EE362 HW #3

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Change your .m file name to the following: name_surname_ID_hw1.m

```
% Please add axis names, legends, titles etc. in all your plots

% Use the already defined variable names whenever possible

% Examine the whole template before you start

% Delete the hints, guidelines etc. given in this template when you prepare
% your solution

% Note that, MATLAB trigonometric functions use radians, not degrees
% Indexes in MATLAB start at 1, not 0

clear
close all
clc
```

Given Parameters

Motor parameters 3 Phase, 30kW, 400V_ll, 6-pole, 50Hz, Delta connected induction machine.

```
% Locked Rotor Test
P_lock = 4800; % input power [W]
V_lock = 100; % line-to-line voltage [V]
I_lock = 72; % line-to-line current [A]

% No Load Test
P_no = 1800; % input power [W]
V_no = 400 ; % line-to-line voltage [V]
I_no = 56 ; % line-to-line current [A]
P_loss_rot = 300 ; % total rotational loss during no-load test [W]

% Measurement
R_l2l_dc = 0.22; % DC resistance between two lines [ohm]

% IM rating
V_1 = 400; % line-to-line voltage [V]
P_1 = 30000; % rated output power [W]
p = 6; % number of poles
m = 3; % number of phases
f = 50; % grid frequency [Hz]
```

Part a

What does the magnetizing inductance represents?

```
fprintf("Lets consider a basic scenario: the windings in a transformer have
 very little resistance. Surprisingly, despite this, they do not get damaged
 and the amount of electricity flowing into them remains low when they are
 connected to the power grid. This happens because of something called the
 law of induction. When an alternating current (AC) is applied, a voltage
 is created across the transformers terminals. This voltage is equal to the
 voltage drop across the primary windings and the voltage induced on the coil.
 Mathematically, we describe this as L(dI/dt), where L represents inductance.
 To ensure the transformer operates properly, we make sure the inductance
 (L) is set to a high value. This means that even a small change in current
 over time creates large voltages that oppose the change. When we connect a
 device to the secondary winding of the transformer, it creates a magnetic
 field that tries to counteract the field created by the load. To maintain
 balance, the transformer draws more current to offset the loads magnetic
 field. If this compensation didn't happen, we wouldn't meet the requirements
 of the Kirchhoff's voltage law (KVL). We can think of induction machines in
 a similar way to transformers, but with a smaller inductance (L) due to the
 presence of an air gap. In simple terms, we include a magnetizing inductance
 to simulate the magnetic field created.\n");
```

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Part b

```
% Phase resistance R_1
R_ph_dc = 0.33; % single phase DC resistance [ohm]
% update the DC resistance by 1.1 skin effect constant at 50Hz)
R_1 = 0.363; % single phase AC resistance [ohm]

% Locked Rotor Test
R_2p = 0.56; % rotor resistance referred to the stator side [ohm]
X_1 = 1.11; % stator leakage reactance [ohm]
X_2p = 1.11; % rotor leakage reactance referred to the stator side [ohm]
fprintf("R_1 is equal to %f. \nR_2' is equal %f. \nX_1 and X_2' are equal %f.
 \n", R_1,R_2p,X_1);

% No load Test
P_c = 500; % core loss (consider rotational loss) [W]
R_c = 320; % resistance for core loss [ohm]
X_m = 12.38; % magnetizing reactance [ohm]
fprintf("R_c is equal to %f. \nX_m is equal %f. \n", R_c,X_m);
```

```
R_1 is equal to 0.363000.
R_2' is equal 0.560000.
X_1 and X_2' are equal 1.110000.
R_c is equal to 320.000000.
X_m is equal 12.380000.
```

Part c

There are several manipulations used on per-phase equivalent circuit to ease up the analysis. Comment on how each of these manipulations diminishes the accuracy of the computations.

```
% i. The shunt branch is moved to the stator terminals.
fprintf("In the equivalent model, there is a component called a ‘shunt branch
 (i.e. parallel branch)’ where Rc and Xm are connected in parallel. Let me
 explain the meaning of these components.\n");
fprintf("Rc represents the equivalent resistance that models the core losses.
 There are two main reasons for these losses. The first one is hysteresis.
 When using magnetically permeable materials to generate more flux, it's
 important to note that these materials are not ideal. They exhibit hysteresis
 characteristics. Imagine an electromagnet used in school projects. Even
 after you stop applying current, it remains magnetically attracted to other
 magnetic materials, such as bolts. This is a basic example of hysteresis.
```

```
 In AC circuits, hysteresis causes power losses. To change the state of
 something, you have to convince it. Additionally, when the material is
 saturated, the magnetizing current is incredibly high, resulting in more
 conduction losses in the windings. However, for now, let's ignore this
 aspect, assuming the motor is designed not to saturate.\n")
fprintf("The second reason is the eddy current losses. The phenomena on which
 induction machines rely are also a significant cause of power losses. As
 the alternating magnetic flux travels through the core material, it induces
 voltages across the core body. Although the core material is designed with
 low conductivity and lamination, it still causes losses. The Rc in the
 parallel branch models the combined 'core' losses.\n")
fprintf("Both hysteresis and eddy current losses are functions of the voltages
 applied to the motor terminals. The stator winding resistance and inductance
 are not significantly high, so we can disregard the voltage drop over
 them. Moving Rc to the input terminals simplifies our analysis without
 significantly changing the voltage drop. Similarly, Xc, which represents the
 magnetizing inductance, is also affected by the voltage drop, but relocating
 it to the terminals does not significantly alter our results.\n")

% ii. The shunt branch is ignored.
fprintf("The purposes of Rc and Xc are discussed in detail in part i. In
 practice, the machine is optimized so that the core losses are low, so we
 may ignore the Rc component. However, we should be more careful when ignoring
 the magnetizing branch. Unlike transformers, induction motors have an air
 gap, which results in a relatively low magnetizing inductance and a not-so-
low magnetizing current. Even though this current results only in reactive
 power, This difference can lead to issues such as blown fuses or a decrease
 in efficiency due to the I^2R losses introduced by the cable carrying the
 additional magnetizing current.\n");

% iii. The resistance representing the core losses, i.e., R_c is ignored.
fprintf('This would be fine if the laminations were sufficiently thin and
 the core material had very low conductivity. It is even better if the motor
 is designed so that its B-H curve is almost linear. Otherwise we should be
 careful about ignoring the Rc\n');
```

