EEE3091F

Induction Motor Project Report

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Signed:

Ankush Chohan (CHHANK001) Ashik John (JHNASH009)

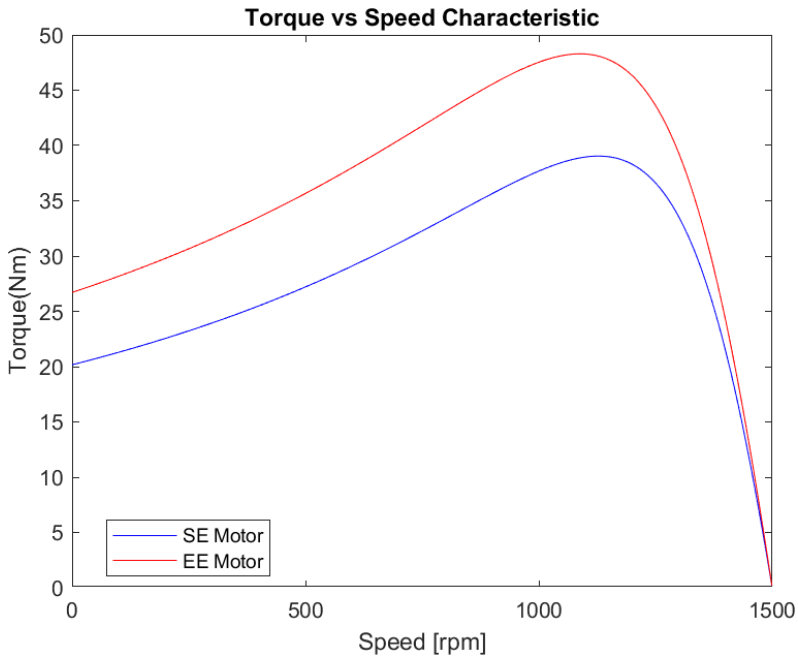
Date: 03/04/2023

Part A – Matlab Code

1.

	SE Motor	EE Motor
V_{th}	206.07 V	208.82 V
R_{th}	1.84 Ω	1.36 Ω
X_{th}	4.07 Ω	3.49 Ω

2.



(a) SE Motor: 20.17 Nm
EE Motor: 26.71 Nm

Starting torque can either be altered by changing the rotor resistance (increasing rotor resistance increases starting torque), or by changing the supply voltage (starting torque increases as supply voltage increases).

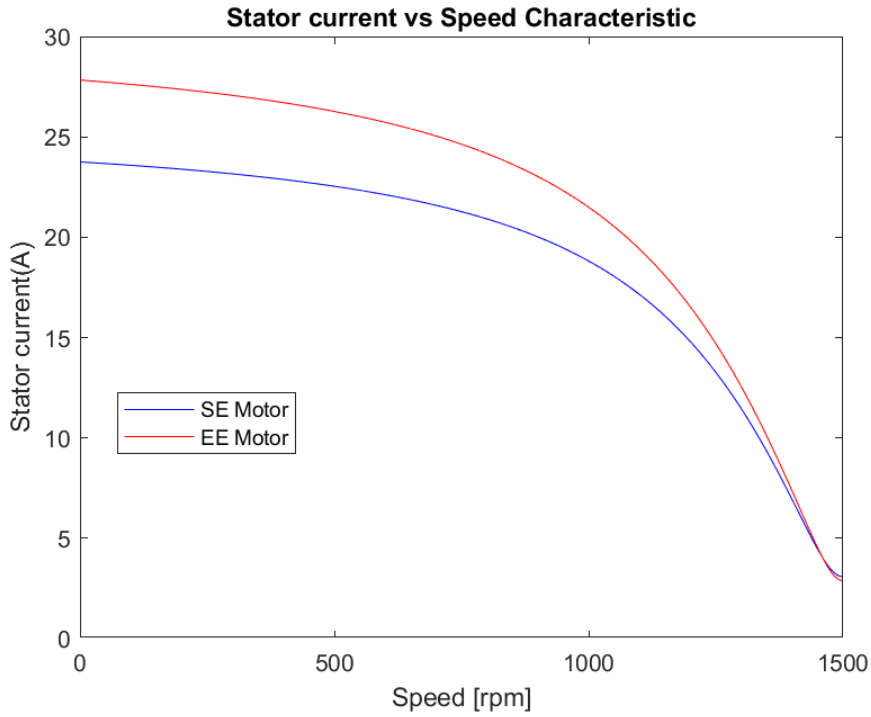
(b) SE Motor: 39.04 Nm
EE Motor: 48.29 Nm

