Total maximum output power from alternator
   is %f MW\n',P);
disp('case b');
pf=r/z; // power factor
ia=round((sqrt(vt^2+Ef^2-2*Ef*vt*pf))/z); //
   armature current
printf('Armature current is %f A\n',ia);
pf=(Ef*z-vt*r)/(ia*z^2);
printf('Power factor under maximum power condition
   is %f leading',pf);
```

Scilab code Exa 5.21 Calculating data needed to plot v curves and pf variation with field current

```
clc;
v=2200; // rated voltage of motor
```

```
r=0.32; // per phase armature resistance
p=1500; // KW rating of motor
ie=15; // exciting current
is=750; // short circuit current
cl=60; // core loss in KW
fl=40; // frictional and windage loss in KW
IF=[5 10 15 20 25 30];
EF0=[ 760 1500 2140 2650 3040 3340]; // excitation
   EMF per phase
EFP=EF0/sqrt(3);
disp('Excitation EMF per phase(V) is');
disp(EFP);
// from table given for ie=15,
Ef=2140; // Excitation EMF
np=3; // number of phases
ef=Ef/sqrt(3); // per phase open circuit voltage
zs=ef/is; // synchronous impedance
vt=floor(v/sqrt(3)); // per phase terminal voltage
i=floor(vt/zs); // current phasor lagging vt
ia=vt/(2*r); // armature current
pd=((p/2)+cl+fl)/np; // mechanical power developed
   per phase at half-full load output
R=ceil(sqrt((ia^2-((pd*1000)/r))));
printf('Radius of power circle is %f A\n',R);
printf('Current phasor is %f A\n',i);
printf('Synchronous impedance is %f ohm\n',zs);
disp('using above data and table given in solution,
   V-curves and variation of p.f. with field
   currents can be plotted');
```

Scilab code Exa 5.22 Determining data to plot v curves and pf variation with field current neglecting armature resistance

```
clc;
v=2200; // rated voltage of motor
```

```
3 p=1500; // KW rating of motor
4 ie=15; // exciting current
5 is=750; // short circuit current
6 cl=60; // core loss in KW
7 fl=40; // frictional and windage loss in KW
8 // from table given in question for ie=15,
9 Ef=2140; // Excitation EMF
10 np=3; // number of phases
11 ef=Ef/sqrt(3); // per phase open circuit voltage
12 xs=ef/is; // synchronous reactance
13 vt=floor(v/sqrt(3)); // per phase terminal voltage
14 i=floor(vt/xs); // current phasor lagging vt
15 pd=((p/2)+cl+fl)/np; // mechanical power developed
     per phase at half-full load output
16 ia=pd*1000/vt; // working component of armature
     current
17 // as resistance =0 , armature current=0 therefore
     radius of power circle=0 that is it becomes line
     with centre at zero
18 printf('Working component of armature current is %f
    A\n',ia);
19 printf('Terminal voltage is %f A\n',vt);
20 printf('Synchronous reactance is %f ohm\n',xs);
21 disp('using above data and table given in solution,
    V-curves and variation of p.f. with field
    currents can be plotted');
```

Scilab code Exa 5.23 Determining armature current power factor and load angle

```
1 clc;
2 v=1100; // rated voltage of motor
3 ef=1650; // emf
4 p=350; // input power in KW
5 zs=0.7+3.2*%i; // synchronous impedance per phase
```

```
vt=v/sqrt(3); // rated per phase voltage
eft=ef/sqrt(3); // per phase emf
i1=vt/abs(zs);
printf('Current phasor lagging terminal voltage is %f A\n', i1);
i2=eft/abs(zs);
printf('Current phasor lagging excitation EMF is %f A\n', i2);
ia=(p*1000)/(3*vt);
printf('Working component of armature current is %f A',ia);
disp('using this data vector diagram is drawn and value of ia and power factor is obtained');
ia=194.5;
pf=19.5;
printf('Power factor is %f leading\n',pf);
printf('Armature current is %f A\n',ia);
de=acosd((ia^2-i1^2-i2^2)/(-2*i1*i2));
printf('Load angle is %f degrees\n',de);
```

Scilab code Exa 5.24 Determining pu excitation voltage

```
clc;
xd=1.2; // d axis synchronous reactance
xq=0.8; // q axis synchronous reactance
ra=0.025; // armature resistance
vt=1; // pu rated per phase voltage
disp('case a');
disp('For lagging power factor')
pf=0.8; // power factor
ia=1*(pf-sqrt(1-pf^2)*%i); // armature current
Ef1=vt+%i*(ia*xq)+ia*ra; // excitation EMF
id=1*sind(atand(imag(Ef1),real(Ef1))+acosd(pf)); // d component of armature current
iq=1*cosd(atand(imag(Ef1),real(Ef1))+acosd(pf)); //
```

```
    q component of armature current
13 Ef=abs(Ef1)+id*(xd-xq); // excitation EMF
14 printf('Excitation EMF is %f p.u. at a load angle of
     %f degrees\n',abs(Ef),atand(imag(Ef1),real(Ef1))
    );
15 disp('case b');
16 disp('For leading power factor')
17 pf=0.8; // power factor
18 ia=1*(pf+sqrt(1-pf^2)*%i); // armature current
19 Ef1=vt+%i*(ia*xq)+ia*ra; // excitation EMF
20 id=1*sind(atand(imag(Ef1),real(Ef1))-acosd(pf)); //
    d component of armature current
21 iq=1*cosd(atand(imag(Ef1),real(Ef1))-acosd(pf)); //
    q component of armature current
22 Ef=abs(Ef1)+id*(xd-xq); // excitation EMF
23 printf('Excitation EMF is %f p.u.at a load angle of
    %f degrees\n',abs(Ef),atand(imag(Ef1),real(Ef1)))
    ;
```

Scilab code Exa 5.27 Calculating 1 power angle armature current and pf 2 maximum power output and power angle

```
1  clc;
2  v=400; // rated voltage of synchronous machine
3  vt=v/sqrt(3); // per phase rated voltage
4  ps=9500; // shaft load
5  xd=5; // per phase d-axis synchronous reactance
6  xq=3.2; // per phase q-axis synchronous reactance
7  l=500; // friction windage and core losses
8  np=3; // number of phases
9  // at rated voltage excitation EMF
10 Ef=v/sqrt(3); // excitation EMF
11 disp('case a');
12 pt=ps+l; // power developed
13 // by using formula pd=np*(((Ef*Ef*sind(de))/xd)+((
```

```
    Ef^2*sind(2*de)*0.5*(xd-xq))/(xd*xq))), and hit
    and trial method we obtain value of load angle
de=11.623; // load angle
id=(Ef-Ef*cosd(de))/xd; // d-axis component of
    armature current
iq=(Ef*sind(de))/xq; // q-axis component of armature
     current
ia=sqrt(id^2+iq^2);
printf('Armature current is %f A\n',ia);
pf=cosd(acosd(iq/ia)-de);
printf('Power factor is %f lagging\n',pf);
disp('case b');
de=acosd((-Ef*xq)/(4*Ef*(xd-xq))+(sqrt(0.5+((Ef*xq)
    /(4*vt*(xd-xq)))^2)));
pd=np*(((Ef*Ef*sind(de))/xd)+((Ef^2*sind(2*de)*0.5*(
    xd-xq))/(xd*xq))); // maximum power developed
po=pd-l;
printf('Maximum power output is %f W',po);
```

Scilab code Exa 5.29 Determining change in synchronous power and reactive power

```
clc;
Ef=1.4; // p.u excitation EMF
xs=1.2; // p.u synchronous reactance
p=0.5; // p.u synchronous power being delivered
i=1; // percentage increment in prime mover torque
vt=1; // rated per phase voltage
de=asind((p*xs)/(Ef*vt)); // load angle
dp=(i*p)/100; // increase in p.u real power
ip=(dp/p)*100;
printf('Percentage increase in real power is %d
    percent of its previous value\n',ip);
iq=-tand(de)*ip;
printf('Percentage decrease in reactive power is %f
```

```
percent of its previous value\n',-iq);
```

Scilab code Exa 5.31 Determining maximum load armature current and pf

```
clc;
v=400; // rated voltage of motor
xd=6; // d-axis synchronous reactance
xq=4; // q-axis synchronous reactance
vt=400/sqrt(3); // rated per phase voltage
// As per the theory given in question, phasor
   diagram is drawn and formula is derived
// After the derived expression, for maximum power
   load angle=45
de=45;
P=(vt^2/2)*((1/xq)-(1/xd))*sind(2*de);
printf('Maximum load that can be put on synchronous
   motor is %f W per phase\n',P);
printf('Maximum load that can be put on synchronous
   motor is %f W for 3-phase\n',3*P);
iq=(vt*sind(de))/xq; // q-axis component of armature
    current
id=(vt*sind(de))/xd; // d-axis component of armature
    current
ia=sqrt(iq^2+id^2);
printf('Armature current is %f A\n',ia);
pf=(3*P)/(sqrt(3)*v*ia);
printf('Power factor at maximum power is %f lagging'
   ,pf);
```

Scilab code Exa 5.32 Determining minimum excitation voltage and maximum stable load angle

```
clc;
// Answer for minimum excitation voltage is given
   wrong in book
v=400; // rated voltage of motor
xd=6; // d-axis synchronous reactance
xq=4; // q-axis synchronous reactance
vt=400/sqrt(3); // rated per phase voltage
p=21; // load carried by motor
pph=(p/3)*1000; // per phase load carried by motor
// As per the theory given in question, expression
   is derived
// After the derived expression,
// cos(de)=(vt^2*(xd-xq)*sin(de)^3)/(pph*xd*xq),
   value of de (load angle is obtained by trial and
   error method  and value of load angle is)
de=63.2;
Ef=(pph-(vt^2/2)*((xd-xq)/(xd*xq))*sind(2*de))/((vt/
   xd)*sind(de));
printf('Maximum stable load angle is %f degrees\n',
   de);
printf('Minimum excitation voltage is %f v\n',Ef);
```

Scilab code Exa 5.34 Determining load angle and excitation voltage

```
clc;
vt=1; // pu rated voltage
xd=1; // pu d-axis synchronous reactance
xq=0.6; // pu q-axis synchronous reactance
p=0.9; // pu power being delivered
pf=0.8; // power factor
ia=p/(vt*pf); // pu armature current
de=atand((ia*xq+vt*sind(acosd(pf)))/(vt*pf))-acosd(
   pf);
printf('Load angle is %f degrees\n',de);
Ef=vt*cosd(de)+ia*sind(de+acosd(pf))*xd;
```

```
11 printf('Excitation voltage is %f p.u.\n',Ef);
12 // when loss of excitation takes place Ef=0, for
      maximum power load angle=45
13 de=45; // load angle
14 pmax=(vt^2*(xd-xq)*sind(2*de))/(2*xd*xq);
15 printf('Maximum power is %f p.u.\n',pmax);
16 disp('As maximum power is less than the power being
      delivered generator will lose synchronism');
```

Scilab code Exa 5.35 Determining excitation voltage power synchronizing power per electrical and mechanical degrees and corresponding torque maximum value of load angle and corresponding power

```
1  clc;
2  v=11000; // rated voltage of motor
3  P=20*10^6; // rated power of motor
4  p=12; // number of poles
5  f=50; // frequency
6  xd=5; // d-axis synchronous reactance
7  xq=3; // q-axis synchronous reactance
8  vt=v/sqrt(3); // per phase rated voltage
9  ia=P/(sqrt(3)*v); // per phase armature current
10 disp('case a');
11 // from phasor diagram
12 Ef=vt-%i*(ia*xq);
13 de=atand((ia*xq),(vt)); // load angle
14 id=ia*sind(de); // d-axis component of armature
      current
15 Ef=ceil(abs(Ef)+id*(xd-xq));
16 printf('Excitation voltage is %f V to neutral\n',Ef)
      ;
17 disp('case b');
18 po=(((Ef*vt*sind(de))/xd)+((vt^2*(xd-xq)*sind(2*de))
      /(2*xd*xq)))/1000;
19 printf('Power is %f KW per phase\n',po);
```

```
po=3*po*1000;
printf('Calculated power %f W is almost equal to
    given rated power i.e %f W\n',po,P);
disp('case c');
ps=((Ef*vt*cosd(de))/xd)+((vt^2*(xd-xq)*cosd(2*de))
    /(xd*xq));
printf('Synchronozing power per electrical degree is
    %f KW\n',(3*ps*%pi)/(180*1000));
ws=(4*%pi*f)/p; // synchronous speed
t=(3*ps*%pi)/(180*ws);
printf('Torque corresponding to synchronous power is
    %f N-m\n',t);
disp('case d');
printf('Synchronozing power per mechanical degree is
    %f KW\n',(3*ps*%pi*p)/(2*180*1000));
t=(3*ps*%pi*p)/(2*180);
printf('Torque corresponding to synchronous power is
    %f N-m\n',t);
disp('case e');
de=acosd((-Ef*xq)/(4*Ef*(xd-xq))+(sqrt(0.5+((Ef*xq)
    /(4*vt*(xd-xq)))^2)));
printf('Maximum value of power angle is %f degrees\n
    ',de);
pmax=(((Ef*vt*sind(de))/xd)+((vt^2*(xd-xq)*sind(2*de
    ))/(2*xd*xq)))/1000;
printf('Maximum power is %f KW per phase\n',pmax);
printf('Maximum power is %f KW for 3 phase\n',pmax
    *3);
```

Scilab code Exa 5.36 Calculate synchronizing power and torque per mechanical degrees 1 at no load and 2 at full load

```
clc;
v=6600; // rated voltage of motor
p=8; // number of poles
```

```
f=50; // frequency of motor
xs=20; // percentage synchronous reactance
P=3000; // rated power of motor
m=3; // number of phases
vt=v/sqrt(3); // per phase rated voltage
ia=(P*1000)/(sqrt(3)*v); // per phase armature
   current
xs=(xs*vt)/(100*ia); // synchronous reactance in ohm
disp('case a');
de=0; // at no load load angle=0 and excitation
   voltage=per phase rated voltage
ps=ceil(((m*vt^2*cosd(de)*%pi*p)/(xs*360))/1000);
printf('Synchronozing power per mechanical degree is
    %f KW\n',ps);
T=((ps*1000*p*60)/(2*%pi*120*f))/1000;
printf('Corresponding synchronizing torque is %f KN-
   m\n',T);
disp('case b');
pf=0.8; //  lagging power factor
Ef=vt+%i*ia*(pf-sqrt(1-pf^2)*%i)*xs; // Excitation
   EMF
de=atand(imag(Ef),real(Ef));
ps=((m*vt*abs(Ef)*cosd(de)*%pi*p)/(xs*360))/1000;
printf('Synchronozing power per mechanical degree is
    %f KW\n',ceil(ps));
T=((ps*1000*p*60)/(2*%pi*120*f))/1000;
printf('Corresponding synchronizing torque is %f KN-
   m\n',T);
```

Scilab code Exa 5.37 Determining 1 synchronizing current power and torque 2 armature current and angle by which rotor slips back

```
clc;
vt=3300; // terminal voltage
xs=11; // synchronous reactance per phase
```

```
4 p=8; // number of poles
5 f=50; // frequency of motor
6 m=3; // number of phases
7 // from fig 5.82
8 // at no load load angle=0 and excitation voltage=
    terminal voltage
9 de=0;
10 s=p/2; // electrical degree equivalent of one
    mechanical degree in space
11 es=2*vt*sind(s/2); // synchronizing voltage
12 is=es/xs;
13 printf('Synchronizing current in the armature is %f
    A\n',is);
14 ps=m*vt*is*cosd(de+s/2);
15 printf('synchonizing power is %f KW\n',floor(ps
    /1000));
16 ws=(2*%pi*120*f)/(60*p);
17 T=ps/ws;
18 printf('Synchronizing torque tending to restore
    rotor to its previous position is %f Nm\n',T);
19 disp('case b');
20 ia=30; // armature current
21 dde=2*(asind((ia*xs)/(2*vt))); // change in load
    angle in electrical degrees
22 s=dde*(2/p);
23 printf('Rotor slips back by %f mechanical degrees',s
    );
```

Scilab code Exa 5.38 Determining 1 load angle armature current and pf 2 maximum load load angle and armature current 3 minimum excitation voltage

```
1 clc;
2 v=400; // rated voltage of motor
3 f=50; // frequency of motor
```

```
4  r=1; // per phase resistance
5  x=5; // per phase reactance
6  m=3; // number of phases
7  p=15000; // rated power of motor
8  disp('case a');
9  EF=480; // Excitation voltage
10 ph=p/m; // per phase power
11 vt=v/sqrt(3); // terminal voltage
12 R0=vt/(2*r);
13 printf('Radius of zero power circle is %f A\n',R0);
14 R1=sqrt(R0^2-(ph/r));
15 printf('Radius of per phase power circle is %f A\n',
     R1);
16 Ef=EF/sqrt(3); // per phase excitation voltage
17 i1=vt/sqrt(r^2+x^2);
18 i2=Ef/sqrt(r^2+x^2); // current phasors lagging
     terminal and excitation voltage
19 printf('Current phasors lagging terminal voltage is
     %f A\n',i1);
20 printf('Current phasors lagging exciation voltage is
     %f A\n',i2);
21 disp('using the above data power circle diagram is
     drawn and value of armature current and power
     factor is obtained');
22 ia=26;
23 pf=0.955;
24 printf('Armature current is %f A\n',ia);
25 printf('Power factor is %f leading\n',pf);
26 disp('case b');
27 // from power circle diagram, radius for maximum
     power is 61 A
28 R2=61; //  radius for maximum power
29 pmax=(R0^2-R2^2)*r;
30 printf('Maximum power per phase is %f KW\n',pmax
     /1000);
31 printf('Maximum power for 3-phase is %f KW\n',(3*
     pmax)/1000);
32 disp('case c');
```