In the equivalent model, there is a component called a 'shunt branch (i.e. parallel branch)' where Rc and Xm are connected in parallel. Let me explain the meaning of these components.

Rc represents the equivalent resistance that models the core losses. There are two main reasons for these losses. The first one is hysteresis. When using magnetically permeable materials to generate more flux, it's important to note that these materials are not ideal. They exhibit hysteresis characteristics. Imagine an electromagnet used in school projects. Even after you stop applying current, it remains magnetically attracted to other magnetic materials, such as bolts. This is a basic example of hysteresis. In AC circuits, hysteresis causes power losses. To change the state of something, you have to convince it. Additionally, when the material is saturated, the magnetizing current is incredibly high, resulting in more conduction losses in the windings. However, for now, let's ignore this aspect, assuming the motor is designed not to saturate.

The second reason is the eddy current losses. The phenomena on which induction machines rely are also a significant cause of power losses. As the alternating magnetic flux travels through the core material, it induces

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 low conductivity and lamination, it still causes losses. The Rc in the
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 significantly high, so we can disregard the voltage drop over them. Moving Rc
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 additional magnetizing current.
This would be fine if the laminations were sufficiently thin and the core
 material had very low conductivity. It is even better if the motor is
 designed so that its B-H curve is almost linear. Otherwise we should be
 careful about ignoring the Rc
```

Part d

```
%Repeat part b without moving the shunt branch to stator terminals. Report
 the differences for per-phase equivalent circuit parameters. (For the locked-
rotor test, ignore the shunt branch)

eqCirc1 = struct;
eqCirc1.R_1 = 0.363; % single phase AC resistance [ohm]

% Locked Rotor Test
eqCirc1.R_2p = 0.56; % rotor resistance referred to the stator side [ohm]
eqCirc1.X_1 = 1.11; % stator leakage reactance [ohm]
eqCirc1.X_2p = 1.11; % rotor leakage reactance referred to the stator side
 [ohm]
fprintf("When the shunt branch is not moved;\nR_1 is equal
 to %f. \nR_2' is equal %f. \nX_1 and X_2' are equal %f. \n",
 eqCirc1.R_1,eqCirc1.R_2p,eqCirc1.X_1);

% No load Test
eqCirc1.P_c = 500; % core loss (consider rotational loss) [W]
eqCirc1.E2 = 364; % voltage drop over shunt branch during no-load test [V]
eqCirc1.R_c = 1098; % resistance for core loss [ohm]
eqCirc1.X_m = 11.25; % magnetizing reactance [ohm]
fprintf("When the shunt branch is not moved;\nR_c is equal to %f. \nX_m is
 equal %f. \n", eqCirc1.R_c,eqCirc1.X_m);

% Report the differences for per-phase equivalent circuit parameters.
fprintf("The power consumption is one of the main interpretation of the
 no-load test. If we move the shunt branch, we ignore the contribution of
```

```
 R1 to the losses. However, if we keep the shunt branch where it should
 be, R1 losses are not ignored and contribute to the total loss. Since the
 voltage drop across Rc and total loss remains more or less the same, we can
 interpret that the Rc value should increase to reduce the power consumption
 compared to the previous case (P = V^2/Rc, where V is more or less constant).
 Thus, the Rc value turns out to be higher. Additionally, it's important to
 note that Xc << Rc. Due to the air gap, Xc = iWL turns out to be low. As a
 result, a significant amount of the current passes through Xc rather than Rc.
 Furthermore, the voltage is more or less the same on the magnetizing branch
 when comparing the two approaches. Since the current and voltage drop are
 approximately the same, in order to generate the same change of flux with
 respect to time, the value of L and consequently the Xc value should be more
 or less the same.\n");
```