This value can be altered by changing the supply voltage. Maximum torque is directly proportional to the square of the supply voltage.

(c) SE Motor: 1127 rpm
EE Motor: 1088 rpm

The speed at which the maximum torque occurs can be altered by changing the rotor resistance, by means of adding external winding resistance. Increasing the rotor resistance decreases the speed at which the maximum torque occurs.

3.



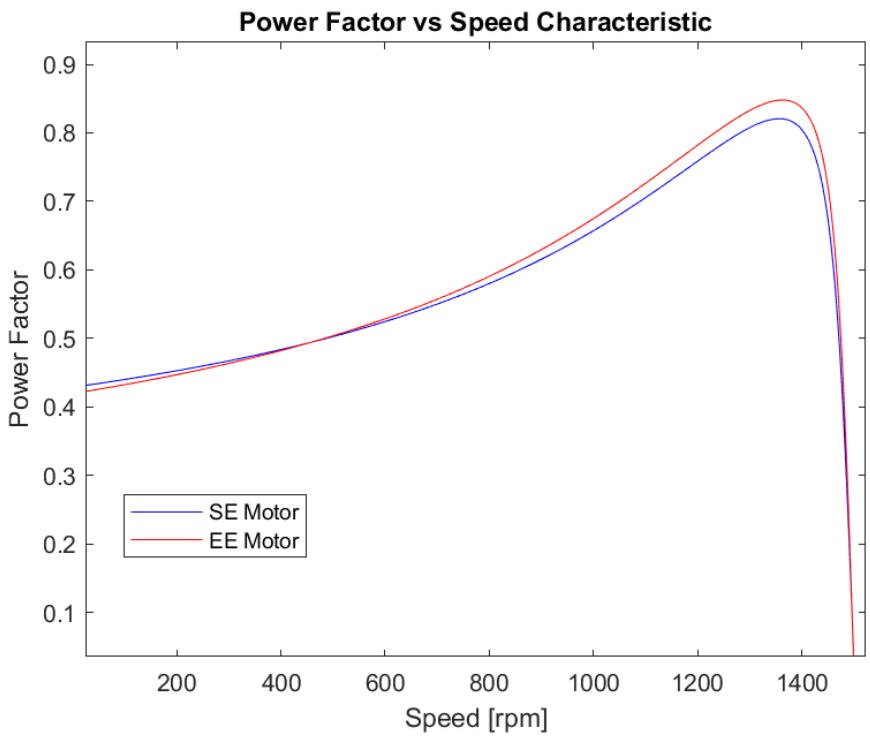
(a) The result is as expected, with start-up currents typically being about 500% the full-load currents. This is because at start up, the slip is close to 1, and the impedance of the circuit will be low, drawing large amounts of current. It can be seen that the start up current of the Energy Efficient motor is about 4A higher than that of the standard motor. This is expected, since the stator and rotor resistances, as well as reactance's of the EE motor is lower than the SE motor. Lower Impedance will draw higher current on start-up.

(b) Regardless of the load at start-up, the stator current will be the same, this is because the rotor speed will be close to zero, meaning the slip would be close to 1. With a slip of 1, the impedance associated with the rotor and parallel branch of the equivalent circuit will be low. The load does not affect the rotor speed at start-up, as the rotor will always start from rest.

