جامعة بيرزيت

BIRZEIT UNIVERSITY

Faculty of Engineering and Technology

Electrical and Computer Engineering Department

ELECTRICAL MACHINES

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Section: 1

Introduction:

induction motor or asynchronous motor is an AC electric motor that makes kinetic energy from electrical energy.

induction Motor Construction

A) Stator

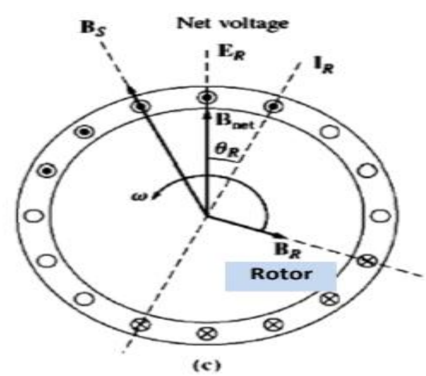
It is the stationary part and is composed of three sets of windings distributed in the stator slots and displaced 120°(electrical)in space. Its station is the same as that of a Synchronous machine. It is connected to an AC power supply. When AC voltage is applied to these windings, it generates a rotating magnetic field.

B: Rotor

is the rotating part and consists of a stack of insulated laminations. The rotor is placed in the stator pat and has free rotate.

Basic Induction Motor Concepts:

Because the current that moves in the motor becomes a uniform magnetic field by the stator called (Bs) which makes a speed for the motor (synchronous speed)



$Nsncs = \frac{120(fe)}{p}$ where is (*fe*) is t electrical frequency (P) is number of poels

We will have a maximum induced voltage when (relative velocity is prandial to Bs)

eind=(v × Bs).L

the concept of rotor slip:

Slip Speed is the difference between the synchronous speed and the rotor mechanical speed

Nslip=Nsync-Nm

The Slip(s): is the relative speed expressed per unit or as a percentage of synchronous speed

$S=\frac{\text{Nsync}-\text{Nm}}{Nsync} \times 100\%$

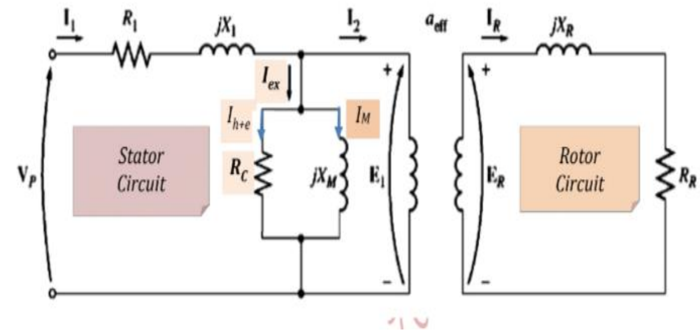
When s=0 then the rotor turns at synchronous speed

When S=1 the rotor is stationary or blocked; the stall condition

Then, the mechanical speed be expressed in terms of the synchronous speed and the slip as:

Nm=Nsync*(1-S) or Wm=Wsnyc *(1-S)

The equivalent circuit of an induction Motor:

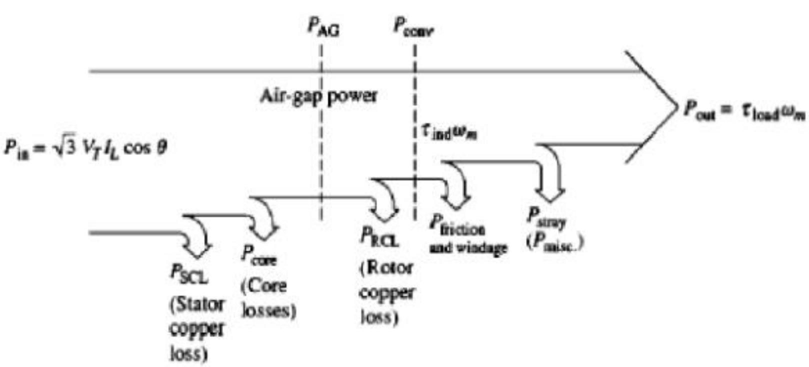


Where:

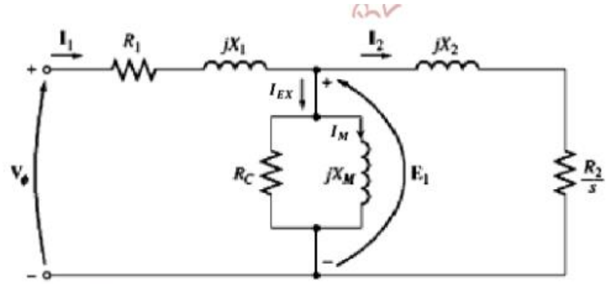
Vp= the rms value, R1:the stator winding restince ,Rc:the core rectince ,Rr=the rotor ricentce, Xm=magnetizing inductance ,x1 the stator inductance the rotor inductance

The final equivalent circuit is similar to the transformer's equivalent circuit, but it is secondary is short-circuited and secondary resistance is dependent on the slip

Power Losses and Power-Flow Diagram



The final equivalent circuit



The current input

$I1=\frac{V\emptyset}{Zeq}$ where $Zeq=((\frac{R2}{s}+ jx2) //(Rc+jXm)) +(R1+Jx1)$

Power laws

$Pin=V\emptyset I1 \cos(\theta)$ or $Pin= \sqrt{3}$ VT Iline $\cos(\theta)$

Pscl=3(I1)^2 R1 , Pcore= 3(E1)^2 (1/RC), PAG=Pin-Pscl-Pcore, Prcl=3(I2)^2 (R2/S), OR Prcl=S*PAG , Pconv= PAG-Prcl ,

Pout=Pconv-PFW-Pstary , Pconv=(1-S)*PAG induced (developed) torqueis:

$Jind = \frac{Pconv}{wm}$, $Jind=\frac{PAG}{WSYNC}$, $jload=\frac{POUT}{WM}$, Jloss=Jind-Jload ;

Code:

```
s=-1.0011:0.0061:2.001;

 vl=380;
vo=vl/sqrt(3);
p=8;
f=50;
xm=50*i;
x1=0.4*i;
x2=0.5*i;
R1=0.05+(0.07*5);
R2=0.13+(0.09*5);
n=(120.*(f))./p;%SPEED IN RPM
nm=(1-s).*n;
w=(n.*2.*pi)./60;%SPEED IN RAD/S
wm =(1-s).*w  ;
R2s=(R2)./(s);

z1 = (R2s)+x2;  % R2/s + jx2
 z2 = (z1.*xm)./(z1+xm); %z1//Xm
 Zeq = x1 + R1+ z2  ;
 Ieq = vo./ Zeq;

Pin = (sqrt(3).*vl).*(abs(Ieq)).*(cos(phase(Ieq)));
 Pscl  = 3.*(abs(Ieq).^2)*R1;
 Pag=Pin-Pscl;% pcore =0
 Prcl=s.*Pag;
 pconv=(1-s).*Pag;
 Pout = Pin - (pconv)
Torq = pconv./wm ;
```

The above code is the function that I use for the project and I use the function for every part