```
33 l=12; // load on motor in KW
34 lp=(l/3)*1000; // per phase load
35 ef=(sqrt(r^2+x^2))*(R0-sqrt(R0^2-lp/r));
36 printf('Minimum excitation voltage is %f V',ef);
```

Scilab code Exa 5.41 Determining 1 excitation voltage 2 reluctance power developed

```
1 clc;
2 n=1490; // speed of machine in rpm
3 p=4; // number of poles
4 f=50; // frequency
5 v=11000; // rated voltage of machine
6 p=20*10^6; // rated power of machine
7 v1=30;
8 v2=25; // per phase voltage for phase A of machine
9 i1=10;
10 i2=6.5; // per phase current for phase A of machine
11 ns=(120*f)/p; // synchronous speed of machine
12 xd=v1/i2; // d-axis synchronous reactance
13 xq=v2/i1; // q-axis synchronous reactance
14 disp('case a');
15 ia=p/(sqrt(3)*v); // armature current
16 vt=v/sqrt(3); // per phase armature voltage
17 Ef=vt+ia*xq*%i;
18 de=atand(imag(Ef),real(Ef)); // load angle
19 id=ia*sind(de); // d-axis current
20 Ef1=abs(Ef)+id*(xd-xq);
21 printf('Per phase excitation value is %f V\n',ceil(
   Ef1));
22 printf('Line value of excitation EMf is %f V\n ',
   ceil(sqrt(3)*Ef1));
23 disp('case 2');
24 pr=(vt^2*(xd-xq)*sind(2*de))/(2*xd*xq);
25 printf('Reluctance power developed by machine is %f
```

```
    KW per phase\n',pr/1000);
26 printf('Total reluctance power developed by machine
    is %f KW',(3*pr)/1000);
```

Scilab code Exa 5.43 Determining efficiency at 1 half load 2 full load

```
1  clc;
2  p=100*10^3; // rated power of alternator
3  v=440; // rated voltage of alternator
4  m=3; // number of phases
5  l1=340; // friction and windage losses
6  l2=480; // open circuit core losses
7  rf=180; // field winding resistance at 75 degree cel
       .
8  ra=0.02; // armature resistance per phase
9  vf=220; // voltage applied to field winding
10 pf=0.8; // power factor
11 disp('At half load');
12 ia=p/(sqrt(3)*v); // full load armature current
13 l3=(m*ia^2*ra)/4; // short circuit load loss at half
       load
14 l4=vf^2/rf; // field circuit loss
15 lt=l1+l2+l3+l4; // net loss
16 n=(1-(lt/((p/2)*pf+lt)))*100;
17 printf('Efficiency is %f percent\n',n);
18 disp('At full load');
19 l3=m*ia^2*ra; // short circuit load loss at full
    load
20 lt=l1+l2+l3+l4; // net loss
21 n=(1-(lt/(p*pf+lt)))*100;
22 printf('Efficiency is %f percent\n',n);
```

Scilab code Exa 5.44 Determining effective resistance in pu and ohms and ratio of ac to dc resistance

```
clc;
p=40000; // rated power of machine
v=400; // rated voltage of machine
l=1500; // short circuit load loss
m=3; // number of phases
ia1=1; // armature current in p.u.
ra=0.118; // dc armature resistance at 30 degree cel
   .
ia2=p/(sqrt(3)*v); // rated armature current
l1=l/p; // short circuit loss in p.u.
ra1=l1/ia1^2;
printf('Effective armature resistance is %f p.u.\n',
   ra1);
l2=l/m; // short circuit load loss per phase
ra2=l2/ia2^2;
printf('Effective ac armature resistance is %f ohm
   per phase\n',ra2);
r=ra2/ra;
printf('Ratio of ac to dc armature resistance is
   given as %f ',r);
```

Scilab code Exa 5.45 Determining 1 efficiency and 2 maximum efficiency

```
clc;
p=500*10^3; // rated power of alternator
v=11000; // rated voltage of alternator
m=3; // number of phases
l1=1500; // friction and windage losses
l2=2500; // open circuit core losses
ra=4; // armature resistance per phase
l3=1000; // field copper loss
pf=0.8; // power factor
```

```
10 disp('case a: Half load');
11 ia=p/(sqrt(3)*v); // armature current
12 l4=(m*ia^2*ra)/4; // short circuit load loss at half
       load
13 lt=l1+l2+l3+l4; // net loss
14 n=(1-(lt/((p/2)*pf+lt)))*100;
15 printf('Efficiency is %f percent\n',n);
16 disp('case b');
17 // for maximum efficiency variable losses=constant
      losses
18 iam=sqrt((l1+l2+l3)/(m*ra)); // armature current at
      maximum efficiency
19 pout=m*(v/sqrt(3))*iam*pf; // output power ta
      maximum efficiency
20 lt=2*(l1+l2+l3); // net losses
21 nm=(1-(lt/(pout+lt)))*100;
22 printf('Maximum efficiency is %f percent\n',nm);
```

Scilab code Exa 5.46 Determining KVA rating of synchronous condenser and KVA of factory

```
1 clc;
2 l=1800; // total load on factory
3 pf=0.6; // power factor
4 pfn=0.95; // desired power factor
5 // from phasor diagram 5.107
6 l1=l/pf; // load in VA
7 a1=acosd(pf); // phase angle between terminal
      voltage and armature current
8 a2=acosd(pfn); // phase angle corresponding to
      desired power factor
9 k1=l1*sind(a1); // KVAr of load
10 k2=l*tand(a2); // combined KVAr
11 disp('case a');
12 s=k1-k2;
```

```
13 printf('Synchronous condenser rating is %f KVA\n',
      floor(s));
14 disp('case b');
15 r=sqrt(l^2+k2^2);
16 printf('Total KVA of factory is %f KVA',r);
```

Scilab code Exa 5.47 Determining 1 total load KVA 2 KVA capacity of motor 3 power factor of motor

```
1  clc;
2  l0=300; // total load on factory
3  pf=0.6; // lagging power factor
4  n=88; // percentage efficiency of motor
5  pfn=0.9; // desired power factor
6  l1=60; // mechanical load to be supplied
7  // from phasor diagram 5.108
8  pi=l1/(n/100); // synchronous motor input
9  lt=pi+l0; // combined load
10 disp('case a');
11 k=lt/pfn;
12 printf('Total load is %f KVA\n',k);
13 disp('case b');
14 a1=acosd(pf); // phase angle between terminal
      voltage and armature current
15 a2=acosd(pfn); // phase angle corresponding to
      desired power factor
16 k1=l0*tand(a1); // KVAr of load
17 k2=lt*tand(a2); // combined KVAr
18 s=k1-k2; // leading KVAr supplied by synchronous
      motor
19 r=sqrt(s^2+pi^2);
20 printf('Capacity of synchronous motor is %f KVA\n',r
      );
21 disp('case c');
22 pfs=pi/r;
```

```
23 printf('Synchronous motor operating power factor is
     %f leading',pfs);
```

Scilab code Exa 5.48 Calculating permissible additional load and rating of synchronous condenser

```
1  clc;
2  p0=1000; // full load power rating of substation
3  pf=0.71; // lagging power factor
4  pfn=0.87; // desired power factor
5  // from phasor dagram 5.109
6  p1=p0*pf; // load KW
7  p2=sqrt(p0^2-p1^2); // load KVAr
8  pn=p0*pfn; // new power delivered to load
9  p0n=pn/pf; // new load KVA
10 pl=p0n-p0;
11 printf('Permissible additional load at %f lagging
     power factor is %f KVA\n',pf,pl);
12 p2n=sqrt(p0n^2-pn^2); // new load KVAr
13 p2ns=sqrt(p0^2-pn^2); // new load KVAr with the use
     of synchronous condensor
14 R=p2n-p2ns;
15 printf('Rating of synchronous condensor is %f KVA',R
     );
```

Scilab code Exa 5.49 Determining new pf and percentage reduction in line current

```
1  clc;
2  p=4000; // load taken by industrial plant in KW
3  pf=0.8; // lagging power factor
4  l=400; // rating of induction motor to be replaced
     by synchronous motor
```

```
5 n=0.9; // efficiency of induction motor and
    synchronous motor
6 pf1=0.9; // lagging power factor at which induction
    motor operates
7 pf2=0.8; // leading power factor at which
    synchronous motor operates
8 A=p-%i*p*tand(acosd(pf)); // complex power of plant
9 pi=1/pf1; // power input to induction motor
10 B=pi-%i*pi*tand(acosd(pf1)); // complex power
    requirement of induction motor
11 C=pi+%i*pi*tand(acosd(pf2)); // complex power
    requirement of synchronous motor
12 pfn=cosd(atand(imag(A-B+C),real(A-B+C)));
13 printf('New power factor of the plant is %f lagging\
    n',pfn);
14 r=(abs(A-B+C)/sqrt(3))/(p/(sqrt(3)*pf)); // ratio of
     new line current to original line current
15 pr=(1-r)*100;
16 printf('Percentage reduction in line current is %f
    percent',pr);
```

Scilab code Exa 5.53 Determining voltage regulation at full load

```
1 clc;
2 m=3; // number of phases
3 p=2; // number of poles
4 P=4*10^6; // rated power of generator
5 v=11000; // rated voltage of generator
6 as=72; // armature slots
7 cs=4; // conductor per armature slot
8 rs=24; // rotor slots
9 rp=10; // rotor slot angular pitch
10 cr=20; // conductors per rotor slot
11 z=0.1+2*%i; // armature leakage impedance per phase
12 pf=0.8; // lagging power factor
```

```
vt=v/sqrt(3); // terminal voltage
ia=P/(sqrt(3)*v); // full load armature current
// Open circuit characteristics have been plotted
   using table given in question.Per phase value of
    excitation voltage is obtained fron table
IF=[ 40 80 120 160 200 240 280 320 360];
EA=[ 2490 4980 7470 9390 10620 11460 12030 12450
   12660 ];
plot(IF,EA/sqrt(3));
xlabel('Field current');
ylabel('open circuit voltage');
title('open circuit characteristics');
Er=vt+ia*(pf-%i*sqrt(1-pf^2))*z; // air gap voltage
printf('Air gap voltage is %f V\n',abs(Er));
disp('Corresponding to magnitude of air gap voltage
   value of field MMF in terms of field current is
   obtained from O.C.C (for textbook refer fig.
   5.114)');
Fr=242; // field MMF in terms of field current
q=rs/p; // rotor slots per pole
kd=sind(q*rp/2)/(q*sind(rp/2)); // distribution
   factor
kp=1 ; // coil span factor for full pitch field coil
kw=kd*kp; // winding factor
Nf=(rs*cr)/p; // total field turns
F1f=(4*kw*Nf)/(%pi*p); // ratio of fundamental field
    mmf per pole to field current
Nph=(as*cs)/(m*p); // series turn per phase
q1=as/(m*p); // armature slots per pole per phase
v1=(p*180)/as; // armature slot angular pitch
kd=(sind(q1*v1/2))/(q1*sind(v1/2)); // distribution
   factor
kw=kd*kp; // winding factor
Fa=(0.9*m*Nph*ia*kw)/(p*F1f); // armature mmf in
   terms of field current
B=acosd(pf)+atand(imag(Er),real(Er)); // power
   factor angle + angle by which air gap voltage
   leads terminal voltage
```

```
39 Ff=sqrt(Fr^2+Fa^2-2*Fr*Fa*cosd(90+B)); // equivalent
       field current
40 printf('Equivalent field current is %f A\n',Ff);
41 // corresponding to equivalent field current,
      excitation voltage is obtained from O.C.C
42 Ef=7168; // excitation EMF per phase
43 vr=((Ef-vt)/vt)*100;
44 printf('Voltage regulation at full load %f lagging
      power factor is %f percent',pf,vr);
```

Scilab code Exa 5.54 Determining terminal voltage and current

```
1  clc;
2  p=2*10^6; // rated power of alternator
3  v=11000; // rated voltage of alternator
4  zs=0.3+5*%i; // synchronous impedance per phase
5  pf=0.8; // lagging power factor
6  vt=v/sqrt(3); // terminal voltage
7  ia=p/(sqrt(3)*v); // full load armature current
8  // with vt as reference phasor
9  Ef=vt+ia*(pf-sqrt(1-pf^2)*%i)*zs;
10 // now excitation level is same but load power
      fcator is leading
11 printf('Load current is %f A\n',ia);
12 de=cosd(atand(imag(Ef),real(Ef))); // angle between
      excitation and terminal voltage
13 vt=abs(Ef)*(de+sqrt(1-de^2)*%i)-ia*(pf+sqrt(1-pf^2)*
      %i)*zs;
14 printf('Terminal voltage at %f leading power factor
      is %f V per phase\n',pf,abs(vt));
15 printf('Line terminal voltage is %f KV',(sqrt(3)*abs
      (vt))/1000);
```

Scilab code Exa 5.55 Determining load angle and power factor

```
clc;
p=30*10^6; // rated power of alternator
v=11000; // rated voltage of alternator
zs=0.005+0.70*%i; // p.u synchronous reactance
Ef=1.5; // p.u. excitation EMF
ia=1; // p.u. armature current
vt=1; // p.u. terminal voltage
t1=Ef^2-(real(zs)*ia)^2-(imag(zs)*ia)^2-1;
t2=sqrt((2*ia*real(zs))^2+(2*ia*imag(zs))^2);
t3=atand((2*ia*real(zs))/(2*ia*imag(zs))); // terms
   needed to find out power factor
pf=cosd(asind(t1/t2)-t3);
printf('Power factor is %f lagging\n',pf);
de=acosd((ia*abs(zs)^2-Ef^2-vt^2)/(-2*Ef*vt));
printf('Load angle is %f degrees',de);
```

Scilab code Exa 5.56 Determining 1 terminal voltage and armature current 2 load angle and excitation voltage

```
clc;
xd=1.2; // pu d-axis synchronous reactance
xq=0.8; // pu q-axis synchronous reactance
xe=0.1; // pu external reactance
vb=1; // voltage of infinite bus
pf=0.9; // lagging power factor
disp('case a');
// vb=vt-j*ia*xe -(1)where ia is armature current
// ia=ia*(pf-%i*sqrt(1-pf^2)); // complex form of
   armature current
// vt*ia=1 therefore ia=1/vt solving equation 1 we
   get a quadratic equation in vt whose terms are
t1=1;
t3=-2*xe*sqrt(1-pf^2)-vb;
```

```
13 t5=(xe*sqrt(1-pf^2))^2-(pf*xe)^2; // terms of
     quadratic equation in terminal voltage
14 p= [t1 0 t3 0 t5];
15 vt=roots(p);
16 ia=1/vt(2); // pu armature current
17 printf('Generator terminal voltage is %f pu\n',vt(2)
     );
18 printf('Armature current is %f pu\n',ia);
19 disp('case b');
20 Ef=vt(2)+ia*(pf-%i*sqrt(1-pf^2))*%i*xq;
21 de=atand(imag(Ef),real(Ef));
22 pa=acosd(pf); // power factor angle
23 id=ia*sind(de+pa); // d-axis component of armature
     current
24 Ef=abs(Ef)+id*(xd-xq);
25 printf('Load angle is %f degrees\n',de);
26 printf('Excitation voltage is %f pu',Ef);
```

Scilab code Exa 5.57 Calculating maximum power output and minimum pu excitation

```
1 clc;
2 xd=0.85; // reactance along d-axis
3 xq=0.55; // reactance along q-axis
4 vt=1; // pu bus voltage
5 Ef=1.2; // pu excitation EMF
6 // P=(Ef*vt*sin(de))/xd + (vt^2/2)*((1/xq)-(1/xd))*
     sin(2*de) where p is power and de is load angle
7 // for maximum power dp/dde(derivative with respect
     to load angle) is zero. Solving we get a
     quadratic equation whose terms are
8 p=[ (vt^2/2)*((1/xq)-(1/xd))*4 (Ef*vt)/xd -(vt^2/2)
     *((1/xq)-(1/xd))*2 ];
9 l=roots(p);
10 an=l(2);
```

```
de=acos(an)*(180/%pi); // load angle

pmax=(Ef*vt*sin(de*(%pi/180)))/xd + (vt^2/2)*((1/xq)
   -(1/xd))*sin(2*de*(%pi/180));
printf('Maximum power output that motor can supply
   without loss of synchronization is %f pu\n',pmax)
   ;
// cos(de)=(vt^2/p)*((xd-xq)/(xd+xq))*sin(de)^3
   where de is load angle for minimum excitation EMF
// by trial and error value of de is
de=63;
P=1; // pu power
Ef=(P-((vt^2/2)*((xd-xq)/(xd*xq))*sind(2*de)))/((vt/
   xd)*sind(de));
printf('Minimum excitation EMF for machine to stay
   in synchronism is %f pu\n',Ef);
```

Scilab code Exa 5.58 Determining voltage regulation