(c) SE Motor: 16.59 A
EE Motor: 19.69 A

(d) SE Motor: 3.10 A
EE Motor: 2.89 A

4.



(a) SE Motor: 0.429
EE Motor: 0.419

(b) SE Motor: 0.7196
EE Motor: 0.7200

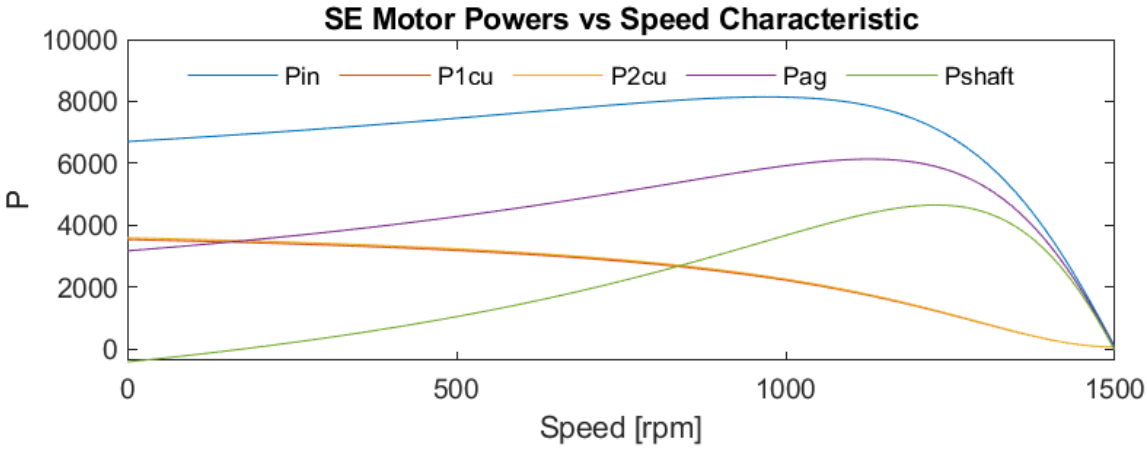
(c) SE Motor: 0.044
EE Motor: 0.037

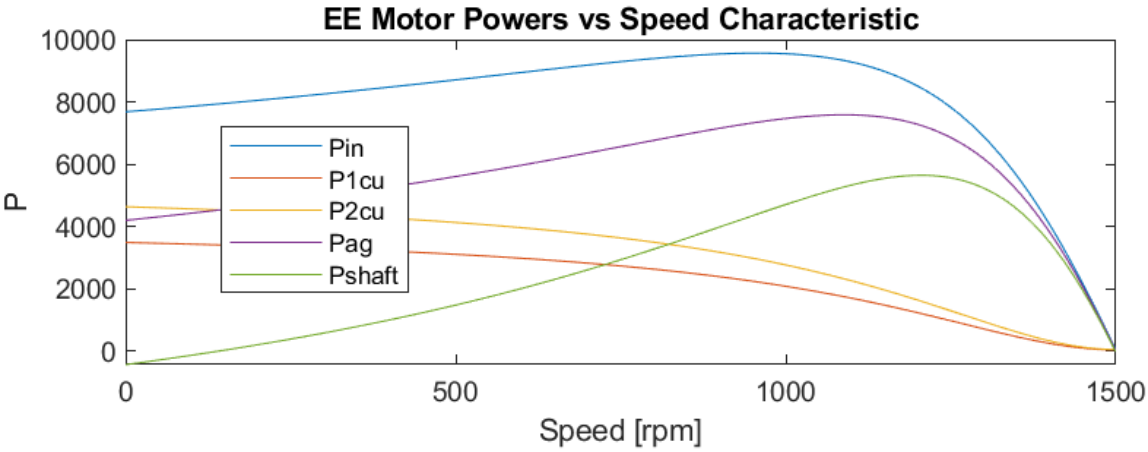
The results are as expected. At high speeds, the impedance of the rotor branch becomes very high due to the low slip level. As a result, current will only be drawn by the magnetising branch, and thus the circuit will be largely inductive. The high inductance leads to a very low power factor. The magnetising inductance of the EE motor is higher, so it will have a lower power factor.