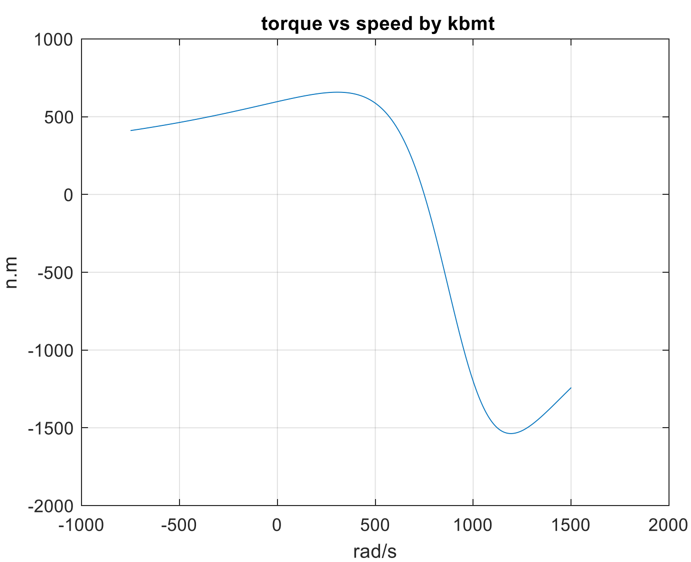
a)

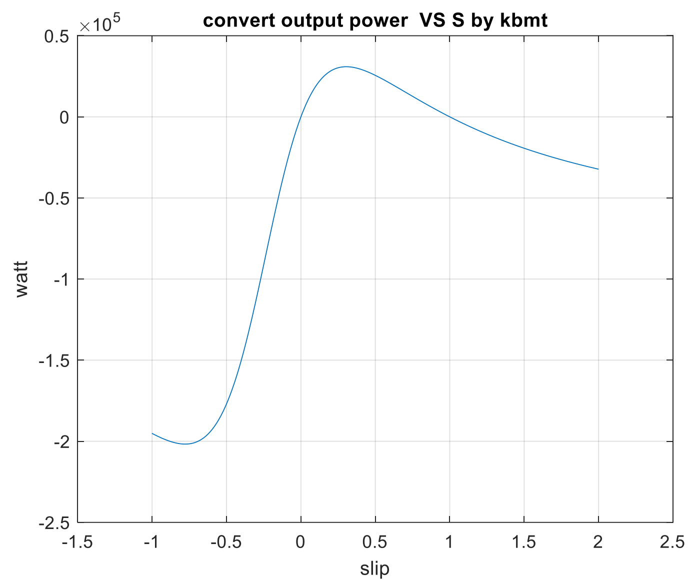
code:

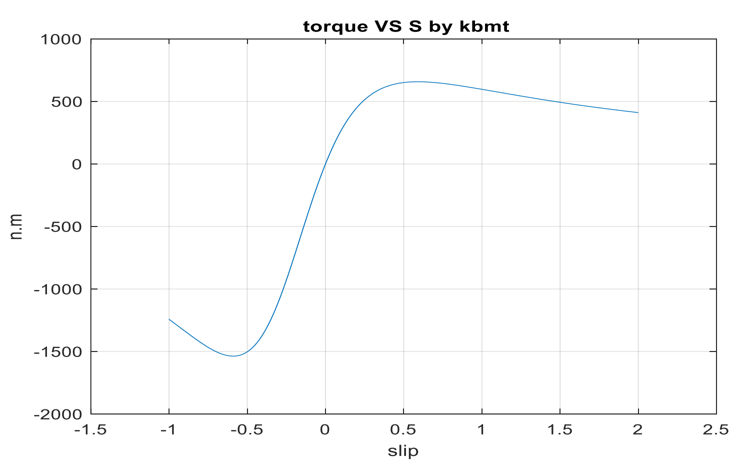
with that code above

```
figure
plot(nm,Torq) ;
title(' torque vs speed by kbmt');
xlabel('rad/s');
ylabel('n.m');
grid on
```

```
figure
plot(s,Torq) ;
title(' torque VS S by kbmt');
xlabel('slip');
ylabel('n.m');
grid on

figure
plot(s,pconv) ;
title(' convert output power  VS S by kbmt ');
xlabel('slip');
ylabel('watt')
grid on
```







Explanation:

When the motor is initially starting, the motor can produce its highest torque. in the first graph, we see that when the speed increases the torque will decrease, and if we look at the torque-induced law

Jind = $\frac{Pconv}{wm}$ we will see that when wm increases the torque decreases

And wm depend on s when wm=(1-s)*wsync and the same for torque with slip

We see the torque increase with slip.

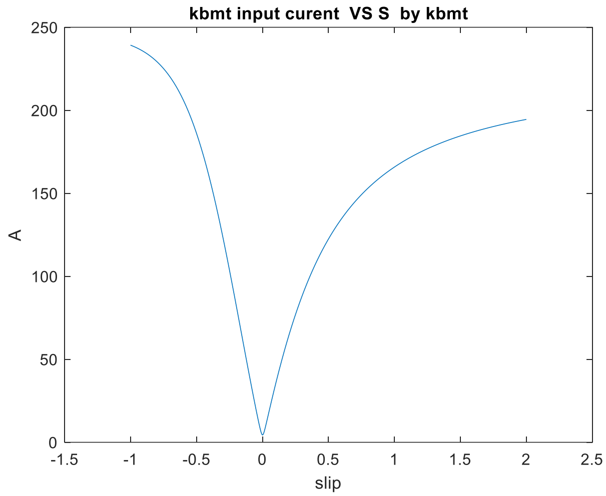
About pconv vs slip, the power will increase with slip and we can check that by pconv=s* page so every time the slip becomes larger the converted power will increase.

Also before the we can see that he genaret the power but after zero it work like a motor

b)

code:

```
figure;
 plot(s, abs(Ieq));
title('kbmt input curent  VS S  by kbmt');
xlabel('slip');
ylabel('A');
 figure
 plot(nm, abs(Ieq));
title('kbmt output curent VS speed  by kbmt ');
xlabel('rad/s');
ylabel('A');
```

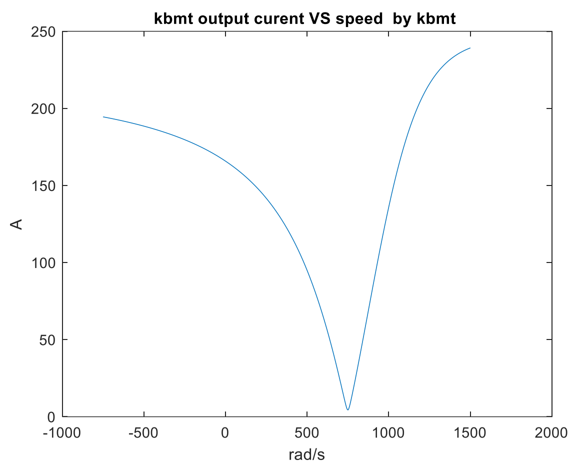


explanation:

we see at the start we have hight current and that because the rotor at the start is stationary and because that there is no electrical force and when the rotor start to move the current will dgrease

when load increases the slip increases so the rotor starts to move and the speed increases also the current increase

and we can see when between -1-0 the indction motor work as genareter and from 1-0 wrork as a motor



