Table of Contents

EE361 HW#5

NAME: *SOLUTION*

STUDENT NUMBER: 123456

PARAMETERS

```
% drag force
p = 1.225; % kg/m^3
A = 10; % m^2
Cd = 0.8;

% friction
K = 10; % kg/s

% gravity
g = 9.8; % m/s^2

% motor
Km = 4; % V/(rad/sec)
Ra = 0.027; % ohm
Prated = 240*1e3; % watt
Nrated = 673; % rpm
Vrated = 300; % volts
Irated = 800; % amps

% train
gear_ratio = 0.72;
wheel_radius = 0.4; % m
mass = 70*1e3; % kg

%Part I
```

Part I-a

```
Ts = 1; % time step (seconds)
t = 0:Ts:1e3; % time vector
Num = numel(t);

Ts = 1; %seconds
```

```
t = 0:Ts:1e3; %seconds
Num = numel(t);
final = 0;
Fnet = zeros(1,Num);
acceleration = zeros(1,Num);
velocity = zeros(1,Num);
position = zeros(1,Num);
Ea = zeros(1,Num);
Ia = zeros(1,Num);
Vt = zeros(1,Num);
wmotor = zeros(1,Num);
Nmotor = zeros(1,Num);
efficiency = zeros(1,Num);
```

part a-(i)

$$w_{rated} = N_{rated} 2\pi/60$$

$$T_{rated} = P_{rated}/w_{rated}$$

$$F_{train} = 2T_{rated} gear/radius$$

$$F_{drag} = 1/2 C_d A p v^2$$

$$F_{friction} = K v^2$$

$$F_{net} = F_{train} - F_{drag} - F_{friction}$$

$$a = F_{net}/m$$

$$v(k+1) = v(k) + a(k)T_s$$

$$x(k+1) = x(k) + v(k)T_s$$

$$w_{motor} = v * gear/radius$$

$$N_{motor} = w_{motor} 60/(2\pi)$$

$$E_a = K_m w_{motor}$$

$$I_a = T_{rated}/K_m$$

$$V_t = E_a + I_a R_a$$

$$P_{in} = V_t I_a$$

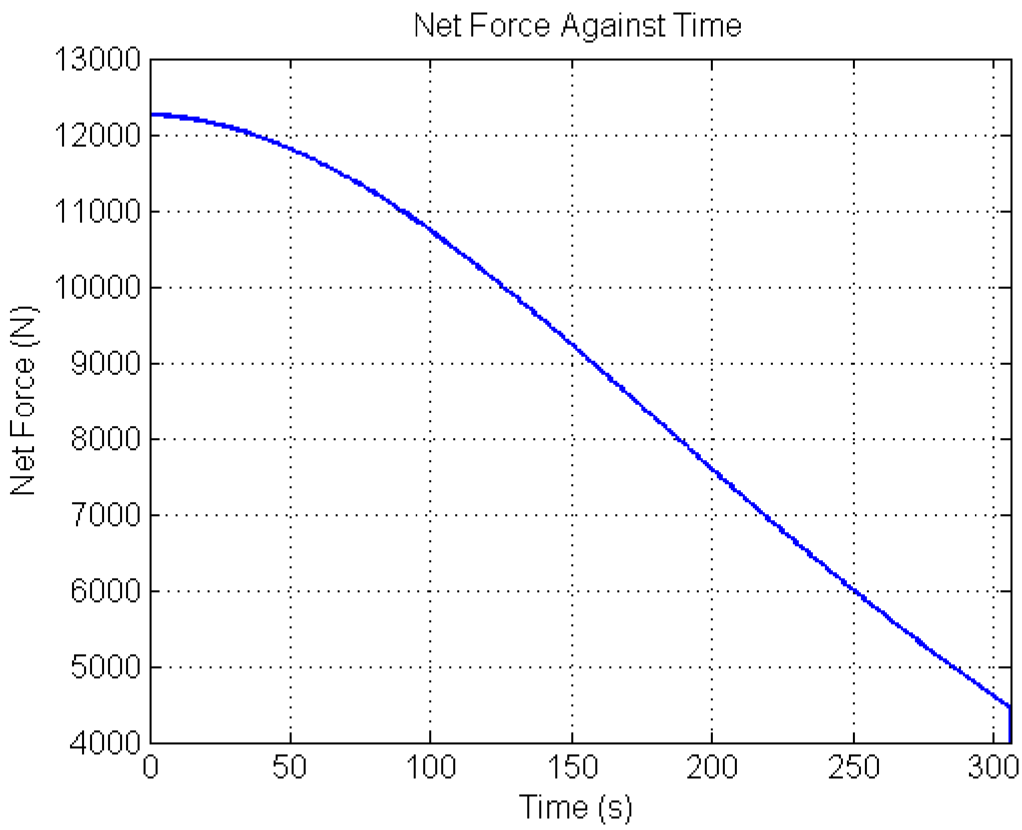
$$P_{out} = E_a I_a$$

$$efficiency = 100 * P_{out} / P_{in}$$

```
wrated = Nrated*2*pi/60;
Trated = Prated/wrated;
Ftrain = Trated*2*gear_ratio/(wheel_radius);


k = 0;
while (1)
    k = k+1;

    Fdrag = (1/2)*Cd*A*p*velocity(k)^2;
    Ffriction = K*velocity(k);
    Fnet(k) = Ftrain-Fdrag-Ffriction;

    acceleration(k) = Fnet(k)/mass;
    velocity(k+1) = velocity(k) + acceleration(k)*Ts;
    position(k+1) = position(k) + velocity(k)*Ts;

    wmotor(k) = (velocity(k)/wheel_radius)*gear_ratio;
    Nmotor(k) = wmotor(k)*60/(2*pi);
    Ea(k) = Km*wmotor(k);
    Ia(k) = Trated/Km;
    Vt(k) = Ia(k)*Ra + Ea(k);
    Pin = Vt(k)*Ia(k);
    Pout = Ea(k)*Ia(k);
    efficiency(k) = 100*Pout/Pin;

    if velocity(k) >= 140/3.6;
        final = k;
        break;
    end
    if k > Num;
        break;
    end
end
```