(d) SE Motor: 0.821
EE Motor: 0.848

(e) SE Motor: 1357 rpm
EE Motor: 1363 rpm

5.





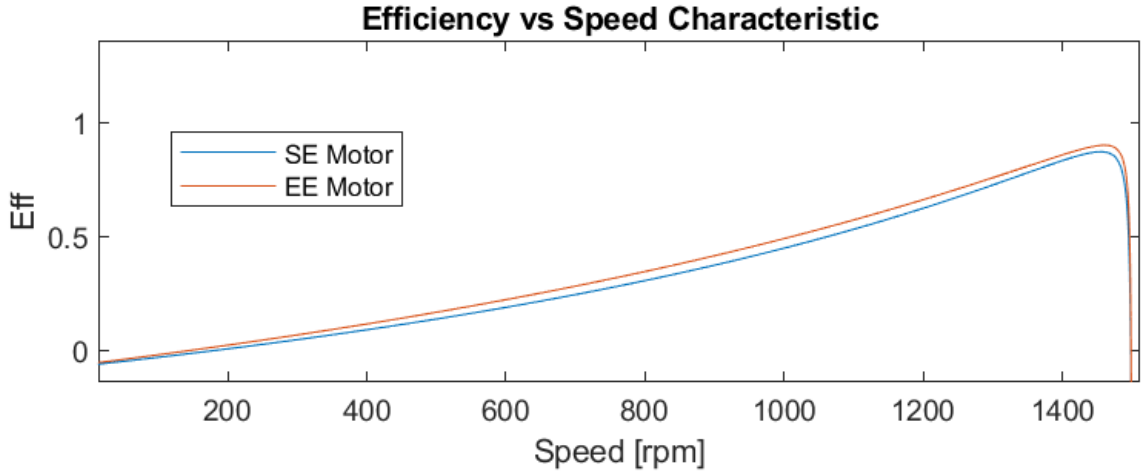
(a)

	SE Motor	EE Motor
Stator Copper Loss	3531.63 W	3485.26 W
Rotor Copper Loss	3590.86 W	4633.07 W

(b)

	SE Motor	EE Motor
Stator Copper Loss	59.98 W	37.58 W
Rotor Copper Loss	60.98 W	49.95 W

6.