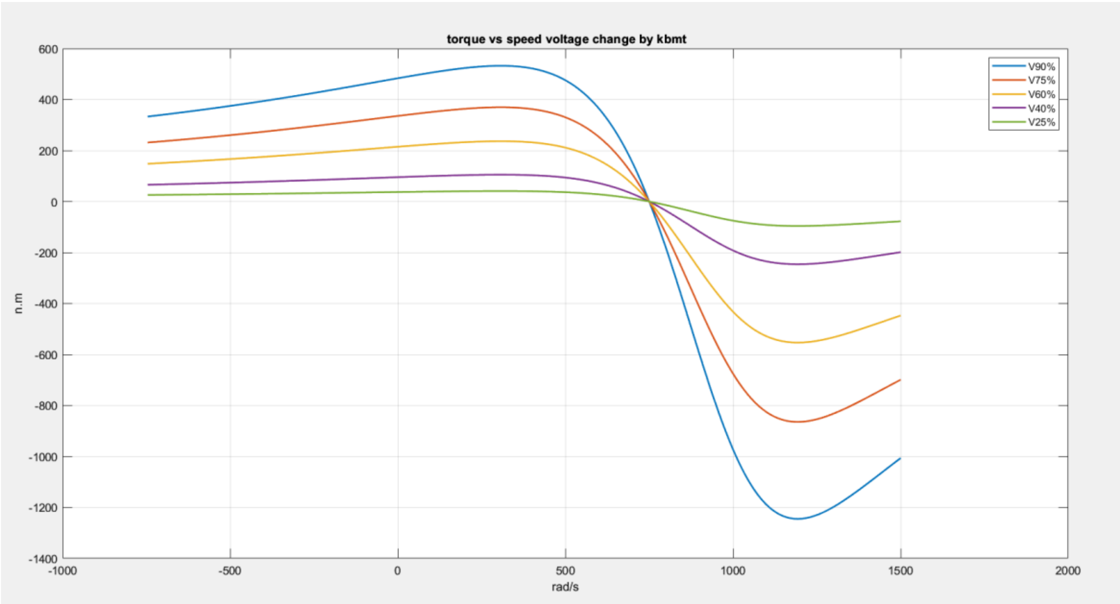
c)

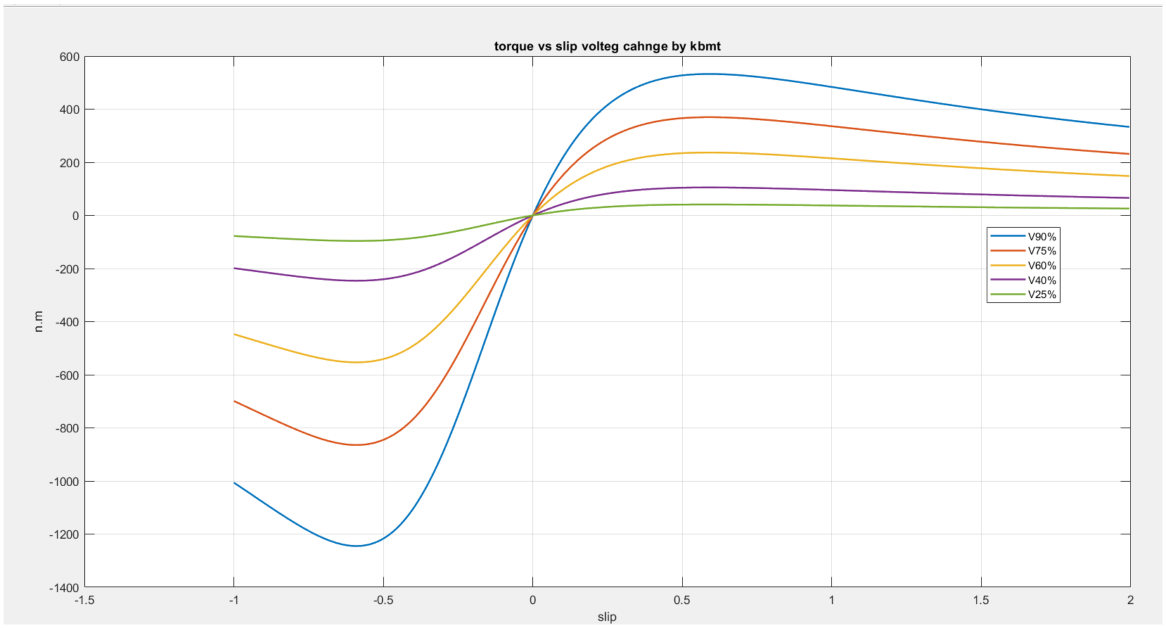
```
vll = [vl*0.9;
vl*0.75;
vl*0.6;
vl*0.4;
vl*0.25];

vth = vll./3^0.5;


for i = 1:size(vll)
```

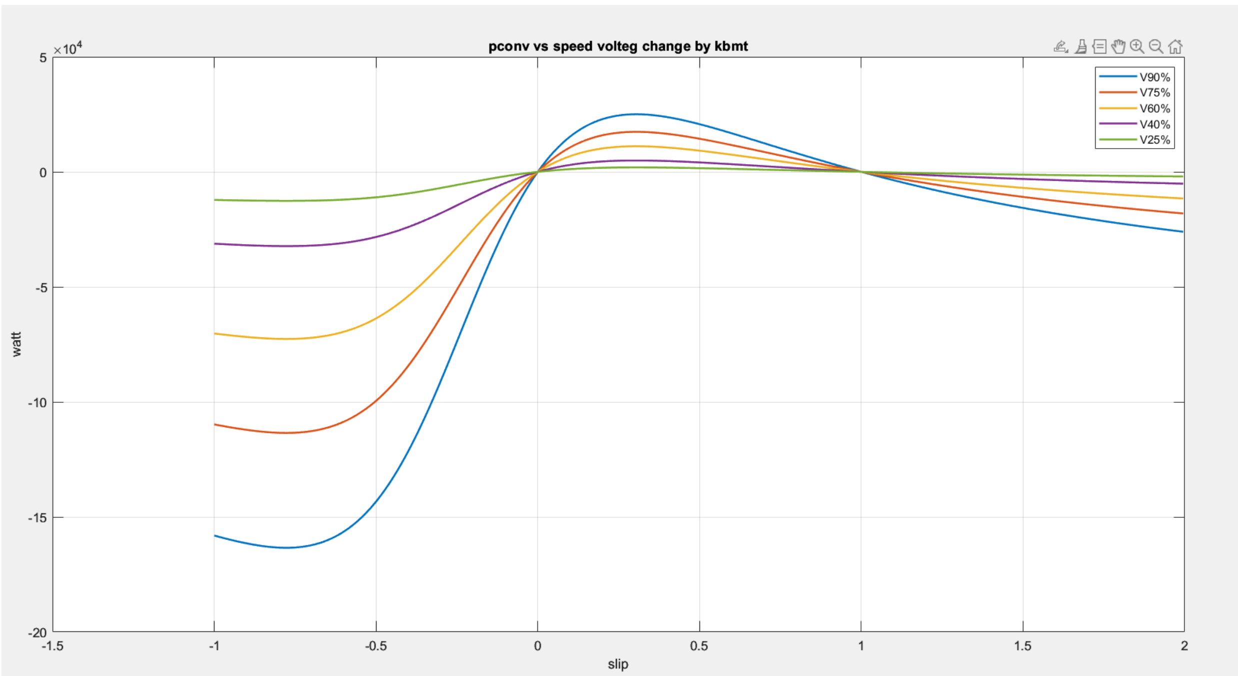


```
 [pconv_vl,Torq_vl]=turq_vl_change(vll(i),vth(i),s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2s);

 plot(nm,Torq_vl);

hold on
grid on
 end
 title(' torque vs speed voltage change by kbmt');
 xlabel('rad/s');
 ylabel('n.m');
 legend('V90%','V75%','V60%','V40%','V25%');

 figure
 for i = 1:size(vll)
 [pconv_vl,Torq_vl]=turq_vl_change(vll(i),vth(i),s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2s);

 plot(s,Torq_vl);

hold on
grid on
  end
  title(' torque vs slip volteg cahnge by kbmt ');
 xlabel('slip');
 ylabel('n.m');
  legend('V90%','V75%','V60%','V40%','V25%');



  figure
  for i = 1:size(vll)
 [pconv_vl, Torq_vl]=turq_vl_change(vll(i),vth(i),s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2s)

plot(s,pconv_vl);

hold on
grid on
  end
  title(' pconv vs speed volteg change by kbmt ');
 xlabel('slip');
 ylabel('watt');
  legend('V90%','V75%','V60%','V40%','V25%');
function [ pconv_vl,Torq_vl ]=turq_vl_change(vl,vo,s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2s);

z1 = (R2s)+x2;  % R2/s + jx2
 z2 = (z1.*xm)./(z1+xm); %z1//Xm
 Zeq = x1 + R1+ z2  ;
```

```
 Ieq = vo./ Zeq;
 i2 = (Ieq .* xm )./(xm+z1);
 Pin = (3^.5*vl).*abs(Ieq).*cos(phase(Ieq));
 Pscl  = 3.*abs(Ieq).^2*R1;
 Pag=Pin-Pscl;
 Prcl=s.*Pag;
 pconv_vl=(1-s).*Pag;;
 Pout_vl = Pin-pconv_vl;
 Torq_vl = pconv_vl./wm ;
end
```