```
clc;
p=3*10^6; // rated power of alternator
v=11000; // rated voltage of alternator
r=0.4; // per phase effective resistance
vl=12370; // line to line voltage at zero leading
   power factor
i=100; // load current at zero power factor
pf=0.8; // lagging power factor at which voltage
   regulation has to be determined
vt=vl/sqrt(3); // per phase terminal voltage
Ef=v/sqrt(3); // per phase excitation EMF
ia=p/(sqrt(3)*v); // full load phase current
// for zero power factor load angle=0
zs=(vt-Ef)/i; // synchronous impedance
xs=sqrt(zs^2-r^2); // synchronous reactance
// From phasor diagram
```

```
15 Ef1=sqrt((Ef*pf+ia*r)^2+(Ef*sqrt(1-pf^2)+ia*xs)^2);
   // excitation EMF at 0.8 power factor
16 vr=((Ef1-Ef)/Ef)*100;
17 printf('Voltage regulation at %f lagging power
   factor is %f percent',pf,vr);
```

Scilab code Exa 5.59 Determining synchronous reactance

```
1  clc;
2  v=11000; // voltage of infinite bus
3  po=15*10^6; // output power of alternator
4  pf=0.8; // operating power factor of synchronous
   machine
5  p=130; // percentage increase in excitation EMF
6  m=3; // number of phases
7  ia=po/(sqrt(3)*pf*v); // per phase armature current
8  vb=v/sqrt(3); // per phase bus voltage
9  //from phasor diagrams in fig 5.117(a) and 5.117(b)
10 xs=(sqrt(((p/100)*vb)^2-(vb*pf)^2)-(vb*sqrt(1-pf^2))
   )/ia; // synchronous reactance
11 printf('Synchronous reactance of machine is %f ohms\
   n',xs);
12 de=asind((po*xs)/(m*vb^2));
13 printf('Load angle of machine before excitation EMF
   is increased is %f degrees\n',de);
14 pf=cosd(de/2);
15 printf('Power factor of the machine before
   excitation EMF is increased is %f leading\n',pf);
16 ia=(2*vb*sind(de/2))/xs;
17 printf('Armature current of the machine before
   excitation EMF is increased is %f A',ia);
```

Chapter 6

Polyphase Induction Motors

Scilab code Exa 6.1 Determining the mechanical angle through which rotor moves

```
1  clc;
2  // after changing dc supply terminals from phase a
      to phase b
3  disp('case a');
4  P=2; // number of poles
5  te=(2/P)*120;
6  printf('Number of mechanical degrees through which
      rotor moves is %d degrees\n',te);
7  disp('case b');
8  P=4; // number of poles
9  te=(2/P)*120;
10 printf('Number of mechanical degrees through which
      rotor moves is %d degrees\n',te);
11 disp('case c');
12 P=6; // number of poles
13 te=(2/P)*120;
14 printf('Number of mechanical degrees through which
      rotor moves is %d degrees\n',te);
```

Scilab code Exa 6.2 Determining 1 full load slip and rotor frequency 2 relative speed of stator with stator structure and rotor structure 3 relative speed of rotor with stator structure rotor structure and stator field

```
clc;
Nf=1440; //full load speed
f=50; //frequency

disp('case a');

P=fix((120*f)/Nf); //formula for finding poles
mprintf('The number of Poles is %d\n',P);

disp('case b');


Ns=(120*f)/P; //finding synchronous speed
s=(Ns-Nf)/Ns; //finding slip at full load
f2=s*f; //rotor frequency
mprintf('The full load slip is %f and the rotor
   frequency is %f Hz\n',s,f2);

disp('case c');


//speed of stator field w.r.t stator structure is Ns
Nss=Ns;
// answer for speed of stator field with respect to
   stator structure is given wrong in book
Wss=(2*%pi*Ns)/60;
Nsr=Ns-Nf; //speed of stator field w.r.t rotor
   structure
Wsr=(2*%pi*Nsr)/60;
printf('The speed of stator field w.r.t stator is %f
```

```
    rad/sec ,%f rpm\n and w.r.t rotor is %f rad/sec
    ,%f rpm\n',Wss,Nss,Wsr,Nsr);
28
29 disp('case d');
30
31
32 //speed of rotor field w.r.t stator structure is Nf+
    Ns
33 Nrr=(120*f2)/P; //speed of rotor field w.r.t rotor
    structure
34 Nrs=Nf+Nrr;
35 // answer for speed of rotor field with respect to
    rotor structure is given wrong in book
36 Wrs=(2*%pi*Nrs)/60;
37
38 Wrr=(2*%pi*Nrr)/60;
39 //The stator and rotor fields are stationary w.r.t
    to each other
40 printf('The speed of rotor field w.r.t stator
    structure is %f rad/sec, %f rpm\n and w.r.t rotor
     structure is %f rad/sec, %f rpm and speed of
    rotor field w.r.t stator field is 0',Wrs,Nrs,Wrr,
    Nrr);
```

Scilab code Exa 6.3 Determining rotor speed

```
1
2 clc;
3 f=50; //frequency of stator
4 P=6;
5 Nof0=90; //number of oscillation
6 f2=Nof0/60; //rotor frequency
7 s=f2/f; //slip
8 Ns=(120*f)/P; //synchronous speed
9 Nr=Ns*(1-s); //rotor speed
```

```
10
11 mprintf('The rotor speed is %f rpm',Nr);
```

Scilab code Exa 6.4 Determining 1 speed of rotor 2 ratio of voltages at slip rings

```
1  clc;
2  f1=50; //frequency of supply
3  f2=20; //frequency required by the load
4  P=4;
5  //for part a
6
7  Nrf_ss=(120*f1)/P; //Speed of rotor field w.r.t
      stator structure
8  Nrf_rs=(120*f2)/P; //Speed of stator field w.r.t
      rotor structure
9  //Nr (+or-) speed of rotor field w.r.t rotor = speed
       of stator field w.r.t stator
10 //for +ve sign rotor must be driven in the direction
       of stator field at a speed
11 Nr1=Nrf_ss-Nrf_rs;
12 Nr2=Nrf_ss+Nrf_rs;
13 mprintf('The two speeds are %d and %d \n',Nr1,Nr2);
14
15
16 //for part b
17
18 //for rotor speed Nr1
19 s1=(Nrf_ss-Nr1)/Nrf_ss;
20 //for rotor speed Nr2
21 s2=(Nrf_ss-Nr2)/Nrf_ss;
22 //On evaluation the ratio of voltages is found as
23  R=s1/s2; //R=E1/E2
24 mprintf('The ratio of two voltages available at the
      slip rings at the two speeds is %d',R);
```

```
25
26 //for part c
```

Scilab code Exa 6.5 Determining 1 rotor current rotor power factor and torque 2 rotor current rotor power factor and torque after insertion of external resistance

```
1  clc;
2  P=4;
3  N=1440;
4  f=50;
5  r2=0.2;
6  x2=1;
7  E2=120;
8
9  //mistake in Te_fl
10
11
12 //for part a
13 disp('For part a');
14 Ns=(120*f)/P;
15 I2_st=120/(sqrt((r2*r2)+(x2*x2)));
16 Rpf=(r2)/(sqrt((r2*r2)+(x2*x2)));
17 Ws=(2*3.14*Ns)/60;
18 Te_st=(3/Ws)*(I2_st)*(I2_st)*(r2/1);
19 s_fl=(Ns-N)/Ns;
20 I2_fl=(s_fl*E2)/(sqrt(r2*r2+(s_fl*x2*s_fl*x2)));
21 Rpf_fl=(r2)/(sqrt(r2*r2+(s_fl*x2*s_fl*x2)));
22 Te_fl=((3)*(I2_fl)*(I2_fl)*(r2))/(Ws*s_fl);
23 RATIOst_fl=I2_st/I2_fl;
24 RATIOtst_tfl=Te_st/Te_fl;
25 mprintf('At starting \n the rotor current is %f amp
     \n Rotor power factor is %f \n Torque is %f rad/
     sec\n',I2_st,Rpf,Te_st);
26 mprintf('At full load \n the rotor current is %f amp
```

```
    \n Rotor power factor is %f \n Torque is %f rad/
    sec\n',I2_fl,Rpf_fl,Te_fl);
27
28
29 //for part b
30 disp('For part b');
31 r2_n=r2+1;
32 I2_stn=E2/(sqrt((r2_n*r2_n)+(x2*x2)));
33 Rpf_stn=(r2_n)/(sqrt(((r2_n)*(r2_n))+((x2)*(x2))));
34 Te_stn=(3/Ws)*(I2_stn)*(I2_stn)*(r2_n/1);
35 mprintf('At starting \n the rotor current is %f amp
    \n Rotor power factor is %f \n Torque is %f rad/
    sec\n',I2_stn,Rpf_stn,Te_stn);
```

Scilab code Exa 6.6 Comparing rotor ohmic losses

```
1  clc;
2  P=6;
3  f=50;
4  N_f=960;
5  Ns=(120*f)/P;
6  n1=800;
7  n2=400;
8
9  s_fl=(Ns-N_f)/Ns;
10 s_1=(Ns-n1)/Ns;
11 s_2=(Ns-n2)/Ns;
12 Ratio_1=s_1/s_fl;
13 Ratio_2=s_2/s_fl;
14 mprintf('The Ratio at %d rpm is %f \n',n1,Ratio_1);
15 mprintf('The Ratio at %d rpm is %f \n',n2,Ratio_2);
```

Scilab code Exa 6.7 Determining 1 stator core loss 2 total rotor losses at full load 3 total rotor ohmic loss at full load 4 full load speed 5 internal torque shaft torque and efficiency

```
clc;
Psh=10000;
P=4;
f=50;
Pi=660;
Pw=420;
I_l=8;
rs=1.2;
Pi_fl=11200;
I_fl=18;
Ns=(120*f)/P;
Ws=(2*3.14*Ns)/60;


//for part a
disp('for part a ');

Pstl=Pi-Pw-((3*I_l*I_l*rs)/(3));
mprintf('The stator core loss is \n %f W \n',Pstl);

//for part b
disp('for part b ');

Pg=Pi_fl-Pstl-(3*(I_fl/sqrt(3))*(I_fl/sqrt(3))*rs);
Prl=Pg-Psh;
mprintf('The rotor loss is %f W \n',Prl);

//for part c
disp('for part c ');

Prol=Prl-Pw;
mprintf('The rotor ohmic loss is %f W \n',Prol);

//for part d
```

```
35 disp('for part d ');
36
37 s_fl=Prol/Pg;
38 Nr=Ns*(1-s_fl);
39 mprintf('Full Load speed of rotor is %f rpm \n',Nr);
40
41 //for part e
42 disp('for part e ');
43
44 Te=Pg/Ws;
45 Tsh=Psh/((Ws)*(1-s_fl));
46 E=(Psh/Pi_fl)*100;
47 mprintf('The internal torque is %f Nm \n The shaft
     torque is %f Nm \n The motor Efficiency is %f
     percent',Te,Tsh,E);
```

Scilab code Exa 6.8 Determining slip of motor

```
1 clc;
2 E=0.9;
3 L=45000;
4 Tl=((1/0.9)-1)*L;
5
6 Rl=(Tl*2)/7; //According to the given conditoins
7 Pg=L+Rl+(Rl/2);
8
9 s=Rl/Pg;
10
11 mprintf('Slip is %f',s);
```

Scilab code Exa 6.9 Determining stator current rotor speed output torque and efficiency

```
1
2  clc;
3  P=4;
4  r1=0.15;
5  x1=0.45;
6  r2=0.12;
7  x2=0.45;
8  Xm=28.5;
9  s=0.04;
10 V=400;
11 f=50;
12 Pfixed=400;
13
14 t1=complex((r2/s),x2);
15 t2=complex(0,Xm);
16 t3=complex((r2/s),(x2+Xm));
17 T=(t1*t2)/t3;
18 Zab=complex(r1,x1)+T;
19 Rf=real(T);
20 I1=V/(sqrt(3)*abs(Zab));
21 ian=atand(imag(Zab),real(Zab));
22 Pf=cosd(ian);
23 I1_mag=sqrt(real(I1)*real(I1)+imag(I1)*imag(I1));
24 Psti=sqrt(3)*I1_mag*V*Pf;
25 Pg=3*I1*I1*Rf;
26 ns=(2*f)/P;
27 nr=(1-s)*ns;
28 Ws=2*3.14*ns;
29 Pm=(1-s)*Pg;
30 Psh=Pm-Pfixed;
31 To=(Psh)/((1-s)*Ws);
32 Psto=3*I1_mag*I1_mag*r1;
33 Prto=s*Pg;
34 Tls=Psto+Prto+Pfixed;
35 Pi=Psh+Tls;
36 E=(1-(Tls/Pi))*100;
37
38 mprintf('staror current = %f amp at lagging phase
```

```
angle of %f w.r.t input voltage \n rotor speed =
 %f rps or %f rpm output torque = %f Nm \n
Efficiency = %f percent',I1,ian,nr,nr*60,To,E);
```

Scilab code Exa 6.10 Determining 1 slip for maximum torque and maximum torque 2 rotor current and starting torque 3 external resistance inserted in rotor circuit 4 internal power developed 5 maximum internal power developed and corresponding slip

```
1
2
3 clc;
4
5 //from 6.9 problem
6 P=4;
7 r1=0.15;
8 x1=0.45;
9 r2=0.12;
10 x2=0.45;
11 Xm=28.5;
12 s=0.04;
13 V=400;
14 f=50;
15 Pfixed=400;
16 t=1.2; // rotor effective turns ratio
17
18 //for part a
19 //According to the conditions and diagram
20 t1=complex(r1,x1);
21 t2=complex(0,Xm);
22 t3=complex(r1,x2+Xm);
23 Ze=(t1*t2)/(t3);
24 Re=real(Ze);
25 Xe=imag(Ze);
26 t4=complex(Re,(x2+Xe));
```

```
27 SmT=(r2)/(sqrt((Re*Re)+((x2+Xe)*(x2+Xe))));
28 Ve=(V/sqrt(3))*(Xm/(x2+Xm));
29 Ws=(4*%pi*f)/P;
30 Tem=(3/Ws)*Ve^2*(1/2)*(1/(Re+sqrt(Re^2+(x2+Xe)^2)));
31 Pm=Tem*(1-SmT)*Ws;
32 Psh=Pm-Pfixed;
33 Tsh=Psh/(Ws*(1-SmT));
34 mprintf('for part a \n slip = %f \n maximun torque =
       %f Nm \n power output = %f KW \n',SmT,Tem,   Psh
   /1000);
35
36
37 //for part b
38 s=1;
39 I2st=(Ve)/(sqrt((r2+Re)*(r2+Re)+(x2+Xe)*(x2+Xe)));
40 Test=(3/Ws)*I2st*I2st*(r2);
41 mprintf(' for part b rotor current = %f A \n torque
   = %f Nm \n',I2st,Test);
42
43
44 //for part c
45 R=sqrt(Re^2+(x2+Xe)^2)-r2;
46 Ra=R/(t^2);
47 mprintf('for part c \n external resisitance value is
       = %f Ohm \n',Ra);
48
49 //for part d
50 s1=0.04;
51 Pm=((3*(Ve)*(Ve))*r2*((1-s1)/s1))/(((Re+r2+((r2*(1-
   s1)/s1))))*((Re+r2+((r2*(1-s1)/s1))))+((x2+Xe)*(
   x2+Xe)));
52 mprintf('for part d \n power developed is %f KW \n',
   Pm/1000);
53
54 //for part e
55 SmP=(r2)/(sqrt(((Re+r2)*(Re+r2))+((x2+Xe)*(x2+Xe)))+
   r2);
56 Pmn=((3/2)*Ve*Ve)/(Re+r2+sqrt((r2+Re)*(r2+Re)+(x2+Xe
```

```
    )*(x2+Xe)));
57 mprintf('for part e \n slip = %f \n power developed
    = %f KW',SmP,Pmn/1000);
```

Scilab code Exa 6.11 Determining maximum internal torque for different cases

```
1  clc;
2  P=4;
3  r1=0.15;
4  x1=0.45;
5  r2=0.12;
6  x2=0.45;
7  Xm=28.5;
8  s=0.04;
9  V=400;
10 f=50;
11 Pfixed=400;
12
13 //from problem 6.10
14 Re=0.1476;
15 Xe=0.443;
16 r2=0.12;
17 x2=0.45;
18
19 a=Xm/(x2+Xm);
20 //Ve=a*V1;
21 Wr=(4*%pi*f)/P;
22 b=(3/Wr)*(1/2)*(1/((Re)+(sqrt((Re*Re)+((x2+Xe)*(x2+
    Xe))))));
23 //Tem=b*Ve*Ve
24
25 //for part a
26 V1=230;
27 Ve1=a*V1;
```

```
Tem1=b*Ve1*Ve1;
mprintf('for part a \n maximum internal torque
   developed is %f Nm \n',Tem1);

//for part b
V2=115;
Ve2=a*V2;
Tem2=b*Ve2*Ve2;
mprintf('for part b \n maximum internal torque
   developed is %f Nm \n',Tem2);

//for f=25 Hz
Xe1=(1/2)*Xe;
x21=(1/2)*x2;
Ws1=(1/2)*Wr;


//for part c
V3=115;
Ve3=a*V3;
Tem3=(3/Ws1)*Ve3*Ve3*(1/2)*(1/((Re)+(sqrt((Re*Re)+((
   x21+Xe1)*(x21+Xe1))))))
mprintf('for part c \n maximum internal torque
   developed is %f Nm \n',Tem3);