```
When the shunt branch is not moved;
R_1 is equal to 0.363000.
R_2' is equal 0.560000.
X_1 and X_2' are equal 1.110000.
When the shunt branch is not moved;
R_c is equal to 1098.000000.
X_m is equal 11.250000.
The power consumption is one of the main interpretation of the no-load test.
 If we move the shunt branch, we ignore the contribution of R1 to the losses.
 However, if we keep the shunt branch where it should be, R1 losses are not
 ignored and contribute to the total loss. Since the voltage drop across
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 respect to time, the value of L and consequently the Xc value should be more
 or less the same.
```

Part e

```
%Mr. Keysan's presentation: http://keysan.me/presentations/
ee362_induction_motors.html#25
n_s = 1000; % calculate the synchronous speed (in rpm)
fprintf("The synchronous speed is %d rpm (repeat per minute)\n", round(n_s));
```

```
The synchronous speed is 1000 rpm (repeat per minute)
```

Part f:

```
%Calculate the slip at maximum torque
%Mr. Keysan's presentation: http://keysan.me/presentations/
ee362_induction_motor_torque_curve.html#51
```

```
R_1 = 0.363; % single phase AC resistance [ohm]
R_2p = 0.56; % rotor resistance referred to the stator side [ohm]
X_1 = 1.11; % stator leakage reactance [ohm]
X_2p = 1.11; % rotor leakage reactance referred to the stator side [ohm]
P_c = 500; % core loss (consider rotational loss) [W]
R_c = 320; % resistance for core loss [ohm]
X_m = 12.38; % magnetizing reactance [ohm]

func_paralel_impedance = @(z_1,z_2) ( (1)/(z_1) + (1)/(z_2))^(-1);
Z_shunt = func_paralel_impedance(R_c,i*X_m);
Z_stator_winding = R_1+i*X_1;
Z_thevenin = func_paralel_impedance(Z_shunt, Z_stator_winding);

V_phase = 400; %phase voltage [V];
w_mmf = 104.71; %rad/s

V_thevenin = (Z_shunt/(Z_shunt+Z_stator_winding) )*V_phase;

func_calculate_I_p_2 = @(V_thv, Z_thv, X_referred, R_referred, slip)
 (abs(V_thv))/(Z_thv+i*X_referred+R_referred/slip);
func_calculate_T = @(I_p_2,R_referred, slip, sync_angular_speed)
 3.*(abs(I_p_2))^(2).*(R_referred)./(sync_angular_speed.*slip);

%we know that the modelled induction machine has only one peak torque value
%with respect to slip. We may find that peak sufficiently close by using
%numeric approach
numeric_accuracy = 0.00001; %slip step amount
max_T_found = 0;
s_Tmax = 0;

for slip = 1:-numeric_accuracy:numeric_accuracy
        I_p_2 = func_calculate_I_p_2(V_thevenin, Z_thevenin, X_2p, R_2p,
 slip);
        T = func_calculate_T(I_p_2, R_2p, slip, w_mmf);
        if T > max_T_found
            max_T_found = T;
            s_Tmax=slip;
        end
end

fprintf("Maximum torque (%d Nm) is observed at slip is equal to %f which
 means %d/100 of the max speed\n", round(max_T_found), s_Tmax, round(100*(1-
s_Tmax)));
```

Maximum torque (781 Nm) is observed at slip is equal to 0.259610 which means 74/100 of the max speed

Part g:

```
%Calculate the maximum torque when half of the rated terminal voltage is
 applied to the machine.

ws = w_mmf; %=104rad/sec  % synchronous speed [rad/s]
```

```
V_ph = 200; % half of the rated phase voltage
V_thevenin = (Z_shunt/(Z_shunt+Z_stator_winding) )*V_ph;

numeric_accuracy = 0.00001; %slip step amount
max_T_found_half_voltage = 0;
s_Tmax_half_voltage = 0;
for slip = 1:-numeric_accuracy:numeric_accuracy
        I_p_2 = func_calculate_I_p_2(V_thevenin, Z_thevenin, X_2p, R_2p,
 slip);
        T = func_calculate_T(I_p_2, R_2p, slip, w_mmf);
        if T > max_T_found_half_voltage
            max_T_found_half_voltage = T;
            s_Tmax_half_voltage=slip;
        end
end

fprintf("For half of the rated voltage (200Vrms-phase), maximum torque (%d
 Nm) is observed at slip is equal to %f which means %d/100 of the max speed
\n", round(max_T_found_half_voltage), s_Tmax_half_voltage, round(100*(1-
s_Tmax_half_voltage)));
```

For half of the rated voltage (200Vrms-phase), maximum torque (195 Nm) is observed at slip is equal to 0.259610 which means 74/100 of the max speed

Part h:

```
%Calculate the starting torque when rated terminal voltage is applied to the
 machine

slip = 1;
V_ph = 400; % phase voltage
V_thevenin = (Z_shunt/(Z_shunt+Z_stator_winding) )*V_ph;

I_p_2_st = func_calculate_I_p_2(V_thevenin, Z_thevenin, X_2p, R_2p, slip);
T_st = func_calculate_T(I_p_2_st, R_2p, slip, w_mmf);
fprintf("The starting torque for rated terminal voltage is found to be (%d Nm)
 with I2 of (%d A)\n",round(T_st), round(I_p_2_st));
```

The starting torque for rated terminal voltage is found to be (406 Nm) with I2 of (60 A)

Part i:

```
%Plot the torque speed characteristics (all three regions) of this machine and
 show those points.
%region 1: speed<0
%region 2: 0<speed<1000
%region 3: 1000<speed

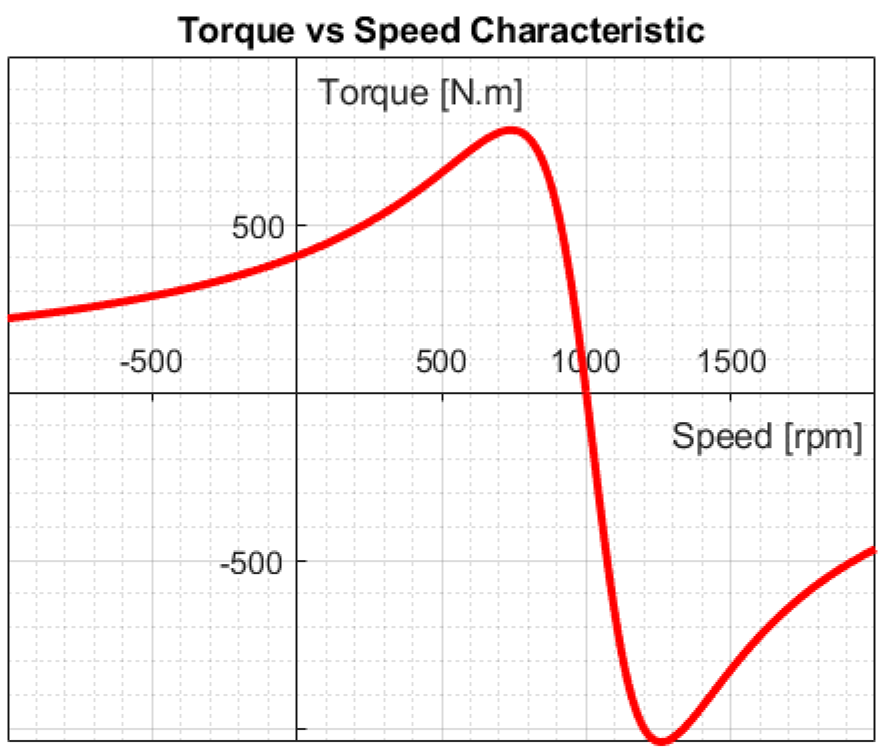
ws = w_mmf; %=104rad/sec  % synchronous speed [rad/s]
ns = ws/(2*pi)*60;
V_ph = 400; % rated phase voltage
```

```
V_thevenin = (Z_shunt/(Z_shunt+Z_stator_winding) )*V_ph;

speed_rpm_array = [];
torque_rpm_array = [];

numeric_accuracy = 0.0001; %slip step amount
for slip = -1:numeric_accuracy:2
        I_p_2 = func_calculate_I_p_2(V_thevenin, Z_thevenin, X_2p, R_2p,
 slip);
        T = func_calculate_T(I_p_2, R_2p, slip, w_mmf);
        speed_rpm_array= [speed_rpm_array ( (1-slip)*ns)];
        torque_rpm_array = [torque_rpm_array T ];
end

figure('Name','part i','DefaultAxesFontSize',12);
plot(speed_rpm_array,torque_rpm_array,'r','LineWidth',3);
title('Torque vs Speed Characteristic' );
ylabel('Torque [N.m]');
xlabel('Speed [rpm]')
grid on;
grid minor;
ax = gca;
ax.XAxisLocation = 'origin';
ax.YAxisLocation = 'origin';
```



Part j

```
%You must comment on the answers. If there is no comment, you take zero credit
 for the question.
% What happens to the maximum torque when the terminal voltage is increased?
fprintf('The torque versus speed characteristic is directly proportional to
 the square of the terminal voltage. For instance, if we double the terminal
 voltage, the torque increases by a factor of four. Similarly, if we halve the
 terminal voltage, the torque decreases to one-fourth of its original value.
\n');

%What happens to the maximum torque when external resistances are connected to
 the rotor windings?
fprintf("The peak torque occurs at lower speeds compared to the previous
 case. Although the peak torque gradually decreases, this decrease can be
 disregarded in most cases. However, if the rotor resistance is increased
 excessively, the torque is diminished to zero. This is an expected outcome
 since, with infinite rotor resistance, there is no current flow, and
 consequently, no Lorentz force is generated.\n");

% What happens to the starting torque when the terminal voltage is increased?
fprintf("Increases due to quadratic relation in between terminal voltage and
 the torque as discussed above.\n")

% What happens to the starting torque when external resistances are connected
 to the rotor windings?
fprintf("Using adjustable external resistances allows us to increase the
 starting torque and achieve a higher peak torque at higher slip values. This
 is beneficial when dealing with heavy loads where the starting torque alone
 may not be enough to accelerate the motor. By using adjustable external
 resistances, we can set them to higher values at the beginning to provide
 more torque. As the motor speeds up, we can gradually reduce the resistance,
 creating an efficient system that maintains both torque and efficiency
 without compromising one for the other.\n");
```