Explanation:

To preduce the tourqe we need relitve motion between the stator and the rotor the relqtive motion indeuce volteg in the rotor and that wich the current flow so it is make the tourq for the motor we can see the tourq will be zero at 750 and that since it is the speed that need to treanced it to make the tourq

And we see every time we increase the volteg we need moor tourq from the motor

Since Ieq will increase so the pin increase so pconv increase and that why jind increase

I=v/zeq , pin= sqrt(3) *v*I*cos(phase) ,pconv=pin-prcl-pcore , jind=pconv/wm

About pconv vs speed when s=0 the rotor turn at a synchronous speed so fr =fe=0 when s=1 the rotor locked which means fr=fe and when we reduce the voltage the convert power will be less and I explain it above why will the pconv reduce

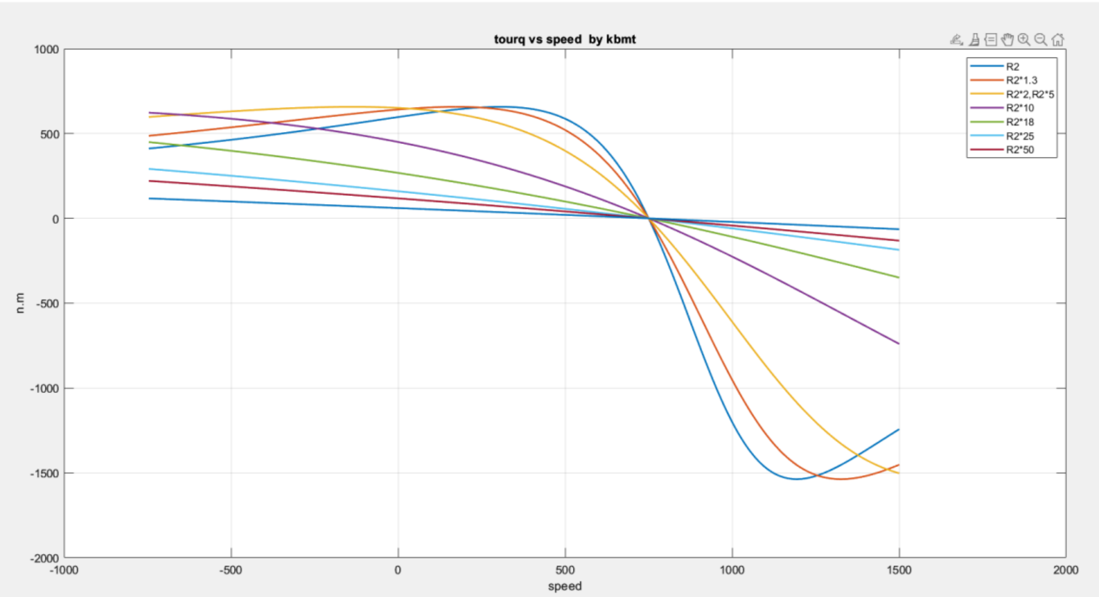
Also we can the motor genareat power before the zero and that because it is work as genareter and the power will be positive aft0 because it is work as motor

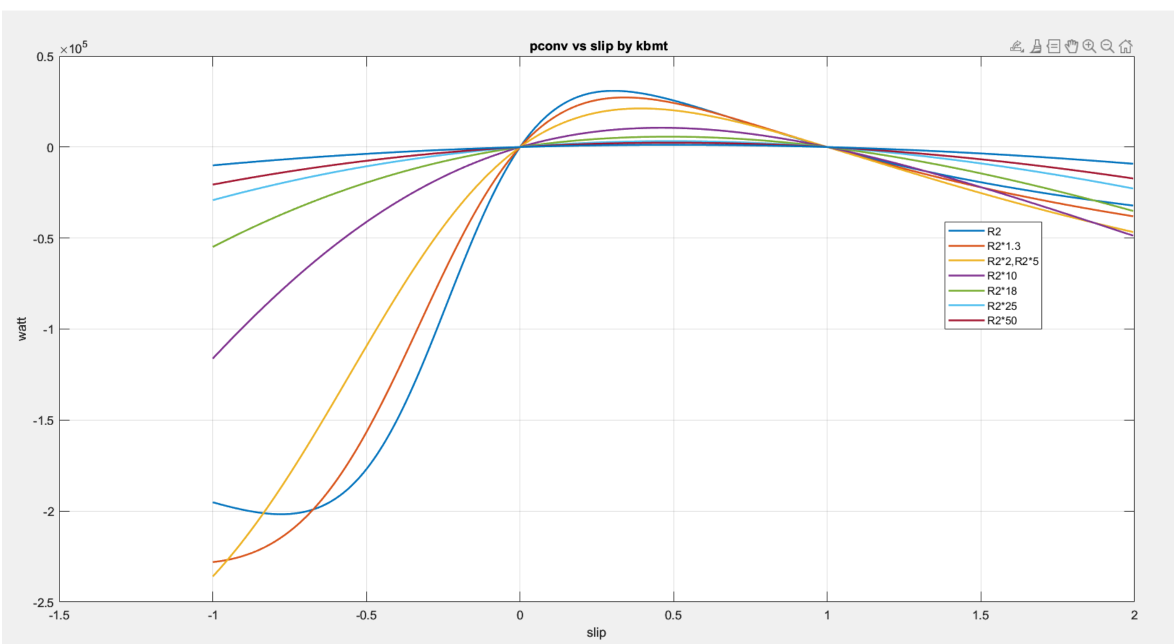
d)