//for f=5 Hz
Xe2=(1/10)*Xe;
x22=(1/10)*x2;
Ws2=(1/10)*Wr;


//for part d
f3=5; //f3=(1/10)*f
V4=23;
Ve4=a*V4;
Tem4=(3/Ws2)*Ve4*Ve4*(1/2)*(1/((Re)+(sqrt((Re*Re)
   +(((x22+Xe2)*(x22+Xe2)))))))
mprintf('for part d \n maximum internal torque
```

```
developed is %f Nm \n',Tem4);
```

Scilab code Exa 6.13 determining 1 slip and rotor speed 2 rotor ohmic loss 3 starting torque 4 starting current 5 stator current 6 full load efficiency 7 slip at maximum torque for new resistance 8 full load slip 9 starting torque 10 starting current 11 rotor losses 12 power

```
1  //answer match + roots
2
3  clc;
4  Pm=10000;
5  V=400;
6  f=50;
7  smT=0.1;
8  P=4;
9  Ns=(120*f)/P;
10
11 //for (i)
12 disp('(i)');
13 //As per given conditions the slip is given by
      equation Sfl2 -0.4 Sfl +0.01=0
14 V=[1 -0.4 0.01];
15 R=roots(V);
16 Sfl=R(2);
17 Nr=Ns*(1-Sfl);
18 mprintf('The slip is %f \n The rotor speed is %f r.p
      .m',Sfl,ceil(Nr));
19
20 //for (ii)
21 disp('(ii)');
22 Pg=Pm/(1-Sfl);
23 Prot=Sfl*Pg;
24 mprintf('The rotor ohmic loss is %f W \n',Prot);
25
26 //for (iii)
```

```
27 disp('(iii)');
28 Tefl=Pg/(2*3.14*(Ns/60));
29 Test=(4*Tefl)/((smT)+(1/smT));
30 mprintf('starting torque is %f Nm \n',Test);
31
32 //for (iv)
33 disp('(iv)');
34 a=sqrt(((Sfl*Sfl)+(smT*smT))/((Sfl)*(Sfl)*(1+(smT)*(
      smT))));
35 mprintf('starting current = %f full load current\n',
      a);
36
37 //for (v)
38 disp('(v)');
39 // answer is slightly different in book
40 b=sqrt((1/2)*(1+(smT/Sfl)^2));
41 mprintf('stator current at maximun torque = %f full
      load current \n',b);
42
43 //for (vi)
44 disp('(vi)');
45 E=(Pm/Pg)*100;
46 mprintf('full load efficiency is = %f percent\n',E);
47
48 //for (vii)
49 disp('(vii)');
50 //As per given conditions
51 smT1=3*smT;
52 mprintf('New slip value is %f \n',smT1);
53
54 //for (viii)
55 disp('(viii)');
56 //According to the given conditions s1(2)-1.2s+0.09
57 VV=[1 -1.2 0.09];
58 RR=roots(VV);
59 s1=RR(2);
60 Nr1=Ns*(1-s1);
61 mprintf('full load slip is %f rotor speed is %f r.p.
```

```
    m',s1,Nr1);
62
63 //for (ix)
64 disp('(ix)');
65 Test1=((2)/((1/0.3)+(0.3)))*(2*Tefl);
66 mprintf('starting torque is %f Nm \n',Test1);
67
68 //for (x)
69 disp('(x)');
70 c=sqrt((s1^2+smT1^2)/(s1^2*(1+smT1^2)));
71 mprintf('starting current = %f full load current \n'
    ,c);
72
73 //for (xi)
74 disp('(xi)');
75 Protfl=s1*Pg;
76 mprintf('Rotor ohmic loss at full load torque is %f
    W \n',Protfl);
77
78 //for (xii)
79 disp('(xii)');
80 Pm1=(1-s1)*Pg;
81 E=Pm1/Pg;
82 mprintf('Efficiency is %f percent',E*100);
```

Scilab code Exa 6.14 Determining 1 maximum torque 2 full load rotor ohmic loss 3 slip at maximum torque 4 full load slip 5 full load torque

```
1
2 clc;
3 Pm=60000;
4 P=6;
5 s=0.04;
6 V=400;
7 smT=0.2;
```

```
f=50;
Ns=(120*f)/P;

Ws=(2*%pi*Ns)/60;
Wr=Ws*(1-s);
Tefl=Pm/Wr;

//for part a
Tem=(((smT/s)+(s/smT))/2)*Tefl;
mprintf('for part a \n the maximun torque is %f Nm\n
    ',Tem);

//for part b
Prot=(s/(1-s))*(Pm);
mprintf('for part b \n the rotor ohmic loss is  %f W
    \n',Prot);

//for part c
smT1=2*smT;
mprintf('for part c \n THe new slip is %f \n',smT1);

//for part d
//On analysis the slip is given by
s2=0.084;
mprintf('for part d \n full load slip is %f \n',s2);

//for part e
T2=Pm/((Ws)*(1-s2));
mprintf('for part e \n the full load torque is %f Nm
    \n',T2);
```

Scilab code Exa 6.15 Determining percentage reduction in rotor circuit resistance

```
1
```

```
clc;
sfl=0.05; //Full load slip
//Test/Tem=a
//Tfl/Tem=b
a=1/2;
b=1/1.6;
//As per the given equation we get smT1^2-2.5smT1
   +1=0
Q=[1 -2.5 1];
R=roots(Q);
smT1=R(2);

//For full load slip of 0.05 we get the equation
   smT2^2-0.20smT2+0.0025
Q1=[1 -0.20 0.0025];
R1=roots(Q1);
smT2=R1(1);

P=((smT1-smT2)/smT1)*100;
mprintf('Percentage reduction in rotor circuit
   resistance is %f percent',P);
```

Scilab code Exa 6.16 Determining external resistance inserted in rotor circuit and percentage change in current and power factor

```

clc;
r2=0.04;
x2=0.2;

//As per given conditions we get a quadratic
   equation in smT which is smT^2-4*smT+1
t1=1; t2=-4; t3=1;
p=[ t1 t2 t3];
smT=roots(p);
```

```
10
11 r22=x2*smT(2);
12 R=r22-r2;
13 mprintf('The external resistane needed to be
      inserted is %f Ohm \n',R);
14
15
16 //say V=400(Input voltage)
17 V=400;
18 //without external resistance
19 Ist=V/(sqrt((r2)*(r2)+(x2)*(x2)));
20 pf=r2/(sqrt((r2)*(r2)+(x2)*(x2)));
21
22 //with external resistance
23 Ist1=V/(sqrt((r22)*(r22)+(x2)*(x2)));
24 pf1=r22/(sqrt((r22)*(r22)+(x2)*(x2)));
25
26 a=((Ist-Ist1)/Ist)*100;
27 b=((pf1-pf)/pf)*100;
28 mprintf('Percentage in starting current is %f \n',a)
      ;
29 mprintf('Percentage in power factor is %f \n',b);
```

Scilab code Exa 6.17 Determining starting torque

```
1 clc;
2 //r2/x2=a
3 a=.5;
4 Test=25;
5
6 //for part a
7 disp('For part a ');
8 //b=3(V1)2/r2Ws
9 //As per given conditions
10 b=Test*5;
```

```
11 //When rotor resistace is doubled
12 Test1=b*(1/4);
13 mprintf('The starting torque is %f Nm\n',Test1);
14 //for part b
15 disp('For part b');
16 //resisance is half
17 Test2=b*(2/17);
18
19
20 mprintf('The starting torque is %f Nm',Test2);
```

Scilab code Exa 6.18 Determining 1 slip at maximum torque 2 full load slip 3 rotor current in terms of full load current

```
1 //equation
2 clc;
3 //Test/Tefl=1.5;
4 d=1.5;
5 //Tem/Tefl=2.5;
6 e=2.5;
7
8 //for part a
9
10 //d=Test/Tefl;
11 //equation of torque gives following equation
12 Q=[1 -3.33 1];
13 R=roots(Q);
14 smT=R(2);
15 mprintf('The slip at maximun torque is %f \n',smT)
16
17 //for part b
18 //equation of torque gives
19 Q=[1 -1.665 0.111];
20 R=roots(Q);
21 sfl=R(2);
```

```
22 mprintf('The slip at full load is %f \n',sfl)
23
24 //for part c
25 //I2st=c*Isfl As per torque equation
26 c=sqrt((d)*(1/sfl));
27 mprintf('The rotor current = %f times full load
     current \n',c)
```

Scilab code Exa 6.19 Determining starting and maximum torque

```
1 clc;
2 Te=200;
3 s=0.04;
4 c=4; //given multiplying factor of leakage reactance
5
6 //3V*V=a*WS
7 a=Te*s*(((1+(1/s))*(1+(1/s)))+((c+c)*(c+c)));
8 Test=a*(1/((1+1)*(1+1)+(c+c)*(c+c)));
9 Tem=a*(1/2)*(1/(1+sqrt((1)*(1)+(c+c)*(c+c))));
10 mprintf('The starting torque is %f Nm \n The maximun
     Torque is %f Nm',Test,Tem);
```

Scilab code Exa 6.20 Determining 1 slip 2 rotor current rotor ohmic loss and rotor power factor 3 power output

```
1 clc;
2 sA=0.05; //slip
3
4 //for part a
5 disp('for part a ');
6 //Torque is proportional to s/r2
7 //As per given conditions sB=a*sA
8 a=4;
```

```
sB=a*sA;
mprintf('The slip is %d times previous slip and \n',
   a);

//for part b
disp('for part b ');
//I2 is directly proportional to s/r2
//As per given conditions I2B=b*I2A
b=sB/(a*sA);
//Rotor ohmic losses is directly proportional to I*I
   *r2
//As per given conditions P2=c*P1
c=a*b;
//As per given conditions Pf2=d*Pf1
d=b;
mprintf('rotor current for new rotor resistance is
   equal to initial rotor current \n Rotor ohmic
   losses for new rotor resistance=%f times initial
   ohmic losses \n  power factor for new rotor
   resistance is equal to initial power factor',c);

//for part c
disp('for part c ');
//As per given conditions Wa=e*Ws
e=1-sA;
//Wb=f*Ws
b=1-sB;
//PB=g*PA
g=b/e;
mprintf('The power output is reduced to %f times
   previous value',g);
```

Scilab code Exa 6.21 Determining 1 rotor and stator input 2 starting torque

```
clc;
```

```
2 f=50;
3 P=6;
4 Pmsh=10000; //Shaft Output
5 N=930;
6 Pw=600;
7 Pf=0.01*Pmsh; //Friction and Windage losses
8 Ns=(120*f)/P;
9 NmT=800; //Speed at maximum torque
10
11
12 //for part a
13 disp('for part a');
14 sfl=(Ns-N)/Ns;
15 Pm=Pmsh+Pf;
16 Pg=Pm/(1-sfl);
17 Pst=Pg+Pw;
18 mprintf('Total Rotor input is %f W \n Total Stator
     input is %f W \n',Pg,Pst);
19
20 //for part b
21 disp('for part b');
22 smT=(Ns-NmT)/Ns;
23 Ws=(2*%pi*Ns)/60;
24 Tefl=Pg/Ws;
25 Test=(((smT/sfl)+(sfl/smT))/2)*(2/((smT)+(1/smT)))*
     Tefl;
26 mprintf('Maximun Torque is %f Nm',Test);
```

Scilab code Exa 6.22 Determining maximum torque corresponding slip and starting torque

```
1 clc;
2 Pm=7500;
3 V=420;
4 f=50;
```

```
5  P=4;
6  s=0.04;
7  r1=1.2;
8  x1=1.4;
9  x2=1.4;
10 Xm=38.6;
11
12 //As per Thevenin's Equivalent circuit
13 Re=(r1*Xm)/(Xm+x2);
14 Xe=(x1*Xm)/(x2+Xm);
15 Ve=(V/sqrt(3))*(Xm/(x2+Xm));
16 r2=(3)*(1-s)*s*Ve*Ve*(1/Pm);
17 smT=r2/(sqrt((Re*Re)+((Xe+x2)*(Xe+x2))));
18 Tem=((3*Ve*Ve)/((((120*f)/P)/60)*2*%pi))*(1/2)*(1/(
     Re+(sqrt((Re*Re)+((Xe+x2)*(Xe+x2))))));
19 Test=((3*Ve*Ve)/((((120*f)/P)/60)*2*%pi))*(r2/(((Re+
     r2)*(Re+r2))+((Xe+x2)*(Xe+x2))));
20 mprintf('maximum torque is %f Nm \n slip is %f \n
     starting torque is %f Nm',Tem,smT,Test);
```

Scilab code Exa 6.23 Determining 1 maximum torque 2 starting torque 3 full load rotor ohmic loss 4 slip at full load 5 full load torque 6 slip at maximum torque

```
1  clc;
2  Pm=100000;
3  V=420;
4  P=6;
5  f=50;
6  sfl=0.04;
7  smT=0.2;
8
9  //for part a
10 disp('for part a');
11 Pg=Pm/(1-sfl);
```

```
Ws=(4*%pi*f)/P;
Tefl=Pg/Ws;
//a=Tefl/Tem
a=(1/(2/((sfl/smT)+(smT/sfl))));
Tem=a*Tefl;
mprintf('Maximum Torque is %f Nm \n',Tem);

//for part b
disp('for part b');
//b=Test/Tem
b=2/((1/smT)+(smT));
Test=b*Tem;
mprintf('The starting Torque is %f Nm \n',Test)

//for part c
disp('for part c');
Prot=sfl*Pg;
mprintf('Rotor Ohmic losses are %f W \n',Prot)

//for part d
disp('for part d');
//Output is proportional to (s(1-s))/r2
//Given conditions gives the equation as s1*s1-s1
   +0.0768
Q=[1 -1 0.0768];
R=roots(Q);
s1=R(2);
mprintf('Slip is %f \n',s1)

//for part e
disp('for part e');
Tefl=(Pm/(1-s1))/Ws;
mprintf('full-load torque is %f Nm \n',Tefl)

//for part f
disp('for part f');
smT1=2*smT;
mprintf('slip at maximum torque is %f',smT1);
```

Scilab code Exa 6.25 Determining 1 speed range of DC motor 2 KVA rating of stator 3 DC motor rating and maximum torque 4 number of poles 5 new speed range

```
clc;
P=10;
f=50;
Pm=48000;
pf=0.8;
f21=120; //min frequency range
f22=300; //max frequency range
Ns=(120*f)/P;

//for f2=300
Nr1=((120*f21)/P)-Ns;
//for f2=600
Nr2=((120*f22)/P)-Ns;
mprintf('Thus the dc motor changes speed from %f to
   %f rpm \n',Nr1,Nr2)

//for part b and c
s1=(Nr1+Ns)/Ns;
s2=(Nr2+Ns)/Ns;
Pr=Pm/pf;
Pr1=Pr/s1;
Pr2=Pr/s2;
R1=(s1-1)*Pr1*pf;
R2=(s2-1)*Pr2*pf;
T1=(R1*60)/(2*%pi*Nr1);
T2=(R2*60)/(2*%pi*Nr2);
// stator should be able to handle higher KVA
mprintf('KVA rating of induction motor stator is %f
   KVA\n',Pr1/1000)
mprintf('DC motor rating is %f KW \n Maximum torque
```

```
    output from DC motor is %f Nm \n',R2/1000,T1);
29
30 //for part d
31 //When speed is limited to 2700 rpm
32 P1=((120*f22)-(120*f))/2700;
33 P1=ceil(P1);
34 mprintf('Number of Poles is %d \n',P1);
35
36 //for part e
37 Nr11=((f22*120)/P1)-((120*f)/P1);
38 Nr22=((f21*120)/P1)-((120*f)/P1);
39 mprintf('Thus the new speed range of dc motor is
    from %f to %f rpm \n',Nr22,Nr11);
```

Scilab code Exa 6.26 Determining starting torque

```
1  clc;
2  f=50;
3  P=4;
4  Pm=10000; //Rated output
5  N=1425;
6  Nm=1200; //Speed at which maximun torque is
       developed
7
8  Ns=(120*f)/P;
9  s=(Ns-N)/Ns;
10 Ws=(2*%pi*Ns)/60;
11 Tefl=(Pm/Ws)*(1/(1-s));
12 smT=(Ns-Nm)/Ns;
13 Tem=Tefl*((s/smT)+(smT/s))*(1/2);
14 Test=Tem*(2)*(1/((1/smT)+(smT/1)));
15 mprintf('The starting torque is %f Nm',Test);
```

Scilab code Exa 6.27 Determining slip frequency and slip at maximum torque

```
clc;
fs=2; //slip frequency
V=400;
f=50;
V2=340; //New voltage
f2=40;  //New frequency
smT=0.1; //slip at which it develops maximum torque

//maximun torque's slip is directly proportional to
   (1/f)
smT1=(f/f2)*smT;

//Maximun Torque is directly proportional to ((V*V)
   /(f*f))
s=fs/f;
//Ted(Developed Torque) is proportional to (Tem/smT)
   *(s/smT)
//Ted1(400V,50Hz)proportional a
a=((V*V)/(f*f))*(s/smT);
//equating the developed torque equation
s1=a*(((f2)*(f2))/((V2)*(V2)))*(smT1);
fs1=s1*f2;
mprintf('The new slip frequency is %f Hz',fs1);
```

Scilab code Exa 6.28 Determining frequency of motor