```
The torque versus speed characteristic is directly proportional to the square
 of the terminal voltage. For instance, if we double the terminal voltage,
 the torque increases by a factor of four. Similarly, if we halve the terminal
 voltage, the torque decreases to one-fourth of its original value.
The peak torque occurs at lower speeds compared to the previous case. Although
 the peak torque gradually decreases, this decrease can be disregarded in most
 cases. However, if the rotor resistance is increased excessively, the torque
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 resistance, there is no current flow, and consequently, no Lorentz force is
 generated.
Increases due to quadratic relation in between terminal voltage and the torque
 as discussed above.
Using adjustable external resistances allows us to increase the starting
 torque and achieve a higher peak torque at higher slip values. This is
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 may not be enough to accelerate the motor. By using adjustable external
 resistances, we can set them to higher values at the beginning to provide
 more torque. As the motor speeds up, we can gradually reduce the resistance,
```

creating an efficient system that maintains both torque and efficiency without compromising one for the other.

Part k

```
%Suppose that a constant torque load is connected to the shaft of this machine
 when the applied voltage is
%rated, and the machine slip is observed as 0.07. What is the load torque?
 What is the rotor speed?

slip = 0.07;
V_ph = 400; % phase voltage
V_thevenin = (Z_shunt/(Z_shunt+Z_stator_winding) )*V_ph;

I_p_2 = func_calculate_I_p_2(V_thevenin, Z_thevenin, X_2p, R_2p, slip);
T_mech = func_calculate_T(I_p_2, R_2p, slip, w_mmf); % torque at 0.07 slip
 [N.m]
n_r1 = (1-slip)*ns; % rotor speed [rpm]
w_r1 = (2*pi)*(n_r1/60); % rotor speed [rad/s]

P_mech = T_mech*w_r1; % mechanical power [W]
P_load = P_mech-P_loss_rot; % load power [W]
T_load = P_load/w_r1; % load torque [N.m]

fprintf("T_load: %.2f N.m\n", T_load);
fprintf("n_r1: %.2f rpm\n", n_r1);
```

```
T_load: 415.52 N.m
n_r1: 929.91 rpm
```

Part l

```
I_p_2 = abs(I_p_2);
w_r1 = w_r1; % rotor speed in rad/sec
P_mech =  T_mech*w_r1; % mechanical power [W]
P_out = P_mech-P_loss_rot; % output power [W]
P_cur = 3*(I_p_2^2)*R_2p; % rotor resistance loss [W]
P_cus = 3*(I_p_2^2)*R_1; % stator resistance loss [W]
Pg = 3*(I_p_2^2)*(R_2p/slip); % air gap power [W]
Pc = 3*(V_ph^2)/(R_c); % Core loss [W],
Pin = P_cus+Pg+Pc; % input power [W]
Eff = P_out/Pin; % efficiency [W]

fprintf('Efficiency is equal to %f percent\n', Eff);
fprintf('Input Power : %f W \n', Pin);
fprintf('Output Power : %f W \n', P_out);
fprintf('Copper Loss in Stator Side : %f W \n', P_cus);
fprintf('Core Loss: %f W \n', Pc);
fprintf('Air Gap Power: %f W \n', Pg);
fprintf('Cupper Loss in Rotor Side: %f W \n', P_cur);
fprintf('Mechanical Power: %f W \n', P_mech);
fprintf('Rotational Loss: %f W \n', P_loss_rot);
```