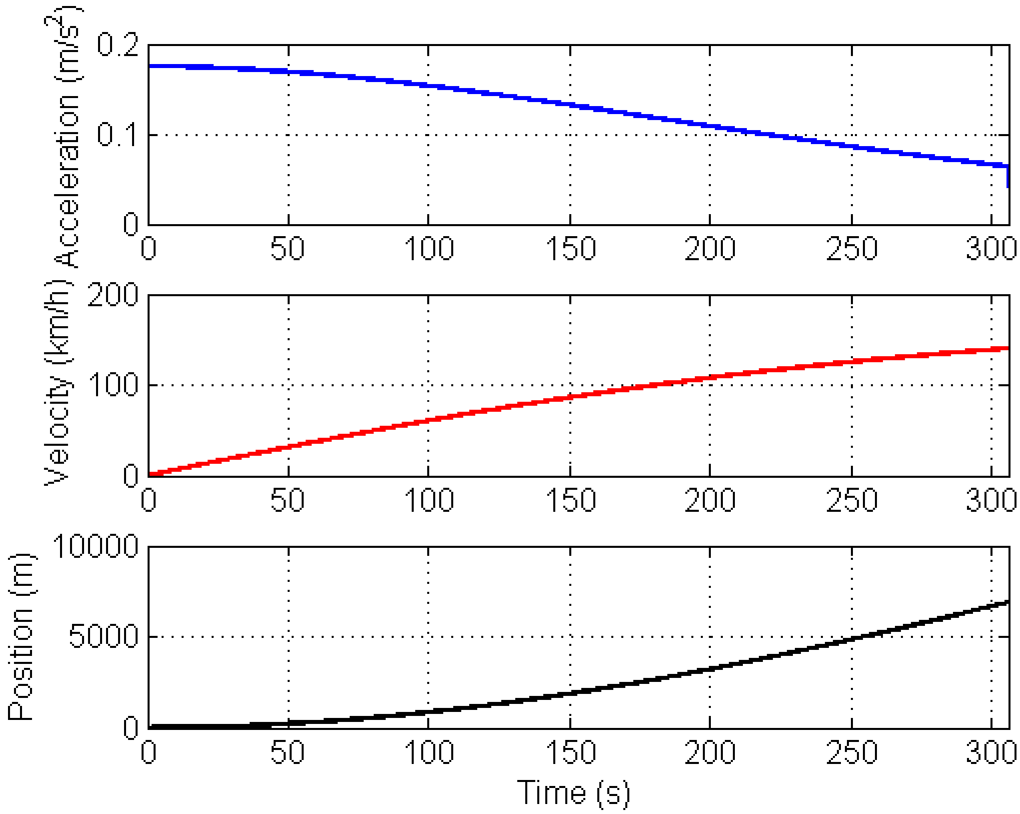
part a-(ii)

```
figure;
plot(t,Fnet,'b -','Linewidth',1.5);
grid on;
xlim([0,t(final)]);
set(gca,'FontSize',12);
xlabel('Time (s)');
ylabel('Net Force (N)');
title('Net Force Against Time');
```



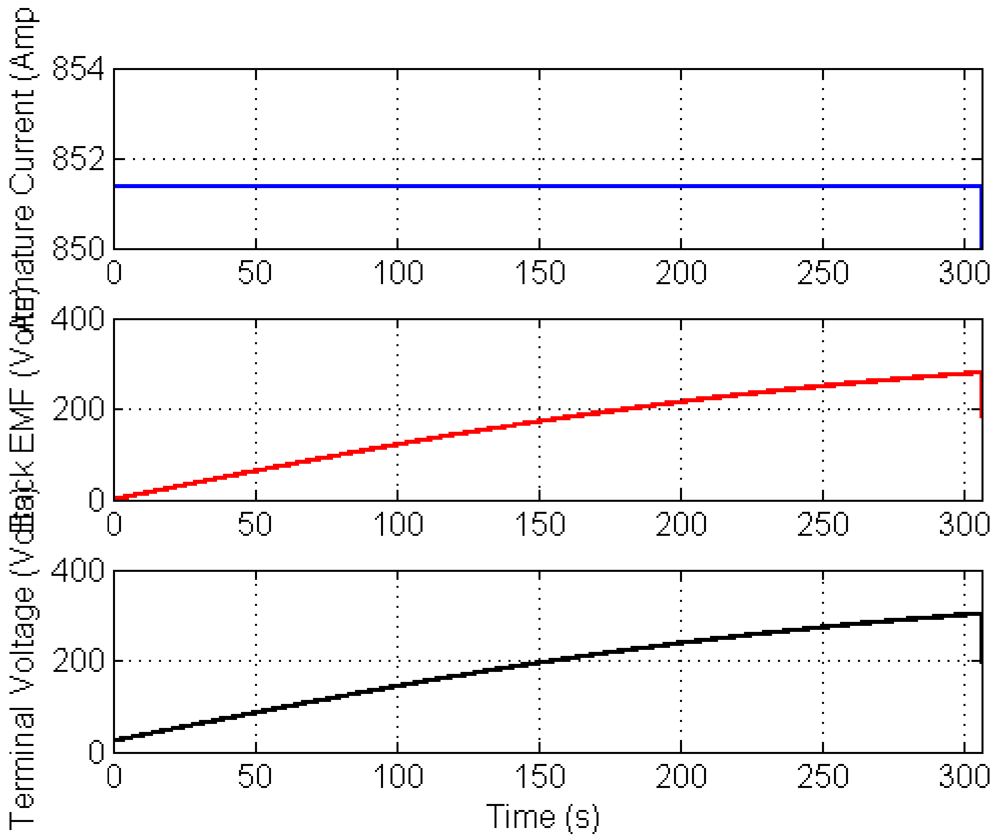
part a-(iii)

```
figure;
subplot(3,1,1);
plot(t,acceleration,'b -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Acceleration (m/s^2)');

subplot(3,1,2);
plot(t,velocity*3.6,'r -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Velocity (km/h)');

subplot(3,1,3);
plot(t,position,'k -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
xlabel('Time (s)');
ylabel('Position (m)');
```