```
clc;
f=50;
V=440;
P=4;
N=1490; //Rated speed
N1=1600; //New Speed
```

```
7
8  Ns=(120*f)/P;
9  s=(Ns-N)/Ns;
10 //With neglecting resistances and leakage reactances
11 //Torque is directly proportional to s/(fr2)
12 //Appllying the condition for same torque we get
13 //a=s/f
14 a=(s/f);
15 //Ns/s=b
16 b=120/P;
17 //s=(Ns-N1)/Ns
18 //Using above equation we get equation (f*f)-7500f
     -400000
19 Q=[1 -7500 400000]
20 R=roots(Q);
21 f1=R(2);
22 mprintf('Value of new Frequency is %f Hz',f1);
```

Scilab code Exa 6.29 Determining power factor input current equivalent rotor current and torque developed maximum torque and corresponding speed

```
1  //debug
2  clc;
3  V1=420; //supply voltage
4  r1=2.95;
5  x1=6.82;
6  r2=2.08;
7  x2=4.11;
8  Iml=6.7; //magnetizing line current
9  Pw=269; //core loss
10 s=0.03; //slip
11 P=12;
12 f=50;
13 N=(120*f)/P;
```

```
Ns=(120*f)/P;

Im=Iml/sqrt(3);
//V1=E1+Im(r1+jx1)
//Above equation on solving gives the solution as E1
   *E1+52.8E1-175572.65
Q=[1 52.8 -175572.62];
R=roots(Q);
E1=R(2);
Xm=E1/Im;
//As per the circuit diagram
a=r2/s;
Zf=(((r2/s)+x2*%i)*Xm*%i)/((r2/s)+((x2+Xm)*%i));
Rf=real(Zf);
Zab=complex((real(Zf)+r1),(imag(Zf)+x1));
I1=420/Zab;
I1M=sqrt((real(I1)*real(I1))+(imag(I1)*imag(I1)));
an1=atand(imag(I1),real(I1));
pf=cosd(atand(imag(I1)/real(I1)));
I2=I1*(Xm*%i)*(1/((r2/s)+((x2+Xm)*%i)));
an2=atand(imag(I2),real(I2));
I2M=sqrt((real(I2)*real(I2))+(imag(I2)*imag(I2)));
T=3*(60/(2*%pi*N))*I1M*I1M*Rf;

mprintf('The power factor is %f Lag\n The input
   current is %f A lagging by an angle of %f degrees
    \n The output rotor current is %f A lagging by
   an angle of %f degrees \n The Torque developed is
    %f Nm \n',pf,I1M,-an1,I2M,-an2,T);


//For maximun Torque
X1=x1+Xm;
Re=(r1*Xm)/X1;
Xe=(x1*Xm)/X1;
smT=r2/(sqrt((Re)*(Re)+(x2+Xe)*(x2+Xe)));
Nm=Ns*(1-smT);
Tem=3*(E1)*(E1)*(1/(Re+(sqrt((Re)*(Re)+(x2+Xe)*(x2+
```

```
    Xe)))))*(1/2)*(1/(2*%pi*(N/60)));
47 mprintf('maximum torque developed is %f Nm \n
    corresponding speed is %f rpm',Tem,Nm);
```

Scilab code Exa 6.30 Determining motor speed and power output

```
1
2 //In solution they have taken different value of
    speed at rated torque from what is given in
    question that is why answer is varying
3 clc;
4 P=4;
5 Pm=10000; //OUTPUT POWER
6 f=50; //FREQUENCY
7 N=1440;  //SPEED AT WHICH RATED TORQUE IS OBTAINED
8 Ns=(120*f)/P;  //SYNCHRONOUS SPEED
9
10 s=(Ns-N)/Ns;
11 //Torque is directly proportional to the slip
12 //As per given conditions
13 s1=(1/2)*s;
14 Nr=Ns*(1-s1);
15 Pm1=(1/2)*(((Pm*60)/(2*%pi*N)))*((2*%pi*Nr)/(60));
16 mprintf('The motor speed is %f rpm \n The power
    output is %f W',Nr,Pm1);
```

Scilab code Exa 6.31 Determining percentage change in motor speed and losses

```
1
2 clc;
3 N=1455;
4 Ns=1500; //General case considered in the problem
```

```
s1=(Ns-N)/Ns;

//for V1=0.9V
//V1/V=a
a=0.9;
//T=(3VVs)/(Wsr2)
//As torque is constant
s2=(s1)/(a*a);
Nr=Ns*(1-s2);
//I=s1V/r2
//I22/I21=b
b=(s2*a)/s1;
//Losses Ratio=c
R=b*b;

d=((N-Nr)/N)*100;
e=((R-1)/1)*100;
mprintf('Percentage reduction in speed is %f percent
   \n',d);
mprintf('Percentage reduction in ohmic losses is %f
   percent\n',e);
```

Scilab code Exa 6.32 Determining no load speed of motor

```
clc;
P=7500; // rated power of induction motor
v=400; // rated voltage of motor
To=6; // no load torque
fs=0.04; // full load slip
p=6; // number of poles
f=50; // frequency
ns=(120*f)/p; // synchronous speed
Tl=(P*60)/(2*%pi*ns*(1-fs)); // full load torque
s=(To*fs*v^2)/(Tl*(v/2)^2); // slip at no load
no=ns*(1-s);
```

```
12 printf('No load speed of motor is %f rpm\n',no);
```

Scilab code Exa 6.33 Determining minimum voltage impressed on motor and additional resistance inserted in rotor circuit

```
1  clc;
2  tr=2.5; // ratio of maximum torque to full load
      torque
3  sm=0.18; // maximum slip
4  r=1; // per phase rotor resistance
5  x2=r/sm; // rotor reactance
6  // using expression for tr we obtain a quadratic
      equation is s(full load slip) whose terms are
7  t1=1;
8  t2=-tr*2*sm;
9  t3=sm^2;
10 t=[ t1 t2 t3 ];
11 s=roots(t);
12 x=sqrt((2*x2)/(((r/s(2))^2+x2^2)*s(2)));
13 printf('Minimum voltage that could be impressed so
      that motor can supply rated torque is %f times
      rated voltage or %f percent of rated voltage\n',x
      ,x*100);
14 // from expression for maximum torque and full load
      torque we get a quadratic equation in R(externall
       resistance) whose terms are
15 t1=1;
16 t2=2-2*x2;
17 t3=1+x2^2-2*x2;
18 t=[ t1 t2 t3 ];
19 R=roots(t);
20 printf('External resistance inserted in rotor
      circuit is %f ohms\n',R(2));
```

Scilab code Exa 6.34 Comparing starting current starting torque and maximum torque at given frequencies and comparing voltage for given frequencies

```
clc;
f1=50; // rated frequency of 3- phase induction
   motor
f2=40; // applied frequency
vr=0.9; // ratio of applied voltage to rated voltage
m=3; // number o phases
fr=f2/f1; // ratio of frequencies
ir=fr/vr;
printf('Ratio of starting current at %d Hz to
   starting current at %d Hz is %f \n',f1,f2,ir);
tr=(m/f1)*(f2/m)*(fr/vr)^2;
printf('Ratio of starting torque at %d Hz to
   starting torque at %d Hz is %f \n',f1,f2,tr);
tmr=(m/f1)*(f2/m)*(fr/(vr)^2);
printf('Ratio of maximum torque at %d Hz to maximum
   torque at %d Hz is %f \n',f1,f2,tmr);
vr1=sqrt((m/f1)*(f2/m)*fr^2);
printf('For the same starting torque ratio of
   voltage at %d Hz to ratio of voltage at %d Hz is
   %f\n',f2,f1,vr1);
vr2=sqrt((m/f1)*(f2/m)*fr);
printf('For the same maximum torque ratio of voltage
    at %d Hz to ratio of voltage at %d Hz is %f\n',
   f2,f1,vr2);
// answer for ratio of v2/v1 for same starting
   torque is slightly different from what is given
   in book
```

Scilab code Exa 6.35 Determining 1 slip at rated load 2 starting torque

```
clc;
P=60000; // rated power of 3-phase induction motor
p=4; // number of poles
f=50; // frequency
po=3000; // no load losses
i=0.3; // ratio of rated current to rated voltage
   when motor is prevented from rotating
pi=4000; // power input when motor is prevented from
    rotating
pr=0.3; //ratio of mechanical losses to no load
   losses
pm=pr*po; // mechanical losses
lsc1=po-pm; // stator core loss
lsc2=pi/2; // stator copper loss=rotor copper loss
disp('case a');
pg=P+pm+lsc2; // air gap power
s=lsc2/pg;
printf('Slip at rated load is %f\n',s);
disp('case b');
pim=pi/i^2; // power input to motor during blocked
   rotor test
pg=pim-lsc1-lsc2; // air gap power
ws=(4*%pi*f)/p; // synchronous speed
T=pg/ws;
printf('Starting torque at rated applied voltage is
   %f Nm\n',T);
```

Scilab code Exa 6.36 Finding ratio of starting current starting torque and maximum torque at given frequencies

```
clc;
sm=0.2; // slip
f1=50; // rated frequency of 3- phase induction
   motor
f2=45; // applied frequency
```

```
fr=f2/f1; // ratio of frequenciesir=fr/vr;
ir=sqrt((sm^2+1)/(sm^2+fr^2));
printf('Ratio of starting current at %d Hz to
   starting current at %d Hz is %f \n',f2,f1,ir);
tr=(sm^2+1)/(sm^2+fr^2);
printf('Ratio of starting torque at %d Hz to
   starting torque at %d Hz is %f \n',f2,f1,tr);
tmr=1/fr;
printf('Ratio of maximum torque at %d Hz to maximum
   torque at %d Hz is %f \n',f2,f1,tmr);
```

Scilab code Exa 6.37 Determining 1 maximum internal torque and internal starting torque 2 slip at maximum torque

```
clc;
P=20000; // rated power of induction motor
v=400; // rated voltage of motor
f=50;  // frequency
m=3; // number of phases
p=4; // number of poles
r1=0.2; // stator resistance
x=0.45; // stator/rotor leakage reactance
xm=18; // magnetising reactance
s=0.04; // slip
pg=P/(1-s); // air gap power
pr=s*pg; // rotor copper loss
vp=v/sqrt(3); // per phase voltage
ve=(vp*xm)/(x+xm); // Thevenin  voltage
re=(r1*xm)/(x+xm); // Thevenin resistance
xe=(x*xm)/(x+xm); // Thevenin reactance
// using Thevenin's theorrm and rotor copper loss
   expression we get a quadratic equation in r2 (
   rotor resistance) whose terms are
t1=pr/s^2;
t2=((2*pr*re)/s)-(m*ve^2);
```

```
t3=pr*((xe+x)^2+re^2);
t=[ t1 t2 t3];
r2=roots(t);
disp('case a');
ws=(4*%pi*f)/p; // synchronous speed
Tm=(m*ve^2)/(ws*2*(re+sqrt(re^2+(x+xe)^2)));
printf('Maximum internal torque is %f Nm\n',Tm);
Ti=(m*ve^2*r2(1))/(ws*((re+r2(1))^2+(x+xe)^2));
printf('Initial starting torque is %f Nm\n',Ti);
disp('case b');
sm=r2(1)/(sqrt(re^2+(xe+x)^2));
printf('Slip at maximum torque is %f ',sm);
```

Scilab code Exa 6.41 Determining rotational losses and equivalent circuit parameters

```
clc;
P=10000; // rated power of squirrel cage induction
   motor
V=400; // rated voltage of motor
m=3; // number of phases
// no load test results
Vo=400; // applied voltage
io=8; // no load current
Po=250; // no load power
// blocked rotor test
vb=90; // applied voltage
ib=35; // current
pb=1350; // input power
// ac resistance is 1.2 times dc resistance
rs=0.6; // per phase dc resistance of stator winding
pr=Po-m*(io/sqrt(3))^2*(1.2*rs); // no load
   rotational losses
znl=Vo/(io/sqrt(3)); // no load impedance
rnl=Po/(m*(io/sqrt(3))^2); // no load resistance
```

```
xnl=sqrt(znl^2-rnl^2); // no load reactance
zbr=vb/(ib/sqrt(3)); // block rotor test impedance
Rbr=pb/(m*(ib/sqrt(3))^2); // block rotor resistance
xbr=sqrt(zbr^2-Rbr^2); // block rotor reactance
x1=xbr/2;
xm=xnl-x1;
X2=xm+x1;
r2=(Rbr-1.2*rs)*(X2/xm)^2;
printf('Rotational losses are %f watts\n',pr);
printf('Stator resistance is %f ohms\n',1.2*rs);
printf('Rotor resistance is %f ohms\n',r2);
printf('Magnetising reactance is %f ohms\n',xm);
printf('Stator reactance is %f ohms\n',x1);
printf('Rotor reactance is %f ohms',x1);
```

Scilab code Exa 6.43 Determining starting torque

```
clc;
p=10000; // rated power of SCIM
v=420; // rated voltage of SCIM
p=4; // number of poles
f=50; // frequency of SCIM
// results of blocked  rotor test
vb=210; // applied voltage
ib=20; // applied current
pb=5000; // power dissipated
l=300; // stator core loss
rs=0.6; // dc stator resistance
m=3; // number of phases
R=(rs*3)/2; // per phase stator resistance
Rs=1.2*R; // Effective stator resistance per phase
pi=pb*(v/vb)^2; // power input at rated voltage
   during block rotor test
is=ib*(v/vb); // stator current at rated voltage
   during block rotor test
```

```
17 pg=pi-m*(is/sqrt(3))^2*Rs-l; // air gap power
18 ws=(4*%pi*f)/p;
19 printf('synchronous speed is %f rad/sec\n',ws);
20 T=pg/ws;
21 printf('Starting torque is %f Nm',T);
```

Scilab code Exa 6.44 Determining starting torque

```
1  clc;
2  p=6; // number of poles
3  m=3; // number of phases
4  f=50; // frequency of motor
5  P=40000; // rated power of induction motor
6  v=400; // rated voltage of induction motor
7  // results of blocked  rotor test
8  vb=200; // applied voltage
9  ib=110; // applied current
10 pf=0.4; // power factor
11 f1=45; // frequency at starting torque is to be
      determined
12 e=380; // voltage at starting torque is to be
      determined
13 vbp=vb/sqrt(3); // per phase voltage during blocked
       rotor test
14 zb=vbp/ib; // total impedance referred to stator
15 R=zb*pf; // net resistance referred to stator
16 X=zb*(sqrt(1-pf^2)); // net reactance referred to
      stator
17 X=X*(f1/f); // net reactance at frequency=45
18 Z=R+X*%i; // impedance at frequency=45
19 v1=e/sqrt(3); // per phase stator
20 is=v1/(Z); // starting current
21 ws=(4*%pi*f)/p; // synchronous speed
22 T=(3/ws)*abs(is)^2*(R/2);
23 printf('Starting torque is %f Nm',T);
```

Scilab code Exa 6.45 Determining 1 mechanical power output 2 net torque 3 efficiency of motor

```
clc;
v=400; // rated voltage of motor
m=3; // number of phases
r=2; // ratio of leakage reactance of stator to
   leakage reactance of rotor
ns=1000; // synchronous speed
n=960; // speed of motor
f=50; // frequency
// no load test results
Vo=400; // applied voltage
io=7.5; // no load current
pfo=0.135; // power factor
// blocked rotor test
vb=150; // applied voltage
ib=35; // current
pfb=0.44; // power factor
znl=Vo/(io*sqrt(3)); // no load impedance
rnl=znl*pfo; // no load resistance
xnl=sqrt(znl^2-rnl^2); // no load reactance
zbr=vb/(ib*sqrt(3)); // block rotor test impedance
Rbr=zbr*pfb; // block rotor resistance
xbr=sqrt(zbr^2-Rbr^2); // block rotor reactance
x2=xbr/3; // leakage reactance of rotor
x1=x2*2; // leakage reactance of stator
xm=xnl-x1; // magnetising reactance
r1=Rbr/2; // stator resistance/rotor resistance
V1=v/sqrt(3); // per phase stator voltage
Ve=(V1*xm)/(x1+xm); // thevenin voltage
Re=(r1*xm)/(x1+xm); // thevenin resistance
Xe=(x1*xm)/(x1+xm); // thevenin resistance
lr=sqrt(3)*v*io*pfo-m*io^2*r1; // rotational losses
```

```
31 s=(ns-n)/ns; // slip
32 ir=Ve/(Re+(r1/s)+%i*(Xe+x2)); // rotor current at
      slip
33 Pm=m*abs(ir)^2*r1*((1-s)/s);
34 disp('case a');
35 Psh=Pm-lr;
36 printf('Mechanical power output is %f KW\n',Psh
      /1000);
37 disp('case b');
38 wr=((2*%pi*f)*(1-s))/m; // speed at which motor is
      running
39 T=Psh/wr;
40 printf('Net torque is %f Nm\n',T);
41 disp('case c');
42 lor=(Pm*s)/(1-s); // rotor/stator ohmic losses
43 Tl=lor*2+lr; // total losses
44 pi=Tl+Psh; // input power
45 ne=Psh/pi;
46 printf('Efficiency of motor is %f percent',ne*100);
```

Scilab code Exa 6.46 Determining new operating speed