```
Efficiency is equal to 0.855093 percent
Input Power : 47320.576545 W
Output Power : 40463.492706 W
Copper Loss in Stator Side : 1988.863959 W
Core Loss: 1500.000000 W
Air Gap Power: 43831.712587 W
Cupper Loss in Rotor Side: 3068.219881 W
Mechanical Power: 40763.492706 W
Rotational Loss: 300.000000 W
```

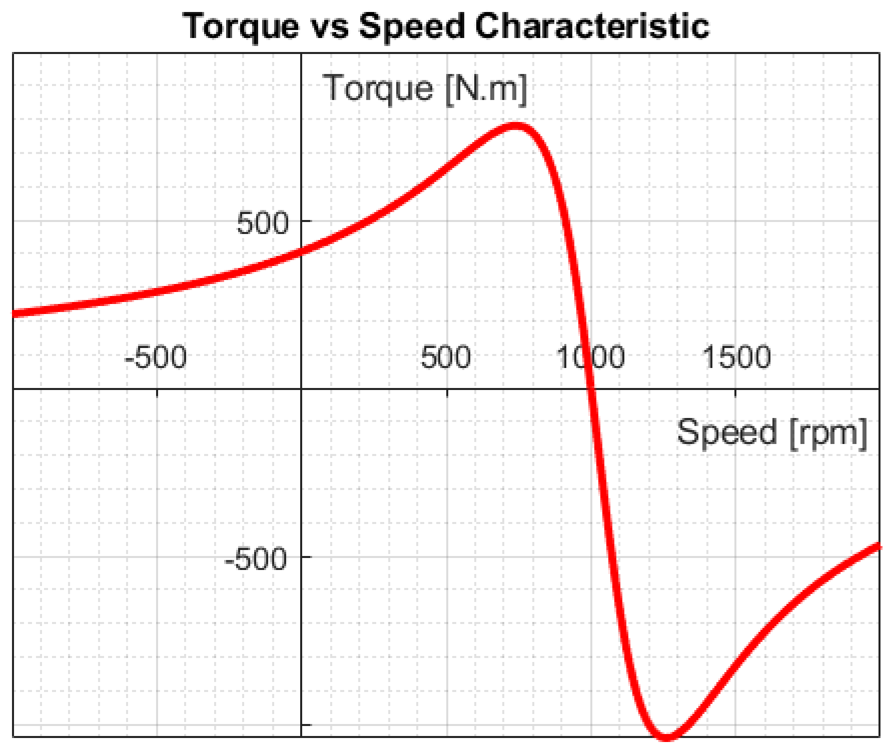
Part m

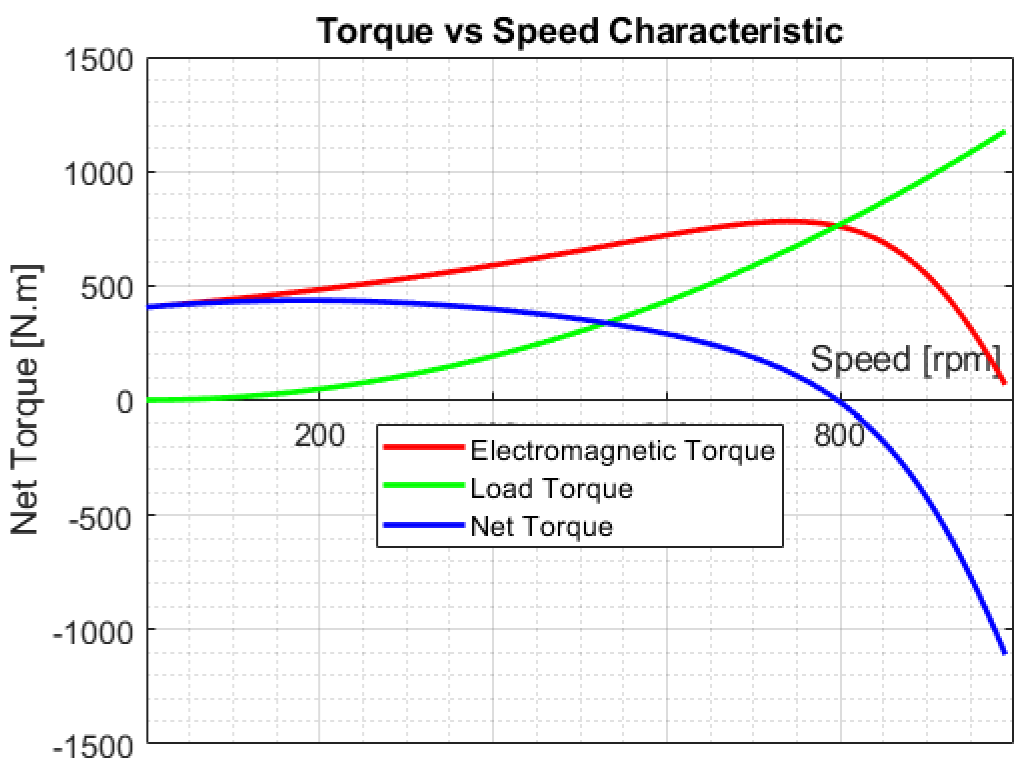
```
%T_mech  = func_T_mech(slip, R_2p, w_mmf,V_thevenin, Z_thevenin, X_2p)
n_s = 1000; %rpm
func_T_mech = @(slip, R_2p, w_mmf,V_thevenin, Z_thevenin, X_2p)
 func_calculate_T(func_calculate_I_p_2(V_thevenin, Z_thevenin, X_2p, R_2p,
 slip), R_2p, slip, w_mmf);
T_rot = @(slip) 1200*(1-slip)^2;  % load torque as anonymous function


s_samples = [];
T1 =[];
T2 = []; % load torque  [N.m]

for slip = 0.01:0.01:1
        mech_T = func_T_mech(slip, R_2p, w_mmf,V_thevenin, Z_thevenin,
 X_2p); % mechanical torque [N.m]
        T1 = [T1 mech_T];
        T2 = [T2 T_rot(slip)]; % load torque  [N.m]
        s_samples= [ s_samples slip];
end