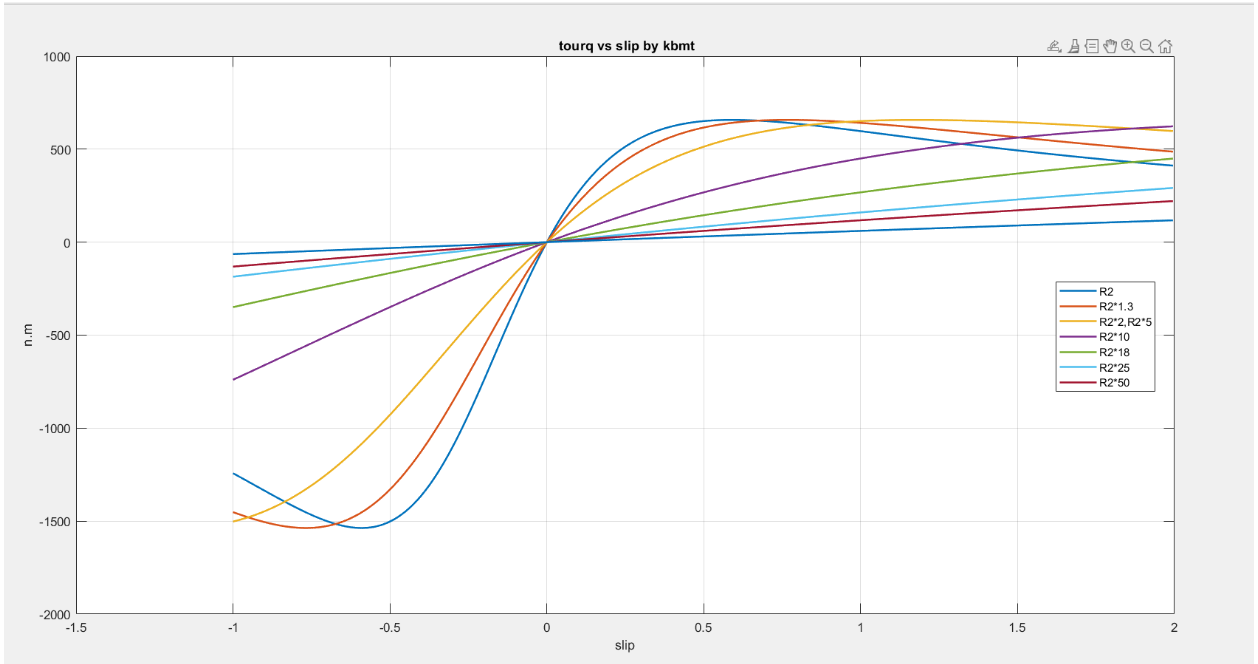
```
R2C=[R2 ;
    R2*1.3;
    R2*2;
    R2*5;
    R2*10;
    R2*18;
    R2*25;
    R2*50;];



figure
for i = 1:size(R2C);

 [Pout_vl,Torq_vl pconv_cR]=turq_R2_change(vl,vo,s,p,f,xm,x1,x2,R1,R2C(i),n,w,wm,nm);

 plot(nm,Torq_vl);

 hold on
grid on
end
title(' tourq vs speed  by kbmt ');
xlabel('speed')
ylabel('n.m')
 legend('R2','R2*1.3', 'R2*2,R2*5' ,'R2*10' ,'R2*18' ,'R2*25' ,'R2*50');


figure
for i = 1:size(R2C);

 [Pout_vl,Torq_vl pconv_cR]=turq_R2_change(vl,vo,s,p,f,xm,x1,x2,R1,R2C(i),n,w,wm,nm);

 plot(s,Torq_vl);
 hold on
grid on
end
title(' tourq vs slip by kbmt');
xlabel('slip');
ylabel('n.m');
```



```
 legend('R2','R2*1.3', 'R2*2,R2*5' ,'R2*10' ,'R2*18' ,'R2*25' ,'R2*50');
figure
for i = 1:size(R2C);

 [Pout_vl,Torq_vl pconv_cR]=turq_R2_change(vl,vo,s,p,f,xm,x1,x2,R1,R2C(i),n,w,wm,nm);

 plot(s,pconv_cR);
 hold on
grid on
end
title('  pconv vs slip by kbmt ')
xlabel('slip');
ylabel('watt');
 legend('R2','R2*1.3', 'R2*2,R2*5' ,'R2*10' ,'R2*18' ,'R2*25' ,'R2*50');


function [ Pout_vl  Torq_vl pconv_cR
]=turq_R2_change(vl,vo,s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm);
 R2s = R2./s ;
 z1 = (R2s)+x2;  % R2/s + jx2
 z2 = (z1.*xm)./(z1+xm); %z1//Xm
 Zeq = x1 + R1+ z2  ;
 Ieq = vo./ Zeq;
 i2 = (Ieq .* xm )./(xm+z1);
Pin = (3^.5*vl).*abs(Ieq).*cos(phase(Ieq));
 Pscl  = 3.*abs(Ieq).^2*R1;
 Pag=Pin-Pscl;
 Prcl=s.*Pag;
 pconv_cR=(1-s).*Pag;;
 Pout_vl = Pin -(pconv_cR);
 %Pscl+Pag+Prcl
 Torq_vl = pconv_cR./wm ; end
```


tourq vs speed by kbmt
R2
R2*1.3
R2*2,R2*5
R2*10
R2*18
R2*25
R2*50
n.m
speed
1000
500
0
-500
-1000
-1500
-2000
-1000
-500
0
500
1000
1500
2000


pconv vs slip by kbmt
$\times 10^5$
R2
R2*1.3
R2*2,R2*5
R2*10
R2*18
R2*25
R2*50
watt
slip
0.5
0
-0.5
-1
-1.5
-2
-2.5
-1.5
-1
-0.5
0
0.5
1
1.5
2



explanation:

every time we increase R2 we need less tourq from the motor

wince increase R2 the zeq will increase so the current will decrease which if we use the function that we approve that if we increase the voltage the jind will increase we will find the tourq will decrease as we increase R2 About pconv vs speed when s=0 the rotor turn at synchronous speed so fr =fe=0 when s=1 the rotor locked that mean fr=fe and when we reduce the voltage the convert power will be less and I explain it above why will the pconv reduceand we cans see how ever we change the volteg or R2 the motor will still work as the genreater before the 0 and motor after 0