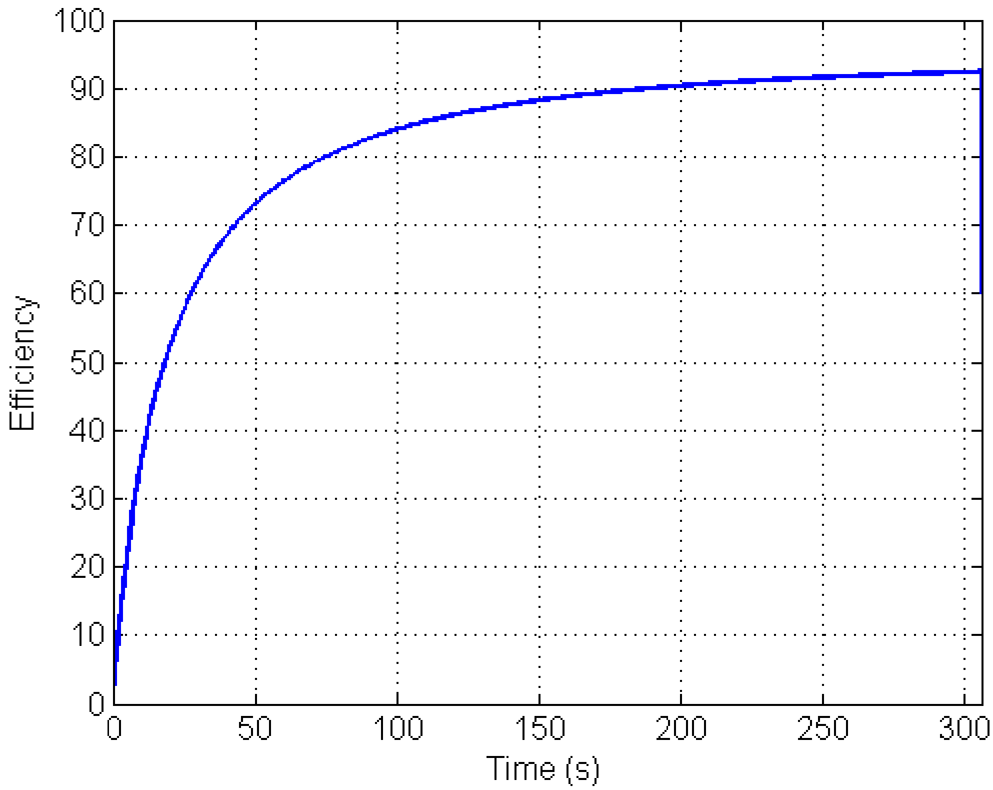
part a-(iv)

```
figure;
subplot(3,1,1);
plot(t,Ia,'b -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Armature Current (Amps)');

subplot(3,1,2);
plot(t,Ea,'r -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Back EMF (Volts)');

subplot(3,1,3);
plot(t,Vt,'k -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
xlabel('Time (s)');
ylabel('Terminal Voltage (Volts)');
```



part a-(v)

```
figure;
plot(t,efficiency,'b -','Linewidth',1.5);
grid on;
xlim([0,t(final)]);
set(gca,'FontSize',12);
xlabel('Time (s)');
ylabel('Efficiency');
ylim([0 100]);
```



part a-(vi)

```
time_length = t(final);
disp(time_length);

            306
```

part a-(vii)

```
position_length = position(final);
disp (position_length);

            6.8932e+03
```

part a-(viii)

The traction machines are operated in motoring mode

Ia is in positive direction

Vt and Ea have positive polarity

Part I-b

```
Ts = 1; %seconds
t = 0:Ts:1e3; %seconds
Num = numel(t);
final = 0;
Fnet = zeros(1,Num);
deceleration = zeros(1,Num);
```

```
velocity = 140/3.6*ones(1,Num);
position = zeros(1,Num);
Ea = zeros(1,Num);
Ia = zeros(1,Num);
Vt = zeros(1,Num);
wmotor = zeros(1,Num);
Nmotor = zeros(1,Num);
efficiency = zeros(1,Num);
```

All parameters found in part (a) are valid at this operating condition except net force. All force components are against (reverse direction to) the speed during acceleration.

The acceleration direction is reversed (deceleration) so that speed formula has a '-' sign.

The machine is in generating mode so that Ea is leading (Ea = Vt+RaIa). Efficiency is calculated such that EaIa is input power and VtIa is output power.

$$F_{net} = F_{train} + F_{drag} + F_{friction}$$

$$v(k+1) = v(k) - a(k)T_s$$

$$V_t = E_a - I_a R_a$$

$$P_{in} = V_t I_a$$

$$P_{out} = E_a I_a$$

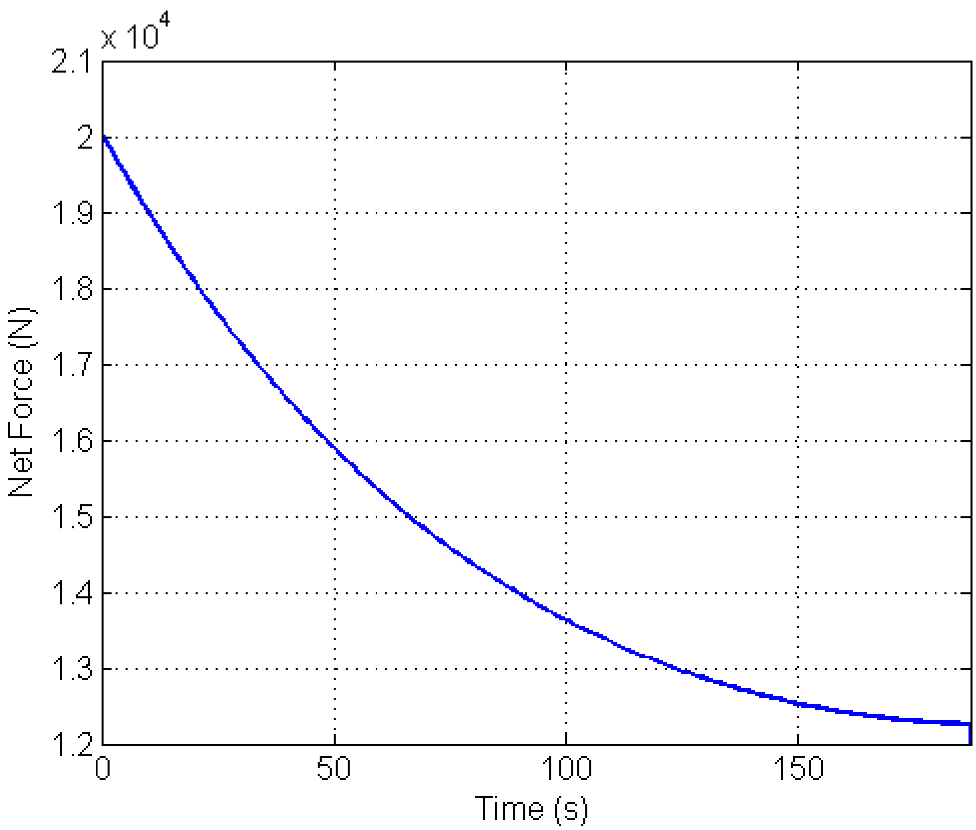
$$efficiency = 100 * P_{out}/P_{in}$$

```
% part a-(i)
wrated = Nrated*2*pi/60;
Trated = Prated/wrated;

Ftrain = Trated*2*gear_ratio/(wheel_radius);

k = 0;
while (1)
    k = k+1;

    Fdrag = (1/2)*Cd*A*p*velocity(k)^2;
    Ffriction = K*velocity(k);
    Fnet(k) = Ftrain+Fdrag+Ffriction;

    deceleration(k) = Fnet(k)/mass;
    velocity(k+1) = velocity(k) - deceleration(k)*Ts;
    position(k+1) = position(k) + velocity(k)*Ts;

    wmotor(k) = (velocity(k)/wheel_radius)*gear_ratio;
    Nmotor(k) = wmotor(k)*60/(2*pi);
    Ea(k) = Km*wmotor(k);
    Ia(k) = Trated/Km;
    Vt(k) = -Ia(k)*Ra + Ea(k);
    if Vt(k) >= 0
        Pout = abs(Vt(k)*Ia(k));
```

```
        Pin = abs(Ea(k)*Ia(k));
    else
        Pout = abs(Vt(k)*Ia(k));
        Pin = abs(Ea(k)*Ia(k));
    end
    efficiency(k) = 100*Pout/Pin;

    if velocity(k) <= 0;
        final = k;
        break;
    end
    if k > Num;
        break;
    end
end
```