figure('Name','part m','DefaultAxesFontSize',12);
plot((1-s_samples)*n_s, T1,'r','LineWidth',2);
hold on;
plot((1-s_samples)*n_s, T2,'g','LineWidth',2);
hold on;
plot((1-s_samples)*n_s,(T1-T2),'b','LineWidth',2);
xlabel('Speed [rpm]');
ylabel('Net Torque [N.m]')
title('Torque vs Speed Characteristic');
legend('Electromagnetic Torque','Load Torque','Net Torque','Location','Best')
grid on;
grid minor;
ax = gca;
ax.XAxisLocation = 'origin';
ax.YAxisLocation = 'origin';
```


Torque vs Speed Characteristic
Torque [N.m]
500
-500
-500
500
1000
1500
Speed [rpm]

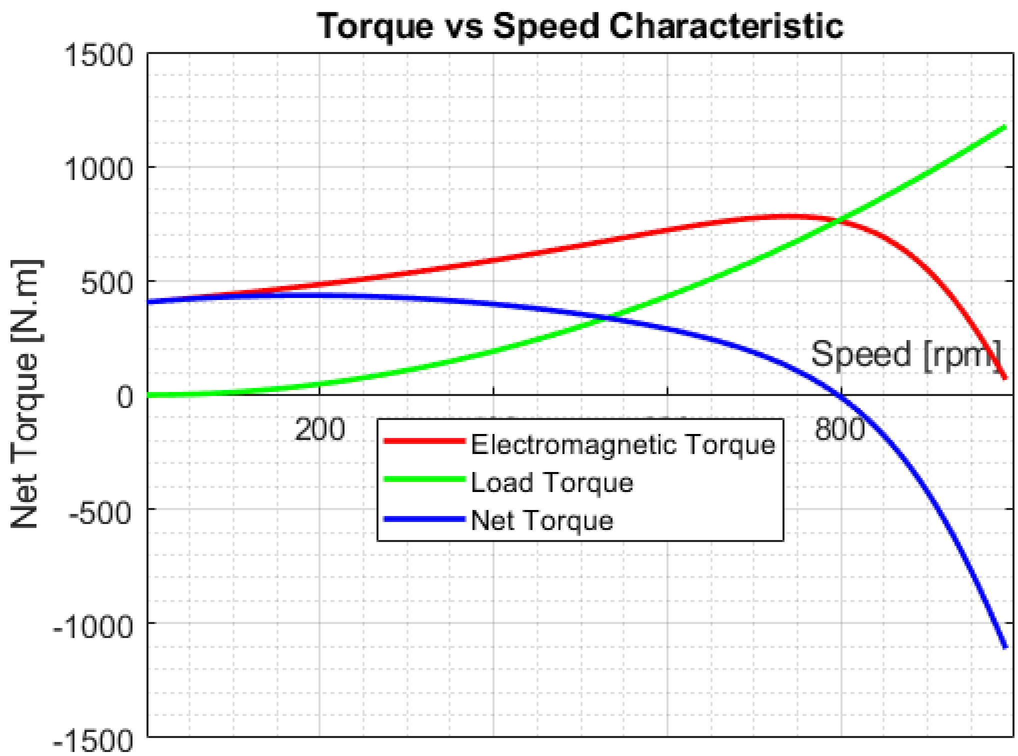

Torque vs Speed Characteristic
1500
1000
500
0
-500
-1000
-1500
Net Torque [N.m]
200
800
Speed [rpm]
Electromagnetic Torque
Load Torque
Net Torque

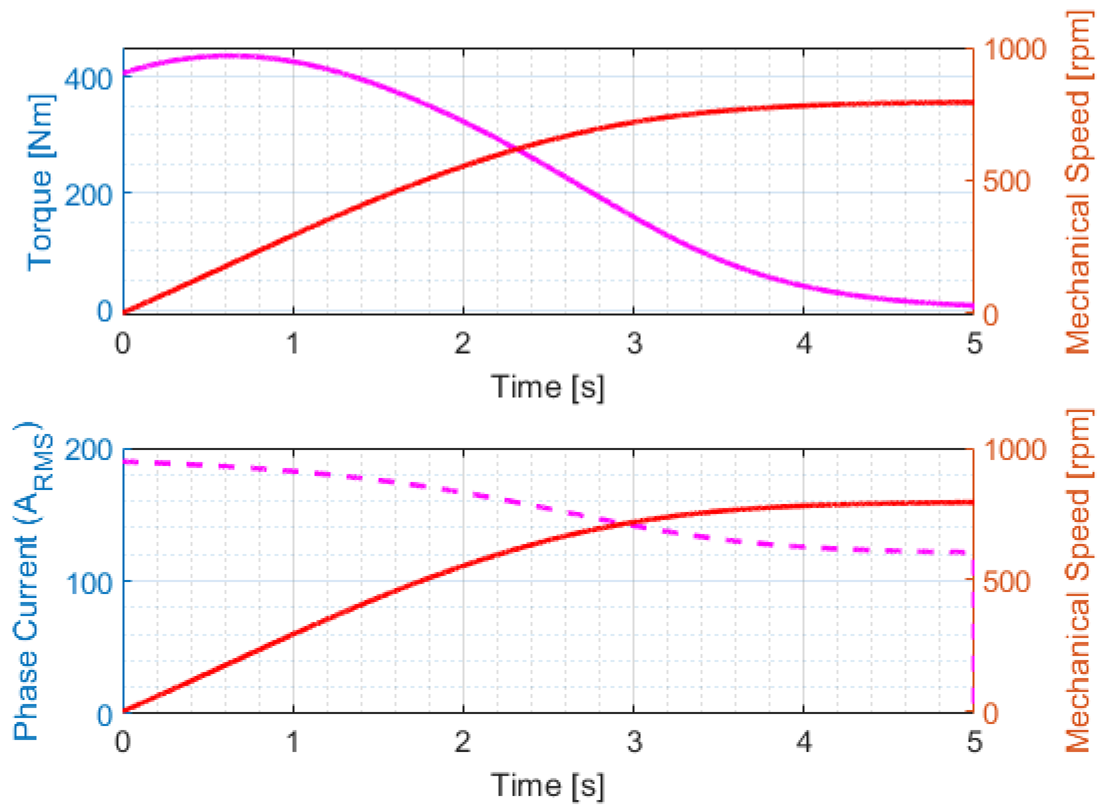
Part n