```
1 clc;
2 f=60; // frequency
3 p=6; // number of poles
4 n=1175; // speed of induction motor
5 re=0.06; // reduction in frequency
6 dv=0.1; // reduction in voltage
7 ws1=(120*f)/p; // synchronous speed
8 s1=(ws1-n)/ws1; // slip
9 s2=((1-re)/((1-dv)^2))*s1; // new slip
10 ws2=ws1*(1-s2)*(1-re);
11 printf('New operating speed is %f rpm',ws2);
```

Scilab code Exa 6.47 Determining 1 line current pf slip torque and efficiency 2 maximum possible pf and corresponding line current 3 maximum power output and maximum power input 4 slip at maximum torque and maximum torque 5 starting torque

```
clc;
P=15000; // rated power of induction motor
V=400; // rated voltage of motor
f=50; // frequency
m=3; // number of phases
po=4; // number of poles
// no load test results
Vo=400; // applied line voltage
io=9; // no load line current
Po=1310; //  power input
// blocked rotor test
vb=200; // line voltage
ib=50; // line current
pb=7100; // input power
pfo=po/(sqrt(3)*io*Vo); // no load power factor
pfb=pb/(sqrt(3)*ib*vb); // short circuit power
    factor
isc=(V/vb)*ib; // short circuit current
printf('Short circuit current is %d A\n',isc);
// circle diagram is drawn in fig 6.37 with scale 6
    A= 1 cm
disp('case a');
x=6; // scale
pps=(V/sqrt(3))*x; // per phase power scale
fp=P/3; // full load power per phase
// as per the construction we obtain OP=6.05 which
    corresponds to full load current
ifl=x*6.05;
printf('Full load line current is %f A\n',ifl);
```

```
// from fig angle POV1=29.5;
fpf=cosd(29.5);
printf('Full load power factor is %f lagging\n',fpf)
    ;
// full load slip is given by ratio ba/bP where ba
    =2.5, bP=38.5
fs=2.5/38.5;
printf('Full load slip is %f \n',fs);
ws=(2*%pi*f*120)/(po*60); // synchronous speed
Ft=(3.85*pps*m)/ws;
printf('Full load torque is %f Nm\n',Ft);
// efficiency is given by ratio aP/dP where aP=3.6,
    dP=4.45
ne=3.6/4.45;
printf('Full load efficiency is %f percent\n',ne
    *100);
disp('case b');
// OP turns out to be tangent to circular locus,
    therefore
disp('Maximum power factor is 0.87 lagging');
disp('Maximum line current is 36.3 A');
disp('case c');
// according to constructions given in solution we
    obtain AA'=5.3 from which maximum power output
    can be calculated
mpo=5.3*m*pps;
printf('Maximum output power is %f KW\n',mpo/1000);
// according to constructions given in solution we
    obtain CC'=8.45=radius of circle from which
    maximum power input can be calculated
mpi=8.45*m*pps+po;
printf('Maximum input power is %f KW\n',mpi/1000);
disp('case d');
// according to constructions given in solution we
    obtain BB'=6.65 from which maximum torque can be
    calculated
Mt=(6.65*m*pps)/ws;
printf('Maximum torque is %f Nm\n',Mt);
```

```
54 // maximum slip is given by ratio fb'/BB' where fb
   '=1.58, BB'=6.65
55 s=1.58/6.65;
56 printf('Maximum slip is %f \n',s);
57 disp('case e');
58 // according to constructions given in solution we
   obtain DG=3.3 from which starting torque can be
   calculated
59 St=(3.3*m*pps)/ws;
60 printf('Starting torque is %f Nm\n',St);
```

Scilab code Exa 6.48 Determining 1 external resistance inserted in rotor circuit 2 stator currents power factor 3 power output operating power factor and efficiency

```
1  clc;
2  P=4500; // rated power of induction motor
3  V=400; // rated voltage of motor
4  f=50; // frequency
5  m=3; // number of phases
6  // no load test results
7  Vo=400; // applied line voltage
8  io=4.2; // no load line current
9  Po=480; //  power input
10 // blocked rotor test
11 vb=215; // line voltage
12 ib=15; // line current
13 pb=1080; // input power
14 rs=1.2; // rotor resistance referred to stator per
   phase
15 nt=2; // stator to rotor turns ratio
16 pfo=Po/(sqrt(3)*io*Vo); // no load power factor
17 pfb=pb/(sqrt(3)*ib*vb); // short circuit power
   factor
18 isc=(V/vb)*(ib*sqrt(3)); // per phase short circuit
```

```
    current
iop=io/sqrt(3); // per phase no load current
x=1; // scale 1 A= 1 cm
// circle diagram is drawn in fig 6.38
disp('case a');
// value of maximum torque at starting is not given
// now we note Bf=4.6 and B'f=1.25 using these
    values external resistance to be inserted is
    calculated
re=(4.6/1.25)*1.2; // external resistance
printf('External resistance referred to rotor is %f
    ohms\n',re/nt^2);
// as per the construction we obtain OB=11.24 which
    is needed to calculate starting line current
is=11.24*sqrt(3);
printf('Starting current is %f A\n',is);
// angle OBB'=45.5 which is needed to calculate
    power factor
pf=cosd(45.5);
printf('power factor is %f lagging\n',pf);
pps=x*V; // per phase power scale
fp=P/m; // full load power per phase
disp('case b');
// now torque is 1.25 times full load torque
// now we note NK=2.9 and N'K=2.1 using these values
     external resistance to be inserted is calculated
re=(2.9/2.1)*1.2; // external resistance
printf('External resistance referred to rotor is %f
    ohms\n',re/nt^2);
// as per the construction we obtain ON=14.35 which
    is needed to calculate starting line current
is=14.35*sqrt(3);
printf('Starting current is %f A\n',is);
// angle ONN'=58.3 which is needed to calculate
    power factor
pf=cosd(58.3);
printf('power factor is %f lagging\n',pf);
disp('case c');
```

```
47 // we obtain OH=5.35 which is per phase output
      current
48 // thetag=41.3
49 opf=cosd(41.3);
50 printf('Operating power factor is %f leading\n',opf)
      ;
51 po=m*5.35*V*opf;
52 printf('Output power is %f KW\n',po/1000);
53 // we note HL=3.95 and Ha=4.90 which is needed for
      efficiency
54 ne=3.95/4.9;
55 printf('Induction generator efficiency is %f percent
      ',ne*100);
```

Scilab code Exa 6.49 Determining 1 rotational and core loss 2 electric power output power factor and efficiency

```
1  clc;
2  p=150000; // rated power of induction motor
3  v=400; // rated voltage of induction motor
4  m=3; // number of phases
5  r1=0.02; // stator resistance
6  r2=0.04; // rotor resistance
7  xm=9.8; // magnetising reactance
8  x1=0.2; // leakage reactance of stator or rotor
9  s=0.04; // slip
10 n=0.93; // efficiency
11 disp('case a');
12 Zf=(((r2/s)+%i*x1)*%i*xm)/((r2/s)+%i*(xm+x1)); //
      per phase impedance offered to stator by rorating
       air gap field
13 z=r1+%i*x1; // impedance of stator
14 Z=Zf+z; // total impedance
15 is=v/(sqrt(3)*abs(Z)); // stator current
16 pg=m*is^2*real(Zf); // air gap power
```

```
l1=m*is^2*r1; // stator copper loss
l2=s*pg; // rotor copper loss
Tl=((1/n)-1)*p; // total losses
lr=Tl-(l1+l2); // rotational and core losses
printf('Rotational and core losses are %f W\n',lr);
disp('case b');
s=-0.04; // slip
Zf=(((r2/s)+%i*x1)*%i*xm)/((r2/s)+%i*(xm+x1)); //
   per phase impedance offered to stator by rorating
    air gap field
Z=Zf+z; // total impedance
is=v/(sqrt(3)*abs(Z)); // stator current
pf=cosd(180-atand(imag(Z),real(Z))); // power factor
printf('Power factor at the generator terminal is %f
    leading\n',pf);
po=sqrt(3)*is*v*pf; // electrical output
printf('Electrical output is %f KW\n',po/1000);
pg=-m*is^2*real(Zf); // air gap power
l1=m*is^2*r1; // stator copper loss
l2=-s*pg; // rotor copper loss
Tl=l1+l2+lr; // total losses
pi=Tl+po; // mechanical power input
ne=po/pi;
printf('Efficiency is %f percent',ne*100);
```

Scilab code Exa 6.50 Determining per phase value of capacitance and total KVA rating of capacitor bank

```
clc;
v=400; // balanced supply voltage
i=10; // line current
f=50; // frequency of supply
m=3; // number of phases
pf=0.8; // lagging power factor
pfn=0.9; // improved power factor
```

```
8  disp('staor in star');
9  i=i*(pf-%i*sqrt(1-pf^2)); // complex form of line
      current
10 il=real(i)/pfn; // line current at improved power
      factor
11 il=il*(pfn-%i*sqrt(1-pfn^2)); // complex form of new
       line current
12 //from fig. 6.39
13 ic=-(imag(i)-imag(il)); // reactive component of
      current to be neutralised
14 // capacitor bank is star connected
15 xcs=v/(ic*sqrt(3)); // capacitance reactance
16 Cs=1/(2*%pi*f*xcs); // capacitance
17 K=m*ic*v/sqrt(3);
18 printf('Per phase value of capacitance for star
      connected capacitor bank is %f microfarad\n',Cs
      *10^6);
19 printf('Total KVA rating for star connected
      capacitor bank is %f KVA\n',K/1000);
20 // delta connected capacitor bank
21 // capacitor bank is delta connected, converting
      into equivalent star Xstar=Xdelta/3
22 xcd=v/(ic*sqrt(3)); // capacitance reactance
23 Cd=1/(2*%pi*f*xcd*m); // capacitance
24 printf('Per phase value of capacitance for delta
      connected capacitor bank is %f microfarad\n',Cd
      *10^6);
25 printf('Total KVA rating for delta connected
      capacitor bank is %f KVA\n',K/1000);
26 disp('Stator in delta');
27 i=(abs(i)/sqrt(3))*(pf-%i*sqrt(1-pf^2)); // complex
      form of line current
28 il=real(i)/pfn; // line current at improved power
      factor
29 il=il*(pfn-%i*sqrt(1-pfn^2)); // complex form of new
       line current
30 //from fig. 6.39
31 ic=-(imag(i)-imag(il)); // reactive component of
```

```
    current to be neutralised
// capacitor bank is star connected
// capacitor bank is star connected, converting
    into equivalent delta Xdelta=3*Xstar
xcs=v/ic; // capacitance reactance
Cs=m/(2*%pi*f*xcs); // capacitance
K=m*ic*v;
printf('Per phase value of capacitance for star
    connected capacitor bank is %f microfarad\n',Cs
    *10^6);
printf('Total KVA rating for star connected
    capacitor bank is %f KVA\n',K/1000);
//  delta connected capacitor bank
xcd=v/ic; // capacitance reactance
Cd=1/(2*%pi*f*xcd); // capacitance
printf('Per phase value of capacitance for delta
    connected capacitor bank is %f microfarad\n',Cd
    *10^6);
printf('Total KVA rating for delta connected
    capacitor bank is %f KVA\n',K/1000);
```

Scilab code Exa 6.51 Determining capacitance of bank and each unit and percentage saving in energy lost

```
clc;
v=3300; // balanced supply voltage
p=500000; // rated power of induction motor
f=50; // frequency of supply
m=3; // number of phases
pf=0.7; // lagging power factor
pfn=0.9; // improved power factor
vc=420; // rated voltage of capacitor
n=0.86; // motor efficiency
i=p/(sqrt(3)*v*pf*n); // line current
i=i*(pf-%i*sqrt(1-pf^2)); // complex form of line
```

```
    current
il=real(i)/pfn; // line current at improved power
    factor
il=il*(pfn-%i*sqrt(1-pfn^2)); // complex form of new
    line current
//from fig. 6.39
ic=-(imag(i)-imag(il)); // reactive component of
    current to be neutralised
// capacitor bank is delta connected
// capacitor bank is delta connected, converting
    into equivalent star Xstar=Xdelta/3
xcd=v/(ic*sqrt(3)); // capacitance reactance
Cd=1/(2*%pi*f*xcd*m); // capacitance
// now each capacitor is rated at 420 V, number of
    capacitor connected in series is
n=ceil(v/vc);
C=Cd*n;
printf('Per phase value of each capacitance for
    delta connected capacitor bank is %f microfarad\n
    ',C*10^6);
// let R be resistance of distribution circuit
// power lost without capacitor bank is m*abs(i)^2*R
// power lost with capacitor bank is m*abs(il)^2*R
    therefore
ps=(abs(i)^2-abs(il)^2)/abs(i)^2
printf('Percentage saving in losses is %f percent',
    ps*100);
```

Scilab code Exa 6.53 Determining tapping on autotransformer and line current at starting

```
clc;
fs=0.05; // full load slip
ir=6; // ratio of starting current and full load
    current
```

```
4 t=1; // ratio of starting torque to full load torque
5 x=sqrt(t/((ir^2)*fs));
6 printf('Tapping point is at %f percent\n',x*100);
7 is=x^2*ir;
8 printf('Starting current is %f times full load
    current\n',is);
```

Scilab code Exa 6.54 Determining starting torque in terms of full load torque

```
1 clc;
2 vr=0.4; // voltage applied during blocked rotor test
    as a fraction of rated voltage
3 ir=2.5; // line current during blocked rotor test as
    a fraction of full load current
4 tr=0.3; // starting torque as a fraction of rated
    torque
5 is=1.5; // starting current as a fraction of full
    load current
6 isc=ir/vr; // short circuit current at rated load
7 x=sqrt(is/isc); // starting current as a fraction of
    short circuit current at rated load
8 T=(x/vr)^2*tr;
9 printf('Starting torque is %f percent of full load
    torque',T*100);
```

Scilab code Exa 6.55 Determining maximum permissible KW rating of motor for different cases

```
1 clc;
2 v=440; // rated voltage of distribution circuit
3 im=1200; // maximum current that can be supplied
4 n=0.85; // efficiency of induction motor
```

```
pf=0.8; // power factor of motor
ir=5; // ratio of starting current to full load
    current
disp('case a');
il=im/ir; //rated line current
p=sqrt(3)*v*il*n*pf;
printf('Maximum KW rating is %f KW\n',p/1000);
disp('case b');
x=0.8; // rated of applied voltage and stepped down
    voltage
il=im/(x^2*ir); //rated line current
p=sqrt(3)*v*il*n*pf;
printf('Maximum KW rating is %f KW\n',p/1000);
disp('case c');
// star-delta converter is same as autotransformer
    starter with 57.8 % tapping therefore
il=im/(0.578^2*ir); //rated line current
p=sqrt(3)*v*il*n*pf;
printf('Maximum KW rating is %f KW\n',p/1000);
```

Scilab code Exa 6.56 Determining 1 voltage applied to motor terminals 2 current drawn by motor 3 line current drawn from supply mains

```
clc;
p=10000; // rated power of motor
v=400; // rated voltage of motor
n=0.87; // full load efficiency
pf=0.85; // power factor
ir=5; // ratio of starting current to full load
    current
tr=1.5; // ratio of starting torque to full load
    torque
disp('case a');
vt=v/sqrt(tr);
printf('Voltage applied to motor terminal is %f V\n'
```

```
    ,vt);
disp('case b');
ifl=p/(sqrt(3)*v*pf*n); // full load current
il=(ir*vt*ifl)/v;
printf('Current drawn by motor is %f A\n',il);
disp('case c');
i=(vt/v)*il;
printf('Line current drawn from supply mains is %f A
    ',i);
```

Scilab code Exa 6.57 Determining ratio of starting torque to full load torque for different starters

```
clc;
tm=2; // ratio of maximum torque to full load torque
r=0.2; // per phase rotor resistance referred to
    stator
x=2; // per phase reactance referred to stator
s=r/x; // slip at maximum torque
disp('case a');
ts1=(2*s*tm)/(s^2+1);
printf('Ratio of starting torque to full load torque
    is %f\n',ts1);
disp('case b');
ts2=ts1/3;
printf('Ratio of starting torque to full load torque
    with star-delta starter is %f\n',ts2);
disp('case c');
t=0.7; // tapping point
ts3=ts1*t^2;
printf('Ratio of starting torque to full load torque
    with autotransformer starter is %f\n',ts3);
```

Scilab code Exa 6.58 Determining resistance of feeder and percentage increase in starting torque

```
clc;
v=400; // supply voltage
f=50;  // frequency of supply
// results of short circuit test
V=200; // applied voltage
i=100; // short circuit current
pf=0.4; // power factor
zsc=(V*sqrt(3))/i; // short circuit impedance
rsc=zsc*pf; // short circuit resistance
xsc=sqrt(zsc^2-rsc^2); // short circuit reactance
R=sqrt(((xsc^2+rsc^2)-3*((rsc/3)^2+(xsc/3)^2))/2);
   // resistance of feeder
disp('with star connection');
ts1=(3*(v/sqrt(3))^2*rsc)/((R+rsc)^2+xsc^2); //
   product of starting torque and synchronous speed
// now two feeders are connected in parallel
   therefore net resistace of feeder is
rp=R^2/(R+R);
ts2=(3*(v/sqrt(3))^2*rsc)/((rp+rsc)^2+xsc^2); //
   product of new starting torque and synchronous
   speed
pr=(ts2-ts1)/ts1;
printf('Percentage increase in starting torque with
   star connection is %f percent\n',pr*100);
disp('With delta connection');
ts1=(3*(v/sqrt(3))^2*(rsc/3))/((R+(rsc/3))^2+(xsc/3)
   ^2); // product of starting torque and
   synchronous speed
// now two feeders are connected in parallel
   therefore net resistace of feeder is
rp=R^2/(R+R);
ts2=(3*(v/sqrt(3))^2*(rsc/3))/((rp+(rsc/3))^2+(xsc
   /3)^2); // product of new starting torque and
   synchronous speed
pr=(ts2-ts1)/ts1;
```