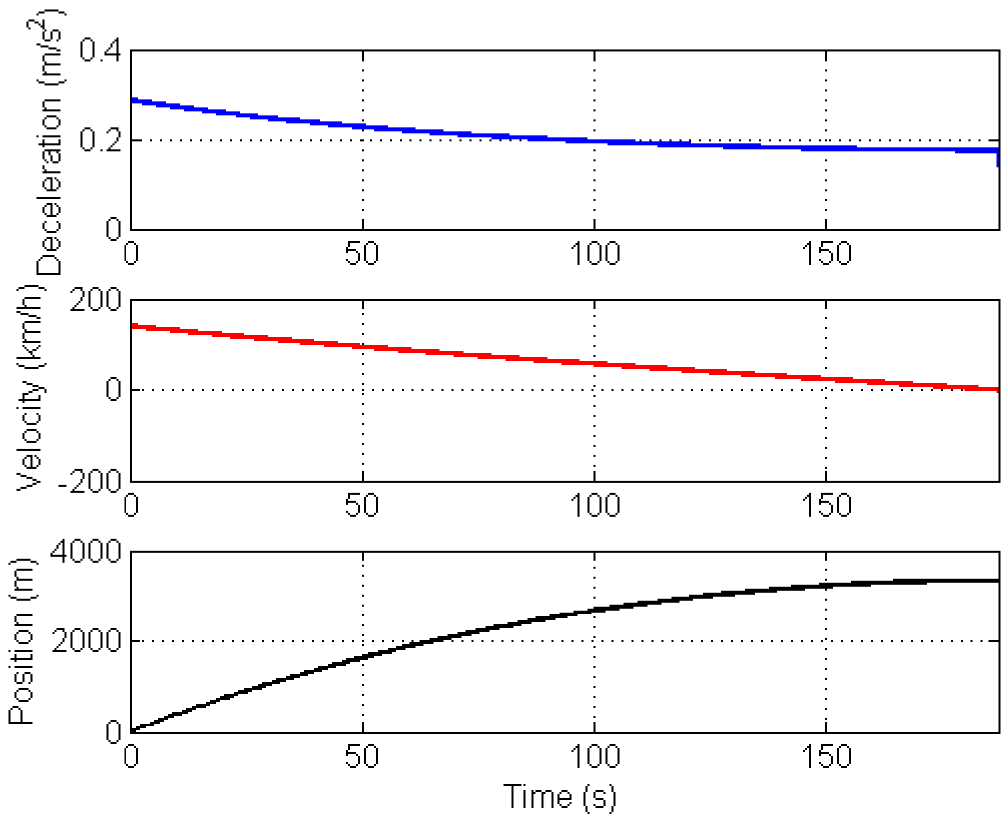
part b-(i)

```
figure;
plot(t,Fnet,'b -','Linewidth',1.5);
grid on;
xlim([0,t(final)]);
set(gca,'FontSize',12);
xlabel('Time (s)');
ylabel('Net Force (N)');
```



part b-(ii)

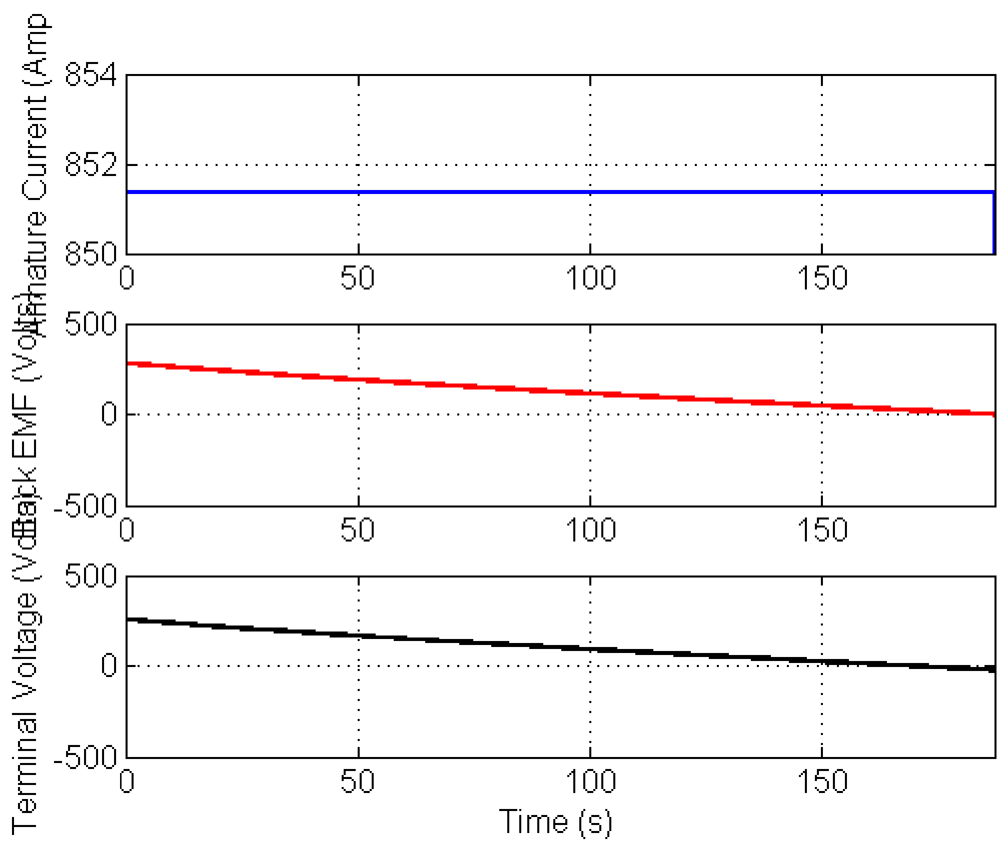
```
figure;
subplot(3,1,1);
plot(t,deceleration,'b -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Deceleration (m/s^2)');

subplot(3,1,2);
plot(t,velocity*3.6,'r -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Velocity (km/h)');

subplot(3,1,3);
plot(t,position,'k -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
xlabel('Time (s)');
ylabel('Position (m)');
```