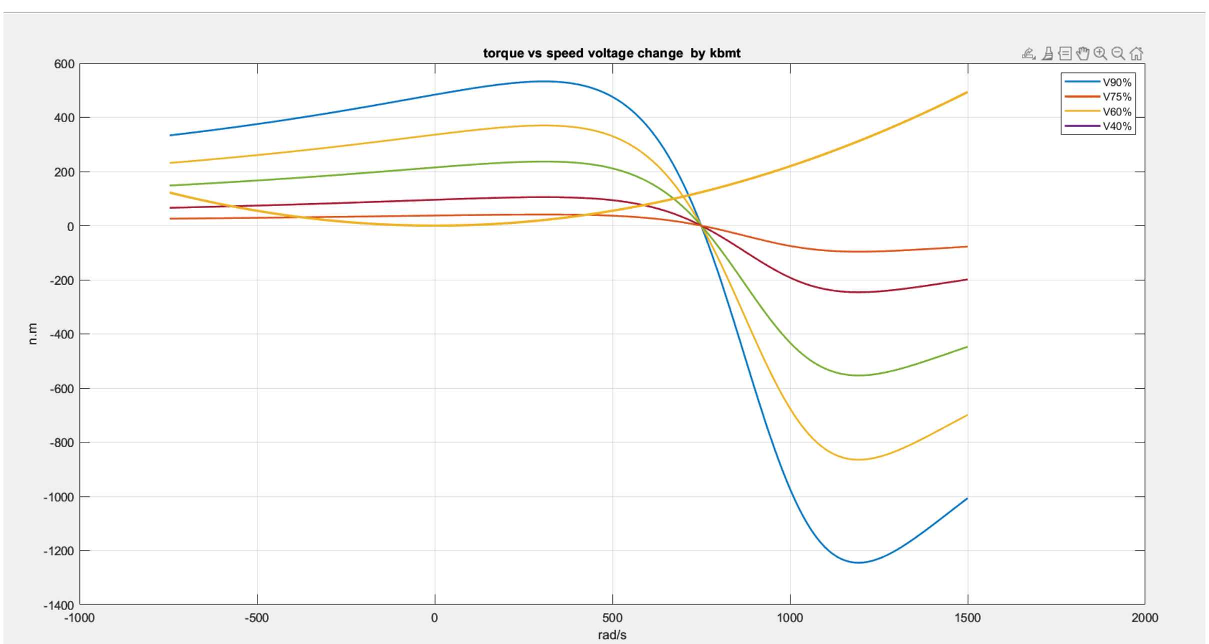
e) from the draw above the maximum torque will be between R2 and R2*1.3

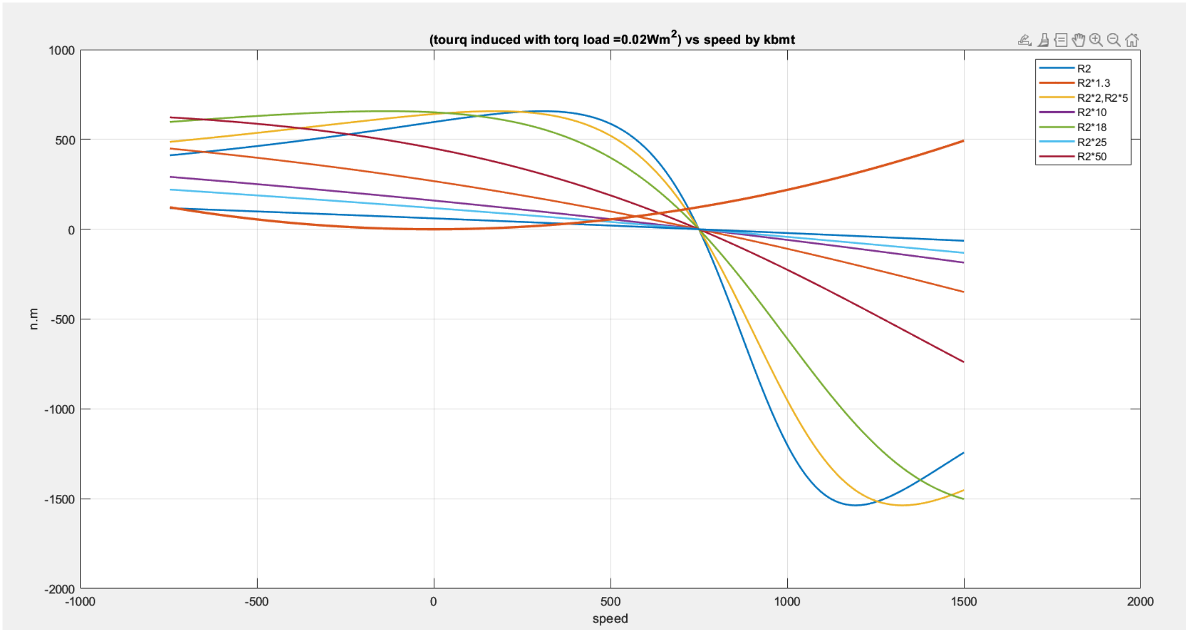
F)

```
vll = [vl*0.9;
vl*0.75;
vl*0.6;
vl*0.4;
vl*0.25];

vth = vll./3^0.5;
 for i = 1:size(vll)
```

```
[Torq_vl,Torq_load]=turq_vl_change_with_load(vll(i),vth(i),s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,
R2s);


 plot(nm,Torq_vl);

 hold on
 plot(nm,Torq_load);

 grid on
 end

 title(' torque vs speed voltage change  by kbmt ');
 xlabel('rad/s');
 ylabel('n.m');
 legend('V90%','V75%','V60%','V40%' );



R2C=[R2 ;
    R2*1.3;
    R2*2;
    R2*5;
    R2*10;
    R2*18;
    R2*25;
    R2*50;]

 figure
for i = 1:size(R2C);

 [Torq_load,Torq_vl]=turq_R2_change_with_load(vl,vo,s,p,f,xm,x1,x2,R1,R2C(i),n,w,wm,nm)
 plot(nm,Torq_vl);
  hold on
 plot(nm,Torq_load)
grid on
end
title(' (tourq induced with torq load =0.02Wm^2) vs speed by kbmt' );
xlabel('speed')
ylabel('n.m')
 legend('R2','R2*1.3', 'R2*2,R2*5' ,'R2*10' ,'R2*18' ,'R2*25' ,'R2*50');
function
[Torq_vl,Torq_load]=turq_vl_change_with_load(vl,vo,s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2s);

 z1 = (R2s)+x2;  % R2/s + jx2
```

```
 z2 = (z1.*xm)./(z1+xm); %z1//Xm
 Zeq = x1 + R1+ z2  ;
 Ieq = vo./ Zeq;
 i2 = (Ieq .* xm )./(xm+z1);
 Pin = (3^.5*vl).*abs(Ieq).*cos(phase(Ieq));
 Pscl  = 3.*abs(Ieq).^2*R1;
 Pag=Pin-Pscl;
 Prcl=s.*Pag;
 pconv=(1-s).*Pag;;
 Pout_vl = Pin -(pconv) ;
 Torq_vl = pconv./wm ;
 Torq_load =(0.02.*(wm.^2));
end
function [Torq_load Torq_vl ]=turq_R2_change_with_load(vl,vo,s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm);
 R2s = R2./s ;
 z1 = (R2s)+x2;  % R2/s + jx2
 z2 = (z1.*xm)./(z1+xm); %z1//Xm
 Zeq = x1 + R1+ z2  ;
 Ieq = vo./ Zeq;
 i2 = (Ieq .* xm )./(xm+z1);
 Pin = (3^.5*vl).*abs(Ieq).*cos(phase(Ieq));
 Pscl  = 3.*abs(Ieq).^2*R1;
 Pag=Pin-Pscl;
 Prcl=s.*Pag;
 pconv=(1-s).*Pag;;
 Pout_vl = Pin -(pconv) ;
 Torq_vl = pconv./wm ;
Torq_load= (0.02.*(wm.^2));;end
```





Explation:

we can see that when we increase R2 take less tourq to make the motor work

also when we increase the volteg s the motor will need more jind

and we can see when add the load the more the volteg small the more that will work faster

also if we increase R2 we need less tourq to make the load start but how ever the load will not move until jind>jload