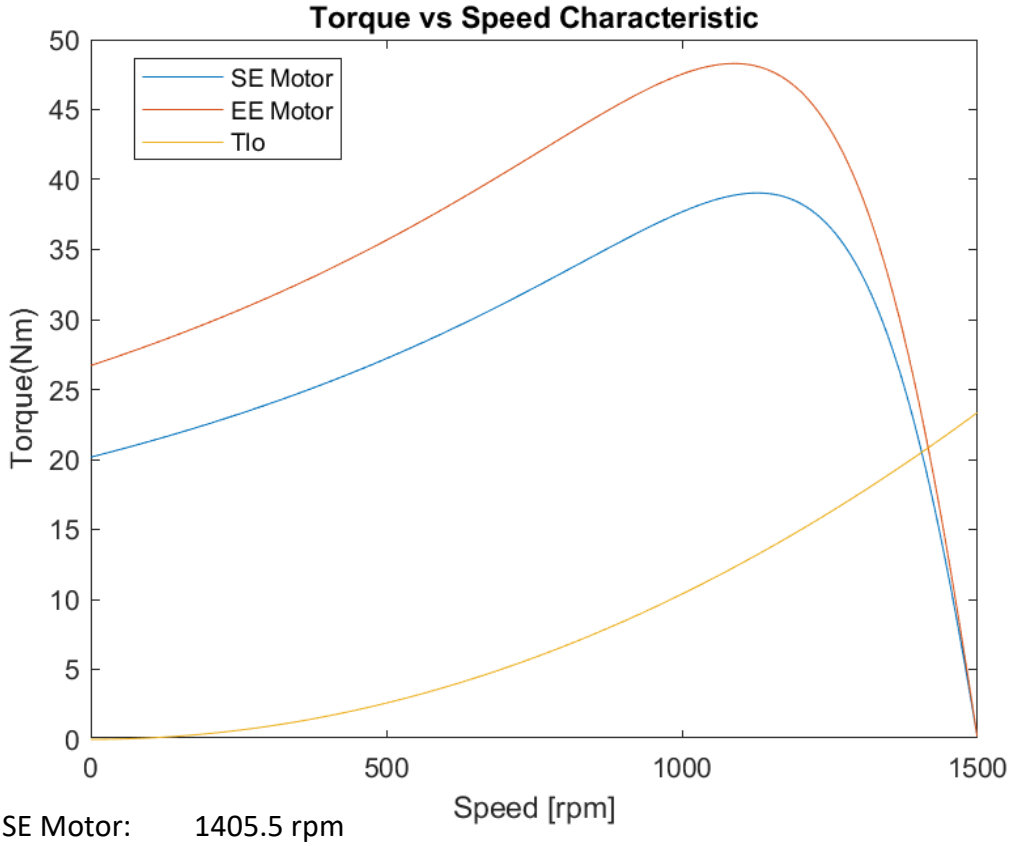


(a) SE Motor: 55.8%
EE Motor: 56.5%

(b) SE Motor: 87.4%
EE Motor: 90.3%

(c) SE Motor: 1455 rpm
EE Motor: 1460 rpm

7.



(a) SE Motor: 1405.5 rpm
EE Motor: 1416.75 rpm

(b) SE Motor: 6.65 A
EE Motor: 6.39 A

(c) SE Motor: 84.02 %
EE Motor: 87.57 %

(d) SE Motor: 2940.48 W
EE Motor: 3016.76 W

(e) SE Motor: 3499.64 W
EE Motor: 3445.11 W

Yes, these input power differences between the two machines are expected. The EE motor, with higher efficiency than the SE Motor, was able to draw less power (3445W < 3499.64W) but still output more power to the shaft than the SE Motor (3017W > 2940W). The benefits of the energy efficient motor are therefore evident.

Part B – Theoretical Questions

1.

(a) Bigger motors can make use of larger copper windings in the stator and rotor. Larger windings mean less resistance, and therefore less copper losses. Less losses means greater efficiency.

(b) Underloading motors decreases the efficiency of the machine. The machines are optimised to have the highest efficiency at the rated load. Characteristics such as torque and current would not be at rated levels, decreasing efficiency.

2.

(a) The following calculations were made:

100% load - Standard Motor					
Qty	Motor Size	Efficiency @ 100%	Input Power Required/Motor/Hour [kW]	Total Power Use/Hour [kW]	Total Power Consumption (12Hrs) [kWh]
150	3	0,819	3,66	549,45	6593,41
110	7,5	0,868	8,64	950,46	11405,53
60	15	0,893	16,80	1007,84	12094,06
40	55	0,932	59,01	2360,52	28326,18
75% load - Standard 55 kW Motor					
Qty	Motor Size	Efficiency @ 75%	Input Power Required/Motor/Hour [kW]	Total Power Use/Hour [kW]	Total Power Consumption (4Hrs) [kWh]
40	55	0,942	58,39	2335,46	9341,83
Daily Usage[kWh]:		67761,01			
Monthly Usage [kWh]:		2032830,23			
Monthly Cost [R]:		575047,02			

From this,

Monthly usage: **2 032 830.23 kWh**
Monthly bill: **R 575 047.02**

(b) The following calculations were made:

100% load - Premium Motor					
Qty	Motor Size	Efficiency @ 100%	Input Power Required/Motor/Hour [kW]	Total Power Use/Hour [kW]	Total Power Consumption (12Hrs) [kWh]
150	3	0,875	3,43	514,29	6171,43
110	7,5	0,893	8,40	923,85	11086,23
60	15	0,915	16,39	983,61	11803,28
40	55	0,942	58,39	2335,46	28025,48
75% load - Premium 55 kW Motor					
Qty	Motor Size	Efficiency @ 75%	Input Power Required/Motor/Hour [kW]	Total Power Use/Hour [kW]	Total Power Consumption (4Hrs) [kWh]
40	55	0,952	57,77	2310,92	9243,70
Daily Usage[kWh]:		66330,11			
Monthly Usage [kWh]:		1989903,259			
Monthly Cost [R]:		562903,83			

From this,

Monthly usage: **1 989 903.26 kWh**
Monthly bill: **R 562 903.83**

(c) The savings from installing premium motors/month will be: **R 12 143.18**

3. Based on the calculations below, it would take 1459 days to retrieve the money.

Consumption Comparison for 15kW Motors					
Type	Motor Size	Efficiency @ 100%	Input Power /Motor/Hour [kW]	Total Consumption/Day [kWh]	Total Cost/Day [R]
Standard	15	0,893	16,80	403,14	114,04
Premium	15	0,915	16,39	393,44	111,30
Savings/Day [R]:		2,74			
Days to Retrieve:		1459			