part b-(iii)

```
figure;
subplot(3,1,1);
```

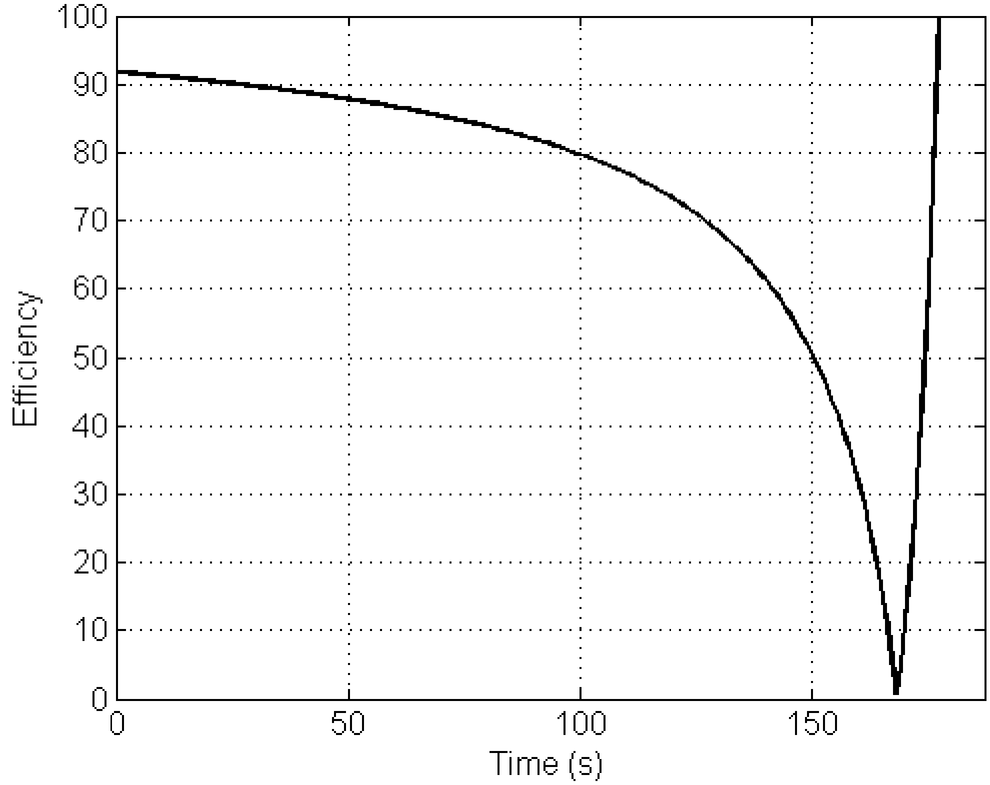
```
plot(t,Ia,'b -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Armature Current (Amps)');

subplot(3,1,2);
plot(t,Ea,'r -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Back EMF (Volts)');

subplot(3,1,3);
plot(t,Vt,'k -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
xlabel('Time (s)');
ylabel('Terminal Voltage (Volts)');
```



part b-(iv)

```
figure;
plot(t,efficiency,'k -','Linewidth',1.5);
grid on;
xlim([0,t(final)]);
```

```
set(gca,'FontSize',12);
xlabel('Time (s)');
ylabel('Efficiency');
ylim([0 100]);
```



part b-(v)

```
time_length = t(final);
disp(time_length);

           187
```

part b-(vi)

```
position_length = position(final);
disp (position_length);

           3.3401e+03
```

part b-(vii)

The traction machines are operated in generating mode (braking)

Ia is in negative direction

Vt and Ea have positive polarity for most of the operation. For very low speeds, since Ea is close to zero, Vt should be reversed by the DC/DC converter (reversed polarity)

Part II

```
Ts = 1; %seconds
t = 0:Ts:1e5; %seconds
Num = numel(t);
final = 0;
Fnet = zeros(1,Num);
acceleration = zeros(1,Num);
velocity = 140/3.6*ones(1,Num);
position = zeros(1,Num);
Ea = zeros(1,Num);
Ia = zeros(1,Num);
Vt = zeros(1,Num);
wmotor = zeros(1,Num);
Nmotor = zeros(1,Num);
efficiency = zeros(1,Num);
```

All parameters found in part (a) are valid at this operating condition except gravitational force. The force produced by the train (traction motors) is against all force components (friction, drag, gravitational)