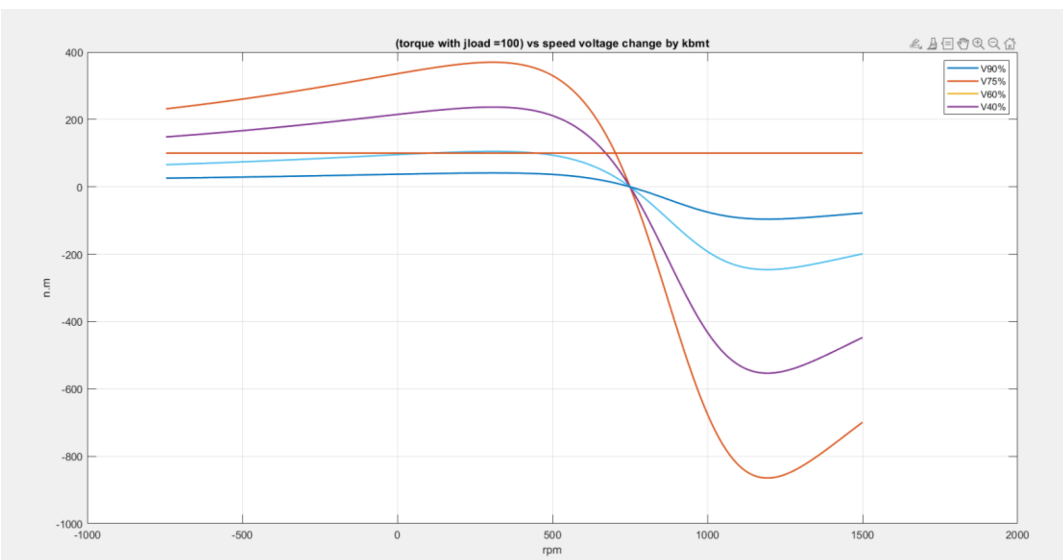
g)

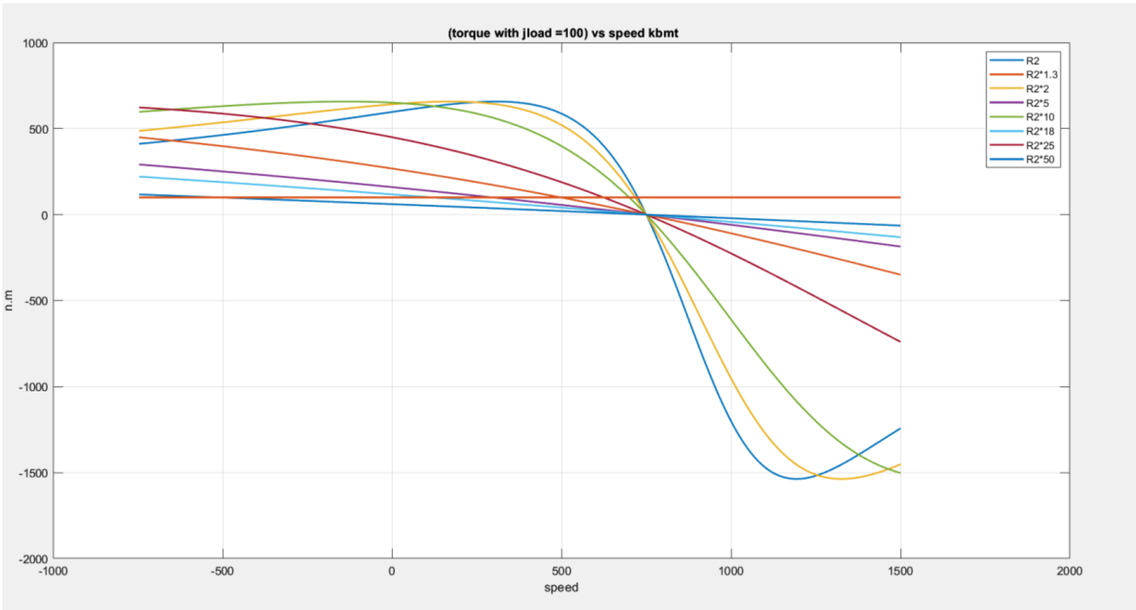
```
vll = [vl*0.9;
vl*0.75;
vl*0.6;
vl*0.4;
vl*0.25];
```



```
vth = vll./3^0.5;
R2C=[R2 ;
    R2*1.3;
    R2*2;
    R2*5;
    R2*10;
    R2*18;
    R2*25;
    R2*50;]




for i = 1:size(vll)
 [Torq_vl,Torq_load]=turq_vl_change_with_load_h(vll(i),vth(i),s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2s,torqh);


plot(nm,Torq_vl,"LineWidth",1.5)

plot(nm,Torq_load,"LineWidth",1.5);


 hold on
 grid on
 end


 title('kbmt (torque with jload =100) vs speed voltage change ');
 xlabel('rpm');
 ylabel('n.m');
 legend('V90%','V75%','V60%','V40%' );




figure
for i = 1:size(R2C);

 [Torq_load,Torq_vl]=turq_R2_change_with_load_h(vl,vo,s,p,f,xm,x1,x2,R1,R2C(i),n,w,wm,nm,R2s,torqh);
  plot(nm,Torq_vl ,"LineWidth",1.5);

  hold on
plot(nm,Torq_load,"LineWidth",1.5) ;
grid on
end
title('kbmt (torque with jload =100) vs speed');
xlabel('speed');
ylabel('n.m');
 legend('R2','R2*1.3', 'R2*2','R2*5' ,'R2*10' ,'R2*18' ,'R2*25' ,'R2*50');


function [Torq_vl,Torq_load]=turq_vl_change_with_load_h(vl,vo,s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2s,torqh);

 z1 = (R2s)+x2;  % R2/s + jx2
 z2 = (z1.*xm)./(z1+xm); %z1//Xm
 Zeq = x1 + R1+ z2  ;
```

```
 Ieq = vo./ Zeq;
 i2 = (Ieq .* xm )./(xm+z1);
 Pin = (3^.5*vl).*abs(Ieq).*cos(phase(Ieq));
 Pscl  = 3.*abs(Ieq).^2*R1;
 Pag=Pin-Pscl;
 Prcl=s.*Pag;
 pconv=(1-s).*Pag;;
 Pout_vl = Pin –(pconv) ;
 Torq_vl = pconv./wm ;
 Torq_load = torqh*ones(size(s));
end


function [Torq_load Torq_vl ]=turq_R2_change_with_load_h(vl,vo,s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2s,torqh);
 R2s = R2./s ;
 z1 = (R2s)+x2;  % R2/s + jx2
 z2 = (z1.*xm)./(z1+xm); %z1//Xm
 Zeq = x1 + R1+ z2  ;
 Ieq = vo./ Zeq;
 i2 = (Ieq .* xm )./(xm+z1);
 Pin = (3^.5*vl).*abs(Ieq).*cos(phase(Ieq));
 Pscl  = 3.*abs(Ieq).^2*R1;
 Pag=Pin-Pscl;
 Prcl=s.*Pag;
 pconv=(1-s).*Pag;;
 Pout_vl = Pin –(pconv) ;
 Torq_vl = pconv./wm ;
 Torq_load= torqh*ones(size(s));end
```