APPPENDIX: MATLAB CODE

```
clc                                                 %Clears the command window
% EEE3091 Project
% Authors:  Ankush Chohan (CHHANK001)
%           Ashik John (JHNASH009)
% Date of last revision: 31/03/2023


% Section A
% Define variables for both motors in an array [SE,EE]

R1 = double([2.087, 1.500]);                        %Stator winding resistance↙
[ohms/phase]
X1 = double([4.274, 3.642]);                        %Stator winding leakage reactance↙
[ohms/phase]
Xm = double([66.560, 72.252]);                      %Stator winding magnetising↙
reactance [ohms/phase]
X2 = double([4.274, 3.642]);                        %Rotor winding leakage reactance↙
reffered to stator [ohms/phase]
R2 = double([2.122, 1.994]);                        %Rotor winding resistance reffered↙
to stator [ohms/phase]
Prot = double([134.669, 88.924]);
Vline = 380;
f = 50;                                             %Supply frequency [Hz]
p = 4;                                              %Number of poles
Vp = double(Vline / sqrt(3));                       %Supply voltage [phase]


disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')
disp('Question 1:Thevenin Equiv Cct Parameters for both motors [SE,EE]:')
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')


Vth = (Xm ./ sqrt(R1.^2 + (X1+Xm).^2)).*Vp;         %Thevenin equiv voltage source [V]


Voc = (complex(0,Xm)./(R1 + complex(0,X1+Xm))).*Vp;
%disp(['Voc = ' num2str(Voc)])

Isc = Vp./(R1 + complex(0, X1));
%disp(['Isc = ' num2str(Isc)])

Zth = Voc ./ Isc;                                   %Thevenin equiv impedance
%disp(['Zth = ' num2str(Zth)])

Rth = real(Zth);                                    %Thevenin equiv resistance [ohms]
Xth = imag(Zth);                                    %Thevenin equiv reactance [ohms]

disp(['Vth = ' num2str(Vth)]);
disp(['Rth = ' num2str(Rth)]);
disp(['Xth = ' num2str(Xth)]);


% Question 2
```

```
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')
disp('Question 2:Torque vs Speed characteristics for both motors:')
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')


Ns = (120*f)/p;                                     %Synchronous speed [rpm]
ws = Ns*(2*pi/60);                                  %Synchronous speed [rad/sec]


% Create s matrix
s = 0.0005:0.0005:1;                                %Slip [pu]
% create Ns matrix
n = (1-s).*Ns;                                      %Rotor speed [rpm]
w = n.*(2*pi/60);                                   %Rotor speed [rad/sec]


% Calc T
Tm1 = 3*(1/ws).*((Vth(1)^2) ./ (((Rth(1)+(R2(1) ./ (s))).^2)+((Xth(1) + X2(1)).↙
^2))).*(R2(1)./(s));
Tm2 = 3*(1/ws).*((Vth(2)^2) ./ (((Rth(2)+(R2(2) ./ (s))).^2)+((Xth(2) + X2(2)).↙
^2))).*(R2(2)./(s));

figure(1);
% Plot Torque vs speed
plot(n,Tm1, 'b-',n,Tm2,'r-')
title('Torque vs Speed Characteristic')
xlabel('Speed [rpm]')
ylabel('Torque(Nm)')
legend('SE Motor', 'EE Motor')



disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')
disp('Question 3:Stator current vs Speed characteristics for both motors:')
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')

Z11 = R1(1) + complex(0, X1(1)) + (complex(0,Xm(1)).*((R2(1)./(s))+complex(0,X2↙
(1)))) ./ ((R2(1)./(s)) + complex(0, Xm(1)+X2(1)));
Z12 = R1(2) + complex(0, X1(2)) + (complex(0,Xm(2)).*((R2(2)./(s))+complex(0,X2↙
(2)))) ./ ((R2(2)./(s)) + complex(0, Xm(2)+X2(2)));

I11 = Vp ./ abs(Z11);                               %Current in motor 1
I12 = Vp ./ abs(Z12);                               %Current in motor 2

% Plot current vs speed characteristic
figure(2);
plot(n,I11, 'b-',n,I12,'r-')
title('Stator current vs Speed Characteristic')
xlabel('Speed [rpm]')
ylabel('Stator current(A)')
legend('SE Motor', 'EE Motor')
```

```
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')
disp('Question 4:Power Factor vs Speed characteristics for both motors:')
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')

theta1 = atan(imag(Z11)./real(Z11));
pf1 = cos(theta1);
theta2 = atan(imag(Z12) ./ real(Z12));
pf2 = cos(theta2);

%plot pf vs speed
figure(3);
%subplot(3,1,3)
plot(n,pf1, 'b-',n,pf2,'r-')
title('Power Factor vs Speed Characteristic')
xlabel('Speed [rpm]')
ylabel('Power Factor')
legend('SE Motor', 'EE Motor')


disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')
disp('Question 5:Power vs Speed characteristics for both motors:')
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~')
% Question 5 rotational loss excluded
% Motor 1                                       % Eqns from slide 21 Week 6
Pin1 = 3*Vp*I11.*pf1;                            % Input power
P1cu1 = 3*(I11.^2)*R1(1);                        % Stator copper loss
P2cu1 = 3*(I11.^2)*R2(1);                        % Rotor copper loss
Pag1 = Pin1 - P1cu1;                             % Airgap power
Pshaft1 = Pag1 - P2cu1;                          % Shaft power


% Motor 2
Pin2 = 3*Vp.*I12 .* pf2;                         % Input power
P1cu2 = 3.*(I12.^2)*R1(2);                       % Stator copper loss
P2cu2 = 3.*(I12.^2)*R2(2);                       % Rotor copper loss
Pag2 = Pin2 - P1cu2;                             % Airgap power
Pshaft2 = Pag2 - P2cu2;                          % Shaft power

% Create figure 4
figure(4);
% Plot for Motor 1
subplot(2,1,1)
plot(n,Pin1,n,P1cu1,n, P2cu1,n, Pag1,n, Pshaft1)
title('Motor 1 Powers vs Speed Characteristic')
xlabel('Speed [rpm]')
ylabel('P')
legend('Pin', 'P1cu', 'P2cu', 'Pag', 'Pshaft')

% Plot for Motor 2
subplot(2,1,2)
plot(n,Pin2,n,P1cu2,n, P2cu2,n, Pag2,n, Pshaft2)
title('Motor 2 Powers vs Speed Characteristic')
xlabel('Speed [rpm]')
```

```
ylabel('P')
legend('Pin', 'P1cu', 'P2cu', 'Pag', 'Pshaft')

disp('~~~
```