```
25 printf('Percentage increase in starting torque with
     delta connection is %f percent\n',pr*100);
```

Scilab code Exa 6.59 Determining minimum allowable cross section area of each conductor of feeder

```
1  clc;
2  z=1.2+3*%i; // per phase standstill impedance
3  v=400; // supply voltage
4  l=500; // length of feeder line
5  tr=30; // maximum percentage reduction possible in
     starting torque
6  ro=0.02; // resistivity of feeder material
7  // equating expression of starting torque with and
     without feeder we get a quadratic equation in R (
     feeder resistance) whose terms are
8  t1=(1-(tr/100));
9  t2=2*real(z)*t1;
10 t3=t1*abs(z)^2-abs(z)^2;
11 p=[ t1 t2 t3 ];
12 R=roots(p);
13 A=(ro*l)/R(2);
14 printf('Minimum allowable cross section is %f mm^2',
     A);
```

Scilab code Exa 6.60 Determining starting torque for different connections

```
1  clc;
2  f=50; // frequency
3  p=10; // number of poles
4  pb=120000; // power dissipated in block rotor test
5  // stator ohmic losses = rotor ohmic losses
```

```
pr=pb/2; // total rotor loss
disp('case a');
ws=(4*%pi*f)/p; // synchronous speed
Ts=pr/ws;
printf('Starting torque is %f Nm\n',Ts);
disp('case b');
pr=pr/3; // total rotor ohmic loss
Ts=pr/ws;
printf('Starting torque is %f Nm\n',Ts);
```

Scilab code Exa 6.62 Determining value of resistance elements for a 4 step starter

```
clc;
s=0.03; // full load slip
R=0.015; // rotor resistance per phase
n=4; // number of step in starter
al=s^(1/n);
R1=R/s; // resistance of whole section
r1=R1*(1-al);
printf('Resistance of first element is %f ohms\n',r1
   );
r2=r1*al;
printf('Resistance of second element is %f ohms\n',
   r2);
r3=r1*al^2;
printf('Resistance of third element is %f ohms\n',r3
   );
r4=r1*al^3;
printf('Resistance of fourth element is %f ohms\n',
   r4);
```

Scilab code Exa 6.63 Designing 5 sections of a 6 stud starter

```
clc;
fs=0.02; // full load slip
ir=2; // ratio of starting current to full load
   current
n=5; // number of section
R=0.03; // rotor resistance
//ir*ifl=(E2/R)*sm where ifl is full load current
   and E2 is induced voltage in rotor therefore
sm=fs*ir; // maximum slip
al=sm^(1/n);
R1=R/sm; // resistance of whole section
r1=R1*(1-al);
printf('Resistance of first element is %f ohms\n',r1
   );
r2=r1*al;
printf('Resistance of second element is %f ohms\n',
   r2);
r3=r1*al^2;
printf('Resistance of third element is %f ohms\n',r3
   );
r4=r1*al^3;
printf('Resistance of fourth element is %f ohms\n',
   r4);
r5=r1*al^4;
printf('Resistance of fifth element is %f ohms\n',r5
   );
```

Scilab code Exa 6.64 Determining 1 starting current and starting torque 2 external resistance to limit starting current and starting torque under this condition

```
clc;
v=3300; // rated voltage of induction motor
p=6; // number of poles
f=50; // frequency
```

```
5  t=3.2; // stator to rotor turns
6  r=0.1; // rotor resistance
7  x=1; // rotor leakage reactance
8  R=t^2*r; // rotor resistance referred to stator
9  X=t^2*x; // rotor reactance referred to stator
10 ws=(4*%pi*f)/p; // synchronous speed
11 disp('case a');
12 is=(v/sqrt(3))/(sqrt(R^2+X^2));
13 printf('Starting current at rated voltage is %f A\n'
      ,is);
14 Ts=(3*is^2*R)/ws;
15 printf('Starting torque at rated voltage is %f Nm\n'
      ,Ts);
16 disp('case b');
17 is=50; // starting current
18 // is=Vp/(sqrt((R+rex)^2+X^2) where rex is external
      resistance and Vp is phase voltage
19 // solving above equation we get a quadratic
      equation in rex whose terms are
20 t1=1;
21 t2=2*R;
22 t3=(R^2+X^2)-((v/sqrt(3))/is)^2;
23 p=[ t1 t2 t3 ];
24 rex=roots(p);
25 printf('External resistance referred to rotor is %f
      ohms\n',rex(2)/t^2);
26 Ts=(3*is^2*(R+rex(2)))/ws;
27 printf('Starting torque under new condition is %f Nm
      \n',Ts);
```

Scilab code Exa 6.65 Determining 1 line current 2 power returned to three phase supply 3 efficiency of motor

```
1 clc;
2 p=6; // number of poles
```

```
3  v=400; // rated voltage of induction motor
4  m=3; // number of phases
5  f=50; // frequency
6  r1=0.2; // stator resistance
7  r2=0.5; // rotor resistance
8  xm=48; // magnetising reactance
9  x1=2; // leakage reactance of stator or rotor
10 n=1050; // speed of motor
11 ns=(120*f)/p; // synchronous speed
12 s=(ns-n)/ns; // operating slip
13 disp('case a');
14 Zf=(((r2/s)+%i*x1)*%i*xm)/((r2/s)+%i*(xm+x1)); //
     per phase impedance offered to stator by rorating
      air gap field
15 z=r1+%i*x1; // impedance of stator
16 Z=Zf+z; // total impedance
17 is=v/(sqrt(3)*abs(Z)); // stator current
18 pf=cosd(atand(imag(Z),real(Z)));
19 printf('Stator line current is %f A\n',is);
20 disp('case b');
21 Po=m*(v/sqrt(3))*is*pf;
22 // negative power indicates induction machine is
     acting as generator
23 printf('Power fed back to 3 phase supply system is
     %f W\n',-Po);
24 disp('case c');
25 lr=600; // rotational and core losses
26 pg=m*is^2*real(Zf); // air gap power
27 l1=m*is^2*r1; // stator copper loss
28 l2=s*pg; // rotor copper loss
29 Tl=lr+l1+l2; // total losses
30 pi=-Po+Tl; // mechanical power input
31 ne=-Po/pi;
32 printf('Efficiency of induction motor is %f percent\
     n',ne*100);
```

Chapter 7

Armature Windings

Scilab code Exa 7.1 Determining the number of commutator segments back pitch and front pitch and commutator pitch

```
clc;
p=6; // number of poles
c=40; // number of coils
w=2; // winding pitch for simplex lap winding
printf('Number of commutator segments is equal to
   number of coils=%f\n ',c);
k=1/3; // integer added(or subtracted) to calculate
   back pitch to make it an odd integer
yb=((2*c)/p)-k;
printf('Back pitch is %f \n',yb);
yf=yb-w;
printf('Front pitch for progressive winding is %f\n'
   ,yf);
yf=yb+w;
printf('Front pitch for retrogressive winding is %f\
   n',yf)
yc=1;
printf('For simplex lap winding, commutator pitch is
    equal to %f ',yc);
```

Scilab code Exa 7.2 Designing the progressive simplex lap winding with two coil sides per slot

```
clc;
p=4; // number of poles
c=12; // number of coils
// Number of commutator segments is equal to number of coils=12
// Each coil has two coil side therefore total coil sides are 24
s=(2*c)/2 ; // total number of slots required
k=1; // integer added(or subtracted) to calculate back pitch to make it an odd integer
w=2; // winding pitch
yb1=((2*c)/p)-k; // back pitch
// or
yb2=((2*c)/p)+k; // back pitch
disp('Back pitch is ');
disp(yb1,'or',yb2);
yf1=yb1-2; // front pitch for yb=5
yf2=yb2-2; // front pitch for yb=7
disp('front pitch for progressive winding is ');
disp(yf1,'or',yf2);
disp('It is desirable that (yb+yf)/2 should be equal to pole pitch that is 6(in terms of coil sides per pole). So choose yb=7 and yf=5');
disp('Commutator pitch for progressive lap winding is');
disp(1);
```

Scilab code Exa 7.3 Determining winding table and position of brushes on commutator

```
clc;
p=4; // number of poles
s=14; // number of slots
cp=2; // coil sides per slots
w=2; // winding pitch
C=(s*cp)/2; // number of coils
yb=(2*C)/p;
disp('Back pitch is');
disp(yb);
yf=yb-w;
disp('Front pitch is');
disp(yf);
disp('winding table for progressive lap winding is')
   ;
disp('(1-8)-(3-10)-(5-12)-(7-14)-(9-16)-(11-18)
   -(13-20)-(15-22)-(17-24)-(19-26)');
disp('-(21-28)-(23-2)-(25-4)-(27-6)');
disp('from winding diagram')
disp('Brush A is touching segments 1 and 2 partly');
disp('Brush B is at segment 5');
disp('Brush C is at segment 8');
```

Scilab code Exa 7.5 Designing a simplex lap winding with the given details

```
clc;
disp('case a');
s=30; // number of slots
c=60; // number of coils
p=4; // number of poles
k=1; // integer added(or subtracted) to calculate
   back pitch to make it an odd integer
tc=c*2; //  total coil sides
u=tc/s; // coil sides per slots
yb1=(tc/p)+k;
```

```
10 yb2=(tc/p)-k;
11 disp('Back pitch is');
12 disp(yb1);
13 disp('or');
14 disp(yb2);
15 disp('for back pitch=29, top coil sides 1 and 3 in
     slot 1 are connected to bottom coil 30 and 32 in
     slot 8. Due to this arrangement split coils can
     be avoided. But for back pitch= 31, coil sides 34
      which is in slot 9 has to be used, so split
     coils are needed ')
16 disp('case b');
17 s=20; // number of slots
18 c=60; // number of coils
19 p=4; // number of poles
20 k=1; // integer added(or subtracted) to calculate
     back pitch to make it an odd integer
21 tc=c*2; //  total coil sides
22 u=tc/s; // coil sides per slots
23 yb1=(tc/p)+k;
24 yb2=(tc/p)-k;
25 disp('Back pitch is');
26 disp(yb1);
27 disp('or');
28 disp(yb2);
29 disp('for back pitch=29, top coil sides 1,3 and 5
     are connected to bottom coil 30, 32 and 34. Due
     to this arrangement split coils cannot be avoided
     . But for back pitch= 31, coil sides 1,3 and 5
     are connected to bottom coil sides 32, 34 and 36
     which are in slot 6,so split coils are not needed
      ');
```

Scilab code Exa 7.6 Designing a simplex wave winding with given details

```
clc;
p=4; // number of poles
s=11; // number of slots
ts=2; // coil sides per slot
C=(s*ts)/2; // total coils
w=((2*C)+2)/(p/2); // winding pitch
// since both back and front pitch should be odd
   choose
Yb=7;
Yf=5;
disp('Back pitch is')
disp(Yb);
disp('Front pitch is')
disp(Yf);
yc=(C+1)/(p/2);
disp('commutator pitch');
disp(yc);
disp('Using this data winding diagram can be drawn')
   ;
disp('Winding table is');
disp('(1-8)-(13-20)-(3-10)-(15-22)-(5-12)-(17-2)
   -(7-14)-(19-4)-(9-16)-(21-6)-(11-18)-1');
```

Scilab code Exa 7.7 Designing the simplex wave winding

```
clc;
p=6; // number of poles
s=72; // number of slots
ts=4; // number of coil sides per slot
C=(s*ts)/2; // total number of coils
// To make commutator pitch an integer one coil is
   made dummy coil therefore
C=C-1;
yc=(C+1)/(p/2);
disp('commutator pitch');
```

```
disp(yc);
yw=((2*C)+2)/(p/2);
disp('Winding pitch is');
disp(yw);
// since back and front pitch should be odd choose
yb=49;
disp('Back pitch is');
disp(yb);
yf=47;
disp('Front pitch is');
disp(yf);
```

Scilab code Exa 7.8 Designing the winding and determining the speed

```
clc;
p=4; // number of poles
z=2540; // number of conductors
s=32; // number of slots
c=127; // number of commutator sectors=total number
    of coils
v=500; // induced voltage required
f=5*10^-3; // field flux per pole
a=2; // number of parallel paths
zs=ceil(z/s); // conductors per slot
// for zs=80
Z=zs*s; // total conductors
t=floor(Z/(2*c)); // turn per coil
C=Z/(2*t); // actual number of coils
// It is necessary that actual coils should be same
    as commutator segments so one coil is made dummy
disp('commutor pitch is')
disp((c+1)/(p/2));
disp('or');
disp((c-1)/(p/2));
disp('Winding pitch is')
```

```
20 disp(((2*c)+2)/(p/2));
21 disp('or');
22 disp(((2*c)-2)/(p/2));
23 disp('For progressive winding, back pitch=65 and
      front pitch=63');
24 disp('For retrogressive winding, back pitch=63 and
      front pitch=63');
25 // since dumy coil is not in circuit, number of
      active conductor is
26 Z=c*t*2;
27 n=(v*a*60)/(f*Z*p);
28 printf('Speed for required induced voltage is %f rpm
      ',n);
```

Scilab code Exa 7.9 Determining the suitable arrangement of equilizer ring for given details

```
1 clc;
2 p=8; // number of poles
3 c=240; // number of coils
4 r=10; // number of equilizer ring
5 Yeq=(2*c)/p;
6 printf('Equipotential pitch is %f coils\n',Yeq);
7 Ytp=(2*c)/(r*p);
8 printf('Tapping point pitch is %f coils',Ytp);
9 disp('Arrangement is shown in tabular form in
      example 7.9');
```

Scilab code Exa 7.10 Determining the resistance measured between two adjacent commutator segments

```
1 clc;
2 disp('b(1)');
```

```
c=12;  // number of coils
r=0.1; // resistance of each coil
// any one coil connected to commutator segment is
   in parallel with other 11 series connected coils
   therefore
R=11*r; // resistance of 11 coil
req=(r*R)/(r+R);
printf('Resistance measured between two adjacent
   commutator segments is %f ohm\n',req);
```

Scilab code Exa 7.11 Determining the details for winding diagram and distribution factor

```
clc;
disp('a');
s=24; // total number of slots
p=4; // number of poles
np=3; // number of phases
ph=60; // phase spread
// given armature has double layer winding and full
   pitch coil span
v=(p*180)/s;
printf('Slot angular pitch is %d degrees\n',v);
disp('Number of adjacent slots in one phase belt is'
   );
disp(ph/v);
cs=s/p;
printf('Coil span is %d slots\n',cs);
disp('Using this data winding table for the three
   phases is shown in Ex7.11')
disp('d');
sp=s/(p*np); // slots per pole per phase
disp('Distribution factor is');
disp(sind(ph/2)/(sp*sind(v/2)));
```

Scilab code Exa 7.12 Determining the details for winding diagram and distribution factor

```
clc;
disp('a');
s=24; // total number of slots
p=4; // number of poles
np=3; // number of phases
ph=120; // phase spread
// given armature has double layer winding and full
   pitch coil span
v=(p*180)/s;
printf('Slot angular pitch is %d degrees\n',v);
disp('Number of adjacent slots in one phase belt is'
   );
disp(ph/v);
cs=s/p;
printf('Coil span is %d slots\n',cs);
disp('Using this data winding table for the three
   phases is shown in Ex7.12')
disp('d');
sp=s/(p*np); // slots per pole per phase
disp('Distribution factor is');
disp(sind(ph/2)/(sp*sind(ph/(2*sp))));
```

Scilab code Exa 7.13 Determining the details for winding table and effective turns per phase

```
clc;
np=3; // number of phase
sp=9; // slots per pole
zs=4; // conductors per slot
```

```
f=0.8; // coil span as a fraction of pole pitch
ph=60; // phase spread
v=180/sp; // slot angular pitch
disp('Number of adjacent slots belonging to any
   phase is ');
disp(ph/v);
printf('Pole pitch is %f slots\n',sp);
c=floor(0.8*sp);
printf('Coil span is of %f slots\n',c);
disp('Using this data, winding table is shown in Ex7
   .13');
t=(sp*zs*4)/2; // total turns in machine
spp=sp/np; // slots per pole per phase
kd=sind(ph/2)/(spp*sind(v/2)); // distribution
   factor
cp=c*v; // coil span in degrees
e=180-cp; // chording angle
kp=cosd(e/2); // coil span factor
kw=kd*kp; // winding factor
tp=(t*kw)/np;
printf('Number of effective turns per phase is %f',
   tp);
```

Scilab code Exa 7.15 Determining and designing the details for winding of 3 phase machine

```
clc;
s=24; // number of slots
p=4; // number of poles
ph=60; // phase spread
ap=(p*180)/s; // slot angular pitch
pp=s/p; // pole pitch
printf('Pole pitch is %d slots\n',pp);
printf('slot angular pitch is %d degrees',ap);
disp('using these data, half coil and whole coil
```

```
single layer concentric windings diagram are
drawn');
```

Chapter 8

Appendix A

Scilab code Exa 8.1 Determining the reluctance of ring and current required to establish the required flux