Explanation:

we can see that when we increase R2 take less tourq to make the motor work

also when we increase the volteg s the motor will need more jind

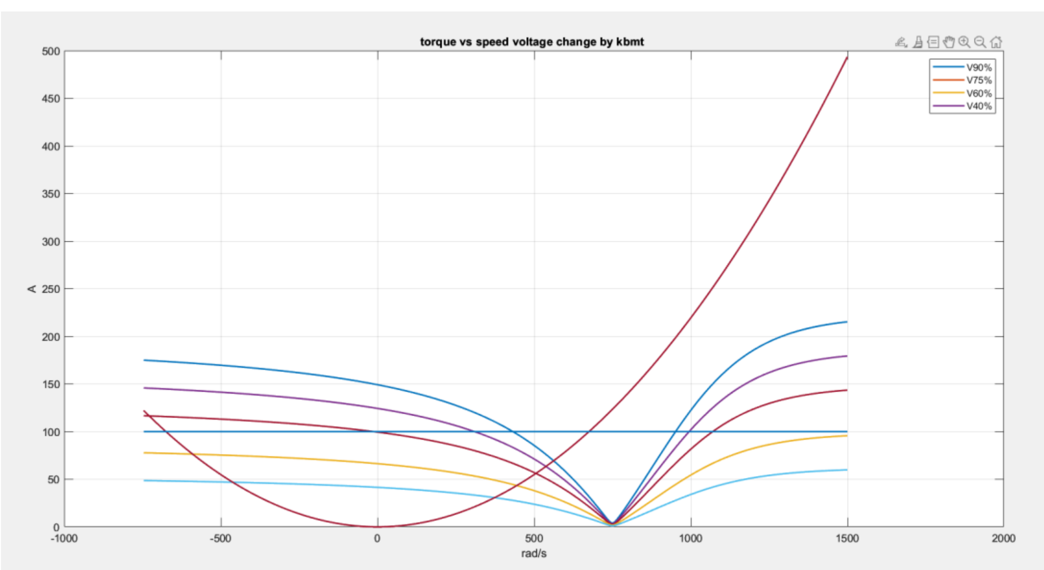
and we can see when we add the load that motor with different volteg will work in the same tourq but it will not when it be 0.25*vl because jind<jload

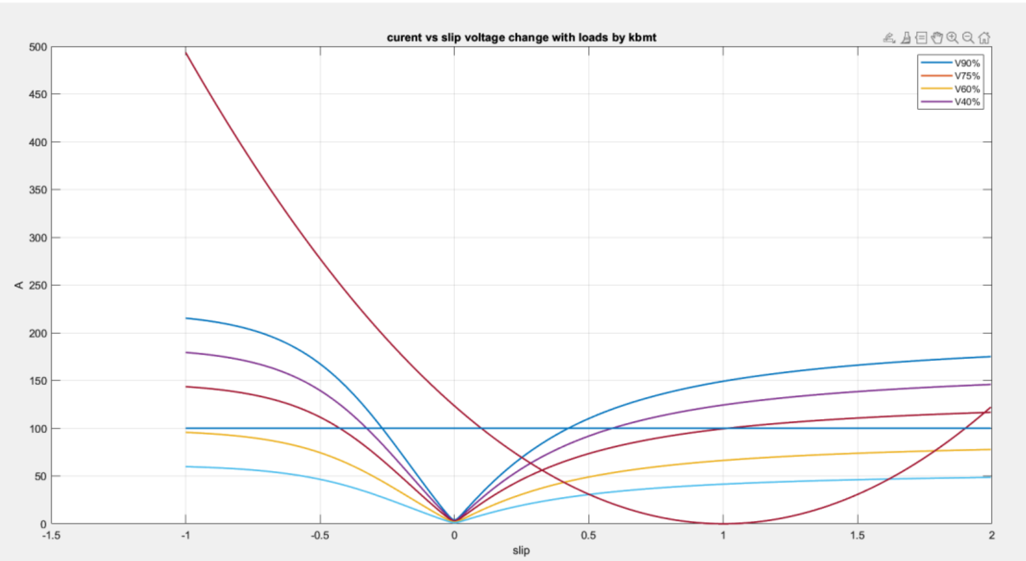
also if we increase R2 we need less tourq to make the load start but how ever the load will not move until jind>jload

H)

```
torqh = 100;
for i = 1:size(vll)
 [Ieq_h,Torq_load1,
Torq_load2]=turq_vl_change_with_load_final(vll(i),vth(i),s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2
s,torqh);


 plot(nm,abs(Ieq_h),"LineWidth",1.5);

 hold on
 plot(nm,Torq_load1,"LineWidth",1.5);
 hold on
 plot(nm,Torq_load2,"LineWidth",1.5);

 grid on
 end

 title('curent vs speed voltage change by kbmt  ');
 xlabel('rad/s');
 ylabel('A');
 legend('V90%','V75%','V60%','V40%' );



for i = 1:size(vll)
 [Ieq_h,Torq_load1,
Torq_load2]=turq_vl_change_with_load_final(vll(i),vth(i),s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2
s,torqh);


 plot(s,abs(Ieq_h),"LineWidth",1.5);

 hold on
 plot(s,Torq_load1,"LineWidth",1.5);
 hold on
 plot(s,Torq_load2,"LineWidth",1.5);
 grid on
 end

 title(' curent vs slip voltage change by kbmt ');
 xlabel('slip');
```

```
 ylabel('A');
 legend('V90%','V75%','V60%','V40%' );
function [Ieq_h,Torq_load1,
Torq_load2]=turq_vl_change_with_load_final(vl,vo,s,p,f,xm,x1,x2,R1,R2,n,w,wm,nm,R2s,torqh
);

 z1 = (R2s)+x2;  % R2/s + jx2
 z2 = (z1.*xm)./(z1+xm); %z1//Xm
 Zeq = x1 + R1+ z2  ;
 Ieq_h = vo./ Zeq;
 i2 = (Ieq_h .* xm )./(xm+z1);
 Pin = (3^.5*vl).*abs(Ieq_h).*cos(phase(Ieq_h));
 Pscl  = 3.*abs(Ieq_h).^2*R1;
 Pag=Pin-Pscl;
 Prcl=s.*Pag;
 pconv=(1-s).*Pag;;
 Pout_vl = Pin -(pconv) ;
 Torq_vl = pconv./wm ;
 Torq_load1 = (0.02.*(wm.^2));
 Torq_load2=  torqh*ones(size(s));
end
```





When we increase the current increase and we see when the load is vrible when the volteg is small ot need less current to work but if we but the constan vraible it will not work for all volteg until the volteg can breduce more than100A to make it work

Cancltion:

From draws above we can counsder that th higst tourqe for indctionmotor be when start and tourqe depand on volteage since when dcrease the volteg the tourqe will decreas and depndt on R2 so when we increase R2 the touque will decrease and when we increase the slip the tourqe will decraes

We can see also that when the load be varible it is depend on volteg were if we reduce the volteg it is take less tourq to make the motor start but if we increase the R2 it neede less tourq to start but we will have problem with heting and winding losess if we do that

But if we have constan load it will take the same tourq for all casese and the motor will not start until jind>jloda

Also we can consider when we increase the volteg the current will increase and if we add vrible tourq load it will take less current to start and it is will work before 500 rad/s but if we but constant tourq it will start at the samcurent and it will depend how much the tourq

We also can see that the current depend on the slip where it will decrease form -1 - 0 and the indction motor work as genraetar and from 0-1 work as a motor

we cans see how ever we change the volteg or R2 the motor will still work as the genreater before the 0 and motor after 0