```
%Take the machine moment of inertia to be 14 [SI unit]
%, and initial mechanic speed to be 0. Plot the transients
%of the mechanic speed (in RPM), net torque (N.m) and a phase current
w_mmf = 104.71;
deltaT = 1e-3; % sample time
t = 0 : deltaT : 5; % duration of simulation [s]
wm = zeros(1,length(t)); % mechanical speed (initialization)
jm = 14; % rotor moment of inertia [kg.m^2]
Tnet = zeros(1,length(t)); % net torque (initialization)
I_ph = zeros(1,length(t)); % phase current (initialization)
for i = 1 : length(t)-1
    slip = (w_mmf-wm(i))/w_mmf; % slip wrt the mechanical speed wm(i)
    Tnet(i) = func_T_mech(slip, R_2p, w_mmf,V_thevenin, Z_thevenin, X_2p)-
T_rot(slip); % mechanical torque [N.m]; % net torque [N.m]
    delta_wm = Tnet(i)/jm;
    wm(i+1) = wm(i)+(delta_wm*deltaT); % mechanical speed for the upcoming
 iteration [rad/s]
    I_ph(i) = abs( func_calculate_I_p_2(V_thevenin, Z_thevenin, X_2p, R_2p,
 slip) + V_phase/(Z_shunt)); % calculate the phase current [A]
end

figure('Name','part n','DefaultAxesFontSize',12);
subplot(2,1,1);
yyaxis right;
plot(t,wm*30/pi,'r','LineWidth',2);
ylabel('Mechanical Speed [rpm]');
ylim([-10,1000]);
hold on;
yyaxis left;
plot(t,Tnet,'m','LineWidth',2);
ylim([-10,450]);
ylabel('Torque [Nm]')
xlabel('Time [s]');
grid on;
grid minor;


subplot(2,1,2);
yyaxis right;
plot(t,wm*30/pi,'r','LineWidth',2);
ylabel('Mechanical Speed [rpm]');
ylim([-10,1000]);
hold on;
yyaxis left;
plot(t,I_ph,'m--','LineWidth',2);
ylabel('Phase Current (A_R_M_S)')
xlabel('Time [s]');
grid on;
grid minor;
```


Torque vs Speed Characteristic
Net Torque [N.m]
Speed [rpm]
1500
1000
500
0
-500
-1000
-1500
200
800
Electromagnetic Torque
Load Torque
Net Torque


Torque [Nm]
Mechanical Speed [rpm]
Time [s]
Phase Current (A_{RMS})
0
200
400
100
500
1000
1
2
3
4
5

Part o

You must comment on the answers. If there is no comment, you take zero credit for the question.

```
% Increasing the inertia reduces the time requiring to reach the steady-state.
fprintf('No. Increasing the inertia results in longer transient time. The net
 torque is equal to the the rate of change of angular velocity multiplied
 by the inertia of the rotating body. When the inertia is increased, the
 derivative of the angular velocity decreases. This is also intuitive as
 larger machines take more time to ramp up their speed, often taking minutes
 due to the increased inertia.\n');

% Decreasing terminal voltage reduces the time requiring to reach the steady-
state.

fprintf('Lowering the terminal voltage does result in a longer transient
 time. As we discussed earlier, the torque generated by the motor is highly
 dependent on the terminal voltage, following a quadratic relationship. When
 the terminal voltage is decreased, the torque produced at any slip rate
 is scaled down, resulting in lower torque values. Consequently, with lower
 torque, the rate of change of angular velocity, which is the derivative of
 the angular velocity, is also reduced. Therefore, decreasing the terminal
 voltage not only lowers the torque but also slows down the rate at which the
 motor accelerates or decelerates.\n');
```

```
No. Increasing the inertia results in longer transient time. The net torque is
 equal to the the rate of change of angular velocity multiplied by the inertia
 of the rotating body. When the inertia is increased, the derivative of the
 angular velocity decreases. This is also intuitive as larger machines take
 more time to ramp up their speed, often taking minutes due to the increased
 inertia.
Lowering the terminal voltage does result in a longer transient time. As we
 discussed earlier, the torque generated by the motor is highly dependent on
 the terminal voltage, following a quadratic relationship. When the terminal
 voltage is decreased, the torque produced at any slip rate is scaled down,
 resulting in lower torque values. Consequently, with lower torque, the
 rate of change of angular velocity, which is the derivative of the angular
 velocity, is also reduced. Therefore, decreasing the terminal voltage not
 only lowers the torque but also slows down the rate at which the motor
 accelerates or decelerates.
```

After you finished

Run the following command from Matlab terminal (command window) Generate a report of your .m file as pdf and ONLY upload the PDF file to ODTUClass.

```
%publish('erdem_canaz_2374676_hw3.m','pdf')
```

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