```
clc;
// answer is given wrong in the book
d=0.2; // mean diameter of mild steel ring
ac=50*10^-4; // cross sectional area of core
uo=4*%pi*10^-7; // free space permeability
ur=800; // relative permeability
f=1*10^-3; // required flux
N=200; // Number of turns
l=%pi*d // length of core
R=l/(uo*ur*ac); // reluctance of ring
printf('reluctance offered by ring is %f AT/Wb\n',R)
   ;
mmf=f*R; // mmf produced in ring
i=mmf/N;
printf('current required to produce the desired flux
    is %f A',i);
```

Scilab code Exa 8.2 Determining the exciting current in coil

```
clc;
ur=10000; // relative permeability of iron
lc=0.5; // core length
lg=4*10^-3; // air gap length
N=600; // number of turns
B=1.2; // desired flux density
uo=4*%pi*10^-7; // free space permeability
Ac=25*10^-4; // core area
mfc=(B*lc)/(uo*ur); // mmf for core
mfg=(B*lg)/uo; // mmf for air gap
mft=mfc+mfg; // net mmf
i=mft/N;
printf('exciting current required to establish the
   desired flux is %f A',i);
```

Scilab code Exa 8.3 Determining the exciting current with and without magnetic leakage and fringing

```
clc;
lc=0.5; // core length in metre
dc=2.85*10^-2; // diameter of cross section of core
lg=2*10^-3; // length of air gap
N=500; // Number oof turns of coil
f=0.8*10^-3; // air gap flux
uo=4*%pi*10^-7; // permeability of free space
HATM=[1500 2210 2720 3500 4100];
BT=[0.9 1.1 1.2 1.275 1.3];
plot(HATM,BT);
xlabel('magnetic field intensity');
ylabel('flux density');
disp('case a');
ur=500; // relative permeability
Ac=(%pi/4)*dc^2; // Area of core
Rlg=lg/(uo*Ac); // reluctance of air gap
Rlc=lc/(uo*ur*Ac); // reluctance of iron core
```

```
Rt=Rlg+Rlc; // Total reluctance
I=(f*Rt)/N; // Exciting current
printf('Exciting current in coil is %f A\n',I);
disp('case b');
Ag=(%pi/4)*(dc+2*lg)^2; // air gap area
Rlg=lg/(uo*Ag); // reluctance of air gap
I=(f*(Rlc+Rlg))/N; // Exciting current
printf('Exciting current after accounting for flux
   fringing is %f A\n',I);
disp('case c');
Bg=f/Ac; // Air gap flux density
Atg=(Bg*lg)/uo; // air gap mmf
// from the plot we can get the values of core flux
   density and magnetic field intensity
Bc=1.245; // core flux density in Tesla
H=3200; // magnetic field intensity in Ats/m
Atc=H*lc; // core mmf
mt=Atg+Atc; // total mmf
I=mt/N; // Exciting current
printf('Exciting current for third case is %f A',I);
```

Scilab code Exa 8.4 Determining the coil current for different values of relative permeability

```
clc;
N=1000; // Number of turns
f=1*10^-3; // flux in central limb
Ac=8*10^-4; // Area of central limb
Ao=4*10^-4; // Area of outer limb
lg=2*10^-3; // length of air gap
lc=0.15; // length of central limb in metre
lo=0.25; // length of outer limb in metre
uo=4*%pi*10^-7; // permeability of free space
disp('case a');
// for ur=infinity , reluctance offered by cast steel
```

```
    is zero
Rl1=lg/(uo*Ao); // reluctance offered by outer limb
Rl2=lg/(uo*Ac); // reluctance offered by central
    limb
// Assuming magnetic circuit as a close circuit,
    applying KVl in one of loop gives
I=(f*(Rl2+(Rl1/2)))/N;
printf('Coil current for first case is %f A\n',I);
disp('case b');
ur=6000; // relative permability
Rlc1=(lc+lo)/(uo*ur*Ao); // reluctance of outer
    steel core (including the top)
Rlc2=(lc)/(uo*ur*Ac); // reluctance offered by
    central steel core
r=(Rlc1+Rl1)/2; // resultant of outer reluctance
// By kVL we get
I=(f*(Rlc2+Rl2+r))/N;
printf('Coil current for second case is %f A\n',I);
```

Scilab code Exa 8.5 Calculating the exciting current to set up required flux

```
clc;
N=500; // number of turns in central limb
ac=600*10^-6; // cross sectional area of central
    limb
ao=375*10^-6; // cross sectional area of outer limb
f=0.9*10^-3; // required flux in Weber
lg=0.8*10^-3; // length of air gap
lc=180*10^-3; // length of central limb
lo=400*10^-3; // length of outer limb
uo=4*%pi*10^-7; // free space permeability
Bg=f/ac; // air gap flux density
Hg=Bg/uo; // magnetic field intensity in air gap
mg=Hg*lg; // mmf required for air gap
```

```
13 // from fig A.7,for B=1.5T, H for cast steel is 3000
      Ats/m
14 H=3000; // magnetic field intensity for cast steel
15 mc=H*lc; // mmf in central limb
16 Bo=f/(2*ao); // flux density in each outer limb
17 // for B=1.2, H=1400
18 H=1400; // magnetic field intensity for cast steel
      for given flux density
19 mo=H*lo; // mmf for outer limb
20 // By KVL
21 I=(mg+mo+mc)/N;
22 printf('The exciting current required to establish
      the desired flux is %f A',I);
```

Scilab code Exa 8.6 Calculating the coil current to establish required flux

```
1 clc;
2 N=400; // number of turns in coil
3 ac=20*10^-4; // area of cemntral limb
4 ao=15*10^-4; // area of outer iimb
5 lg=1*10^-3; // length of air gap
6 lc=40*10^-2; // length of central limb
7 lo=60*10^-2; // length of each outer limb
8 f=0.9*10^-3; // required flux
9 uo=4*%pi*10^-7; // free space permeability
10 Bg=f/ao; // air gap flux density
11 mg=(Bg*lg)/uo; // mmf or air gap
12 // for B=0.6,H=575 AT/m from fig A.7
13 H=575; // magnetic flux intensity for given flux
      density
14 mo=H*lo; // mmf of outer limb which contain air gap
15 mt=mo+mg; // combined mmf of air gap and outer limb
16 // this mmf acts across the other outer limb
17 haeb=mt/lo; // magnetic field intensity in outer
      limb which does not contain air gap
```

```
18 // for H=1370.77, B=1.19 T from fig A.7
19 Bo=1.19; // flux density for given magnetic field
      intensity
20 faeb=Bo*ao; // flux in outer limb
21 fnet=f+faeb; // net flux through central limb
22 Bc=fnet/ac; // flux density in central limb
23 // from fig A.7
24 H=1900; //  magnetic field intensity for given flux
      density
25 mc=H*lc; // mmf in central limb
26 // by KVL in one of the loop
27 I=(mc+mt)/N;
28 printf('Exciting current required to establish the
      given flux is %f A',I)
```

Scilab code Exa 8.7 Finding the exciting current in given coil

```
1  clc;
2  a=30*10^-4; // cross sectional area of ferromagnetic
       core
3  uo=4*%pi*10^-7; // free space permeability
4  ur=4000; // relative permeability for core
5  f=10*10^-3; // flux in central limb
6  n1=200; // number of turns in coil 1
7  m1=5000; // mmf for coil 1
8  n2=100; // number of turns in coil 2
9  lc=0.3; // length of central limb
10 lo=0.6; // length of outer limb
11 lg=1*10^-3; // length of air gap
12 rc=lc/(uo*ur*a); // reluctance for central limb
13 ro=lo/(uo*ur*a); // reluctance for outer limb
14 rg=lg/(uo*a); // reluctance for air gap
15 mc=f*(rc+rg); // mmf in central limb
16 // by KML, flux in outer limb containing coil 1 is
17 f1=(m1-mc)/ro;
```

```
// By flux law at node a in fig A.17, flux in outer
   limb contaning coil 2 is
f2=f1-f;
// by mmf law , mmf in coil 2 is
m2=mc-f2*ro;
I2=m2/n2; // current in coil 2, upper polarity is
   assumed positive
printf('Current in coil 2 is %f A',I2);
disp('As the mmf of coil 2 is positive , assumed
   polarity is correct. Therefore terminal A is
   positive because current enters through it and
   terminal B is negative ');
```

Scilab code Exa 8.8 Determining the emf induced in conductor for different angles of conductor with field flux

```
clc;
l=0.8; // length of conductor
B=1.2; // flux density of uniform magnetic field
v=30; // speed of conductor
disp('case a');
// conductor motion is normal to field flux
theta=90; // angle between direction of motion and
   field flux
e=B*l*v*sin(theta*(%pi/180));
printf('EMF induced is %f V\n',e);
disp('case b');
// conductor motion is at an angle of 30 degrees
   from direction of field
theta=30; // angle between direction of motion and
   field flux
e=B*l*v*sin(theta*(%pi/180));
printf('EMF induced is %f V\n',e);
disp('case c');
// conductor motion is parllel to field flux
```

```
17 theta=0; // angle between direction of motion and
     field flux
18 e=B*l*v*sin(theta*(%pi/180));
19 printf('EMF induced is %f V\n',e);
```

Scilab code Exa 8.9 Determining the emf induced in square coil for different angles of coil with field flux

```
1  clc;
2  // After deriving the expression
3  a=0.1; // side of square coil
4  N=100; // number of turns
5  n=1000; // speed of rotation on rpm
6  B=1; // flux density of a uniform magnetic field
7  disp('case a');
8  theta=90; // angle of coil with the field
9  w=(2*%pi*n)/60; // angular speed of coil in rad/s
10 e=N*B*a^2*w*cos(theta*(%pi/180));
11 printf('Emf induced in coil is %f V\n',e);
12 disp('case b');
13 theta=30; // angle of coil with the field
14 w=(2*%pi*n)/60; // angular speed of coil in rad/s
15 e=N*B*a^2*w*cos(theta*(%pi/180));
16 printf('Emf induced in coil is %f V\n',e);
17 disp('case c');
18 theta=0; // angle of coil with the field
19 w=(2*%pi*n)/60; // angular speed of coil in rad/s
20 e=N*B*a^2*w*cos(theta*(%pi/180));
21 printf('Emf induced in coil is %f V\n',e);
```

Scilab code Exa 8.10 Determining the emf induced in conductor

```
1  clc;
```

```
2 l=0.5; // length of conductor lying along Y-axis
3 B=1.2; // Flux density along the X-axis
4 v=2; // velocity of conductor
5 //e=Blv; for maximum induced emf all the three
     quantities should be perpendicular to each other
6 e=B*l*v;
7 printf('Maximum induced EMF in conductor is %f V',e)
     ;
```

Scilab code Exa 8.12 Determining the inductance for given circuit by using the given expression

```
1 clc;
2 disp('case a');
3 // as per the data taken from Ex 1_3
4 rlg=24.948*10^5; // air gap reluctance for example 1
     _3(a)
5 rlc=12.474*10^5; // iron core reluctance for example
      1_3(a)
6 rl=rlg+rlc; // net reluctance
7 N=500; // Number of turns
8 L=(N^2/rl)*1000;
9 printf('Inductance for case a is %f mH\n',L);
10 disp('case b');
11 // as per the data taken from Ex 1_3 part(c)
12 B=1.254; // calculated flux density
13 H=3200; // magnetic field intensity obtained from
     magnetisation curve corresponding to the flux
     density calculated
14 uo=4*%pi*10^-7; // free space permeability
15 ur=B/(H*uo); // relative permeability of iron core
16 d=2.85*10^-2; // diameter of cross section
17 A=(%pi*d^2)/4; // area of core
18 l=0.5; // core length
19 rlc=l/(ur*uo*A); // reluctance of iron core for part
```

```
    C
rt=rlg+rlc; // net reluctance
L=(N^2/rt)*1000;
printf('Inductance for case b is %f mH\n',L);
```

Scilab code Exa 8.13 Determining the inductance of coils for given circuit

```
clc;
// data taken from Ex A.7, fig A.16
N1=200; // number of turns in coil 1
f1=53.97*10^-3; // flux in outer limb containing
   coil 1
m1=5000; // mmf for coil 1
I1=m1/N1; // current in coil 1
N2=100; // number of turns in coil 2
f2=43.97*10^-3; // flux in outer limb containing
   coil 2
m2=1102; // mmf for coil 2
I2=m2/N2; // current in coil 2
L1=(N1*f1)/I1;
printf('Inductance for coil 1 is %f H\n',L1);
L2=(N2*f2)/I2;
printf('Inductance for coil 2 is %f H\n',L2);
```

Chapter 9

Appendix B

Scilab code Exa 9.3 Determining phase and line current power factor total active and reactive power for star and delta connected load

```
1  clc;
2  vl=400; // line voltage
3  z=10+7.5*%i; // load impedance per phase
4  disp('For star connected load');
5  vp=vl/sqrt(3); // phase voltage
6  ip=vp/abs(z);// phase and line current are same in
       the case of star connected load
7  an=atand(-imag(z),real(z));
8  pf=cosd(an);
9  P=sqrt(3)*vl*ip;
10 pa=sqrt(3)*vl*ip*pf;
11 pr=-sqrt(3)*vl*ip*sind(an);
12 printf('Phase and line currents are %f A\n',ip);
13 printf('Power factor is %f lagging \n',pf);
14 printf('Total volt ampere is %f VA\n',P);
15 printf('Total active power is %f W\n',pa);
16 printf('Total reactive power is %f VAr\n',pr);
17 disp('For delta connected load');
18 vp=vl // phase voltage and line voltage are same in
       the case of star connected load
```

```
ip=vp/abs(z);
il=ip*sqrt(3);
an=atand(-imag(z),real(z));
pf=cosd(an);
P=sqrt(3)*vl*il;
pa=sqrt(3)*vl*il*pf;
pr=-sqrt(3)*vl*il*sind(an);
printf('Phase current is %f A\n',ip);
printf('Line current is %f A\n',il);
printf('Power factor is %f lagging\n',pf);
printf('Total volt ampere is %f VA\n',P);
printf('Total active power is %f W\n',pa);
printf('Total reactive power is %f VAr\n',pr);
```

Scilab code Exa 9.4 Determining per phase circuit parameters

```
clc;
il=48; // load current(leading)
p=30; // load power in KW
vl=500; // line voltage
f=50; // supply frequency
pf=(p*1000)/(sqrt(3)*vl*il);
vp=vl/sqrt(3); // phase voltage
zp=vp/il; // magnitude of phase impedance
rp=zp*pf;
// since current is leading other parameter must be
   a capacitor
xc=zp*sqrt(1-pf^2); // reactance
c=(10^6)/(2*%pi*f*xc);
disp('circuit parameters are');
printf('Load resistance is %f ohm\n',rp);
printf('Load capacitance is %f micro farad',c);
```

Scilab code Exa 9.5 Finding total line current power factor total and reactive power

```
clc;
zs=10+15*%i; // star connected load per phase
zd=12-15*%i; // delta connected load per phase
vl=400; // supply line voltage
disp('case a');
// converting delta connected load to star connected
    load
zd=zd/3;
vp=vl/sqrt(3);
i1=vp/zs; // line current in star connected load
i2=vp/zd; // line current in delta connected load
i=abs(i1+i2);
printf('Total line current is %f A\n',i);
an=atand(imag(i1+i2),real(i1+i2));
pf=cosd(an);
P=(sqrt(3)*vl*i*pf);
pr=sqrt(3)*vl*i*sqrt(1-pf^2);
printf('Power factor is %f leading\n',pf);
printf('Total power is %f W\n',P);
printf('Total reactve power is %f VAr',pr);
```

Scilab code Exa 9.6 Determining input power line current power factor and shaft power

```
clc;
w1=85; // reading of wattmeter 1;
w2=35; // reading of wattmeter 2;
P=w1+w2; // total input power
n=0.85; // efficiency of motor
vl=1100; // supply voltage
pf=cosd(atand((sqrt(3)*(w1-w2))/(w1+w2)));
il=(P*1000)/(sqrt(3)*vl*pf); // line current
```

```
ps=n*P;
printf('Input power is %f KW\n',P);
printf('Line current is %f A\n',il);
printf('power factor is %f lagging\n',pf);
printf('shaft power is %f KW',ps);
```

Scilab code Exa 9.7 Determining no load losses and no load power factor

```
clc;
w1=2000; // reading of wattmeter 1 under no load
w2=-400; // reading of wattmeter 2 under no load,
   since the connections are reversed that is why
   negative sign
theta=atand((sqrt(3)*(w1-w2))/(w1+w2));
pl=w1+w2;
pf=cosd(theta);
printf('No load losses are %f W\n',pl);
printf('No load power factor is %f lagging',pf);
```

Scilab code Exa 9.8 Calculating reading of wattmeters and input power to load

```
clc;
vl=230; // line voltage
f=50; // frequency of supply
c=100*10^-6; // value of capacitance in each phase
vp=230/sqrt(3); // phase voltage
zp=1/(2*%pi*f*c); // phase impedance
il=vp/zp; // line current
// value of cos(theta) is taken from figB.15
w1=vl*il*cosd(120);
w2=vl*il*cosd(60);
printf('Reading of wattmeter 1 is %f W\n',w1);
```

```
12 printf('Reading of wattmeter 2 is %f W\n',w2);
13 p=w1+w2;
14 printf('Total input power is %f W',p);
```