$$F_{net} = F_{train} - F_{drag} - F_{friction} - F_{gravitational}$$

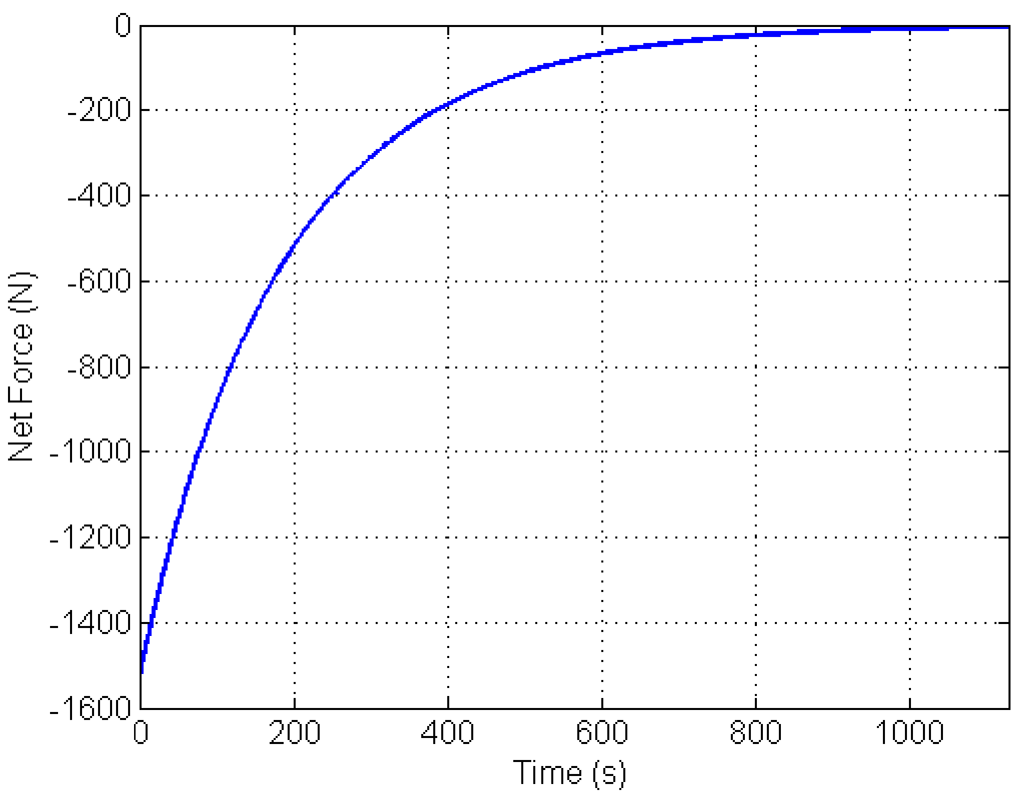
$$F_{gravitational} = mgsin(0.5)$$

```
wrated = Nrated*2*pi/60;
Trated = Prated/wrated;

Ftrain = Trated*2*gear_ratio/(wheel_radius);

k = 0;
while (1)
    k = k+1;

    Fdrag = (1/2)*Cd*A*p*velocity(k)^2;
    Ffriction = K*velocity(k);
    Fgravity = mass*g*sin(0.5*pi/180);
    Fnet(k) = Ftrain-Fdrag-Ffriction-Fgravity;

    acceleration(k) = Fnet(k)/mass;
    velocity(k+1) = velocity(k) + acceleration(k)*Ts;
    position(k+1) = position(k) + velocity(k)*Ts;

    wmotor(k) = (velocity(k)/wheel_radius)*gear_ratio;
    Nmotor(k) = wmotor(k)*60/(2*pi);
    Ea(k) = Km*wmotor(k);
    Ia(k) = Trated/Km;
    Vt(k) = Ia(k)*Ra + Ea(k);
    Pin = Vt(k)*Ia(k);
    Pout = Ea(k)*Ia(k);
    efficiency(k) = 100*Pout/Pin;

    if position(k) >= 40000;
        final = k;
```

```
        break;
    end
    if k > Num;
        break;
    end
end
```

part II-(i)

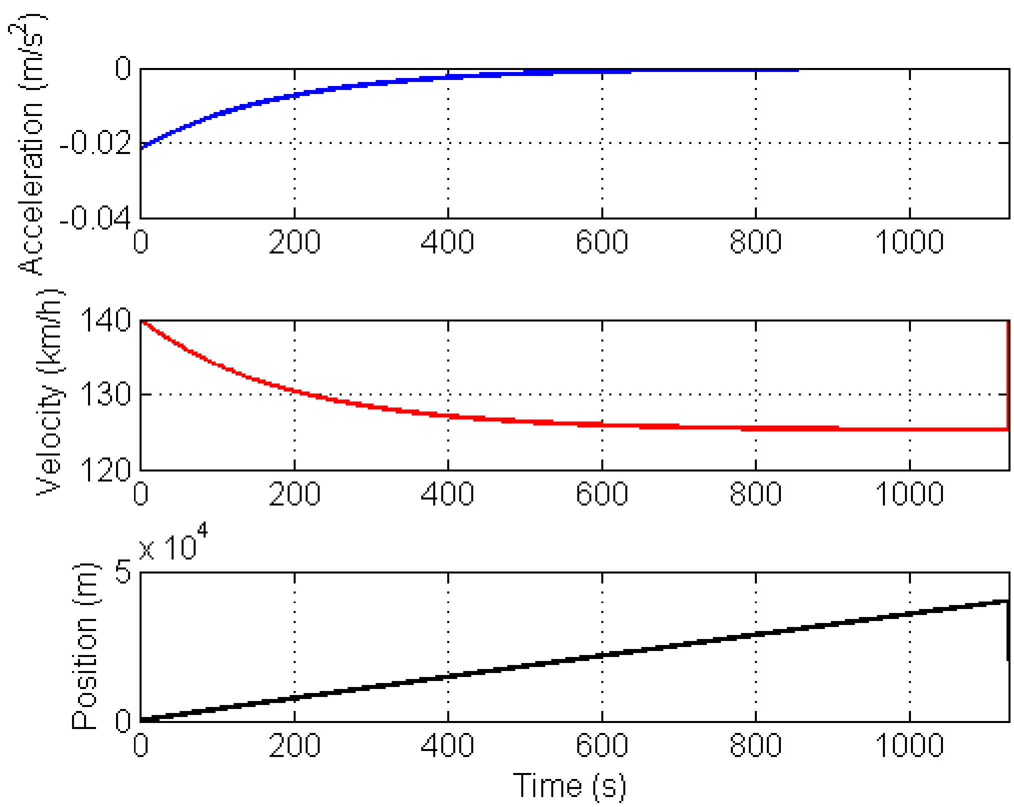
```
figure;
plot(t,Fnet,'b -','Linewidth',1.5);
grid on;
xlim([0,t(final)]);
set(gca,'FontSize',12);
xlabel('Time (s)');
ylabel('Net Force (N)');
```



part II-(ii)

```
figure;
subplot(3,1,1);
plot(t,acceleration,'b -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Acceleration (m/s^2)');
```

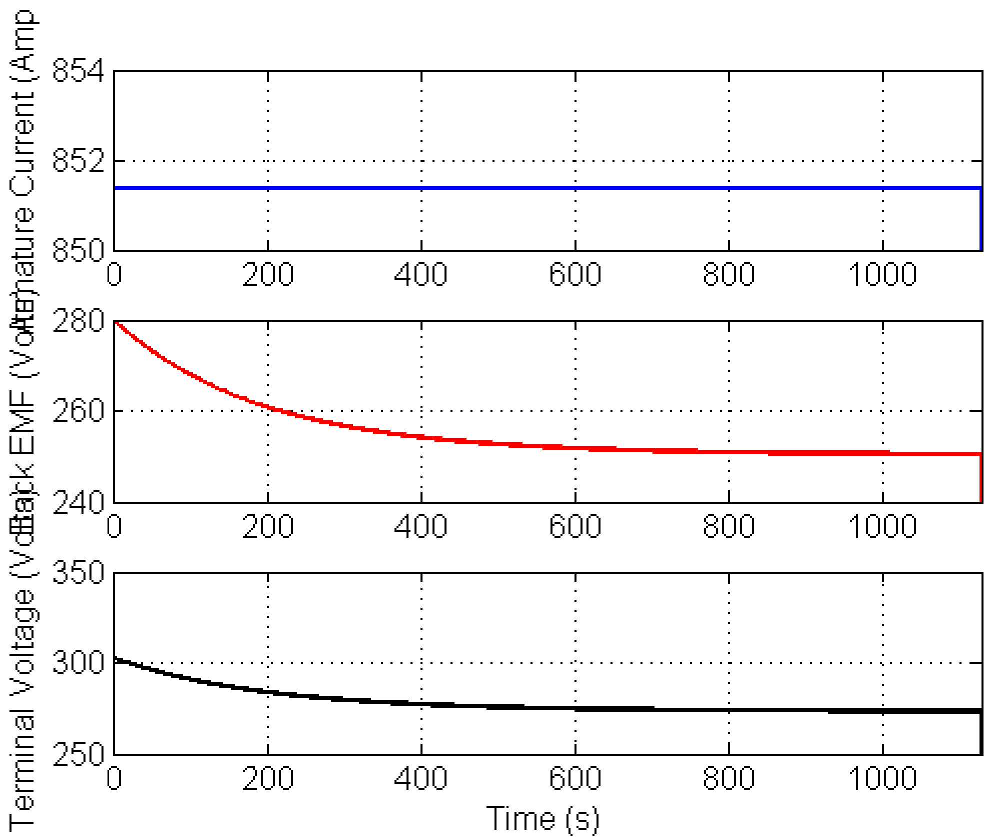
```
subplot(3,1,2);
plot(t,velocity*3.6,'r -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Velocity (km/h)');

subplot(3,1,3);
plot(t,position,'k -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
xlabel('Time (s)');
ylabel('Position (m)');
```



part II-(iii)

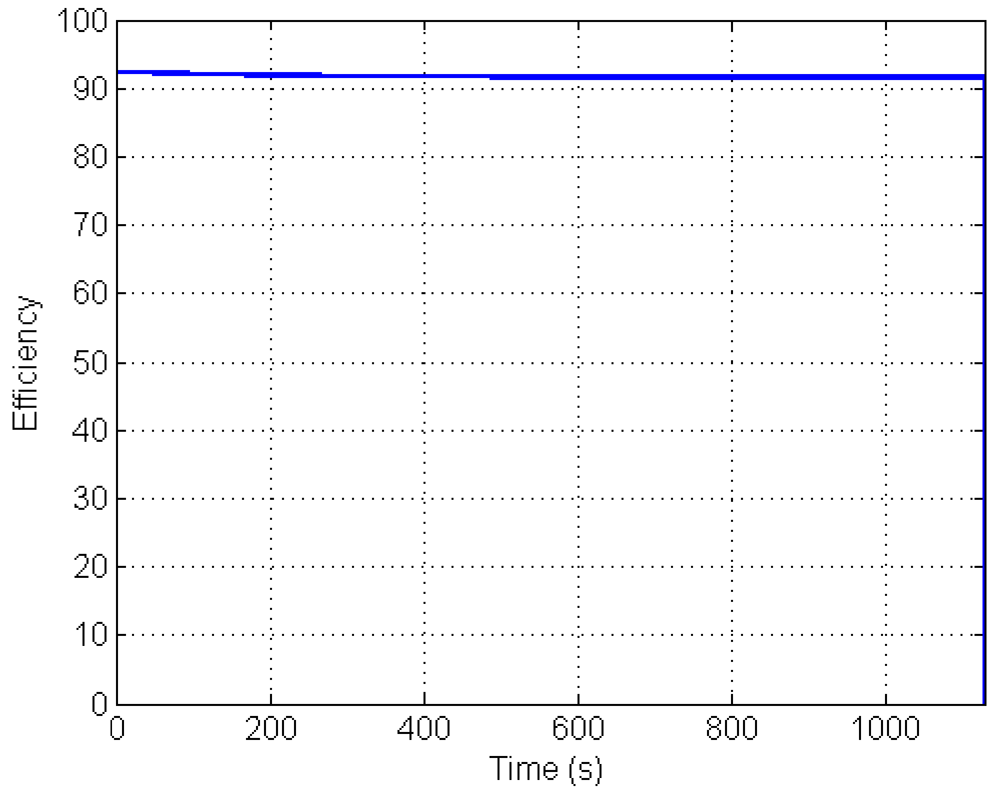
```
figure;
subplot(3,1,1);
plot(t,Ia,'b -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Armature Current (Amps)');

subplot(3,1,2);
plot(t,Ea,'r -','Linewidth',1.5);
```

```
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Back EMF (Volts)');

subplot(3,1,3);
plot(t,Vt,'k -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
xlabel('Time (s)');
ylabel('Terminal Voltage (Volts)');
```



part II-(iv)

```
figure;
plot(t,efficiency,'b -','Linewidth',1.5);
grid on;
xlim([0,t(final)]);
set(gca,'FontSize',12);
xlabel('Time (s)');
ylabel('Efficiency');
ylim([0 100]);
```



part II-(v)

```
time_length = t(final);
disp(time_length);
```

1128

part II-(vi)

The traction machines are operated in motoring mode

Ia is in positive direction

Vt and Ea have positive polarity

Part III

```
Ts = 1; %seconds
t = 0:Ts:1e5; %seconds
Num = numel(t);
final = 0;
Fnet = zeros(1,Num);
acceleration = zeros(1,Num);
velocity = 50/3.6*ones(1,Num);
%velocity = zeros(1,Num);
position = zeros(1,Num);
Ea = zeros(1,Num);
Ia = zeros(1,Num);
```

```
Vt = zeros(1,Num);
wmotor = zeros(1,Num);
Nmotor = zeros(1,Num);
efficiency = zeros(1,Num);
```

In this part, initial speed and electromagnetic torque (which produces Ftrain) are changed.

During downhill railroad, Ftrain, Fdrag anfd Ffriction are in the opposite direction with the speed whereas gravitational force is in the same direction. Thus net force changes as below.

As in part (I-b), the generation mode formulas are used.

$$F_{train} = (1/5)2T_{rated}gear/radius$$

$$v(0) = 50/3.6m/s$$

$$F_{net} = -F_{train} - F_{drag} - F_{friction} + F_{gravitational}$$

$$F_{gravitational} = mgsin(0.5)$$

$$V_t = E_a - I_a R_a$$

$$P_{in} = V_t I_a$$

$$P_{out} = E_a I_a$$

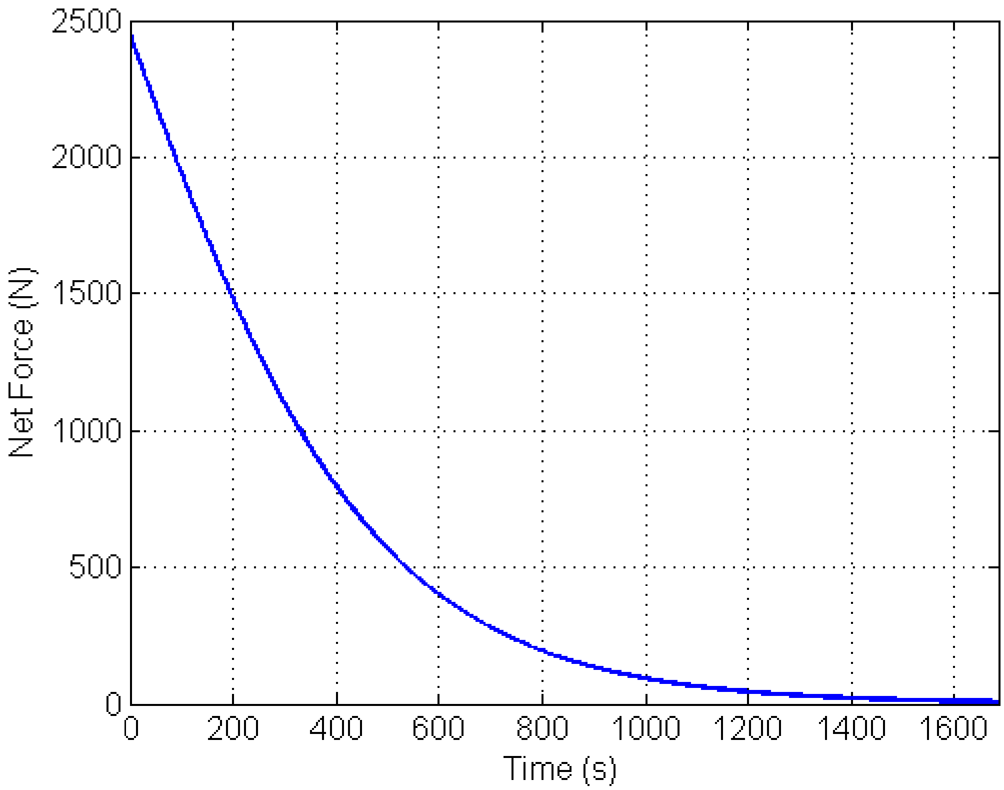
$$efficiency = 100 * P_{out}/P_{in}$$

```
wrated = Nrated*2*pi/60;
Trated = Prated/wrated;

Ftrain = (0.2)*Trated*2*gear_ratio/(wheel_radius);

k = 0;
while (1)
    k = k+1;

    Fdrag = (1/2)*Cd*A*p*velocity(k)^2;
    Ffriction = K*velocity(k);
    Fgravity = mass*g*sin(0.5*pi/180);
    Fnet(k) = -Ftrain-Fdrag-Ffriction+Fgravity;

    acceleration(k) = Fnet(k)/mass;
    velocity(k+1) = velocity(k) + acceleration(k)*Ts;
    position(k+1) = position(k) + velocity(k)*Ts;

    wmotor(k) = (velocity(k)/wheel_radius)*gear_ratio;
    Nmotor(k) = wmotor(k)*60/(2*pi);
    Ea(k) = Km*wmotor(k);
    Ia(k) = Trated/(5*Km);
    Vt(k) = -Ia(k)*Ra + Ea(k);
```

```
    Pin = Ea(k)*Ia(k);
    Pout = Vt(k)*Ia(k);
    efficiency(k) = 100*Pout/Pin;

    if position(k) >= 40000;
        final = k;
        break;
    end
    if k > Num;
        break;
    end
end
```

part III-(i)

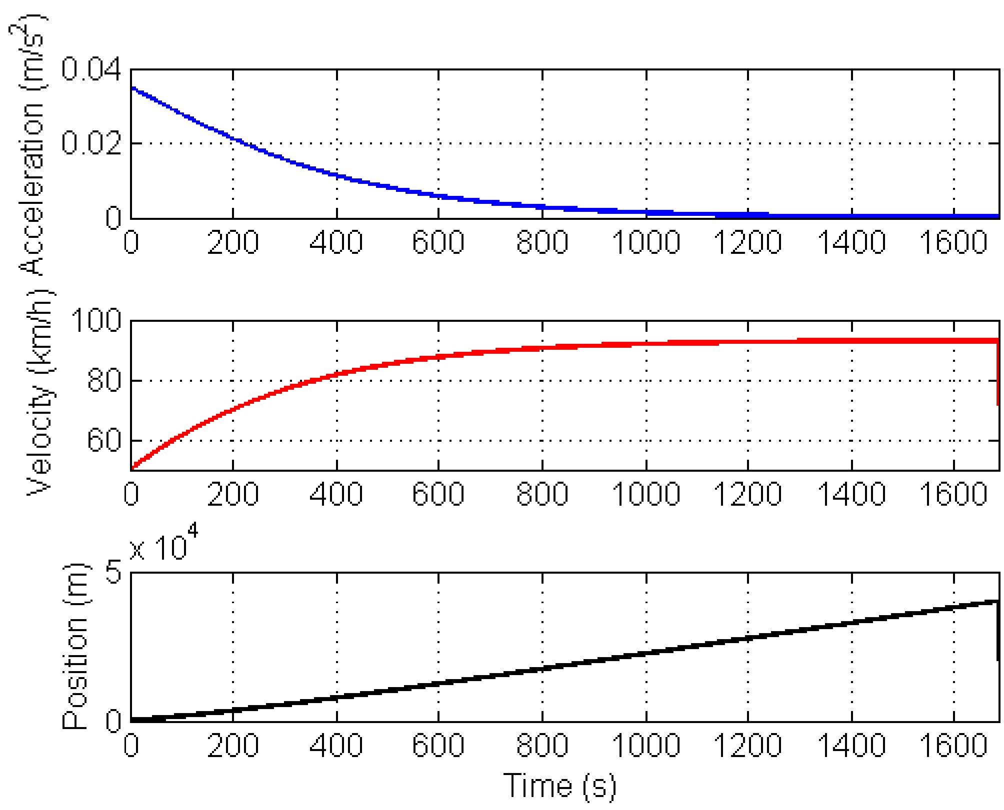
```
figure;
plot(t,Fnet,'b -','Linewidth',1.5);
grid on;
xlim([0,t(final)]);
set(gca,'FontSize',12);
xlabel('Time (s)');
ylabel('Net Force (N)');
```



part III-(ii)

```
figure;
subplot(3,1,1);
```

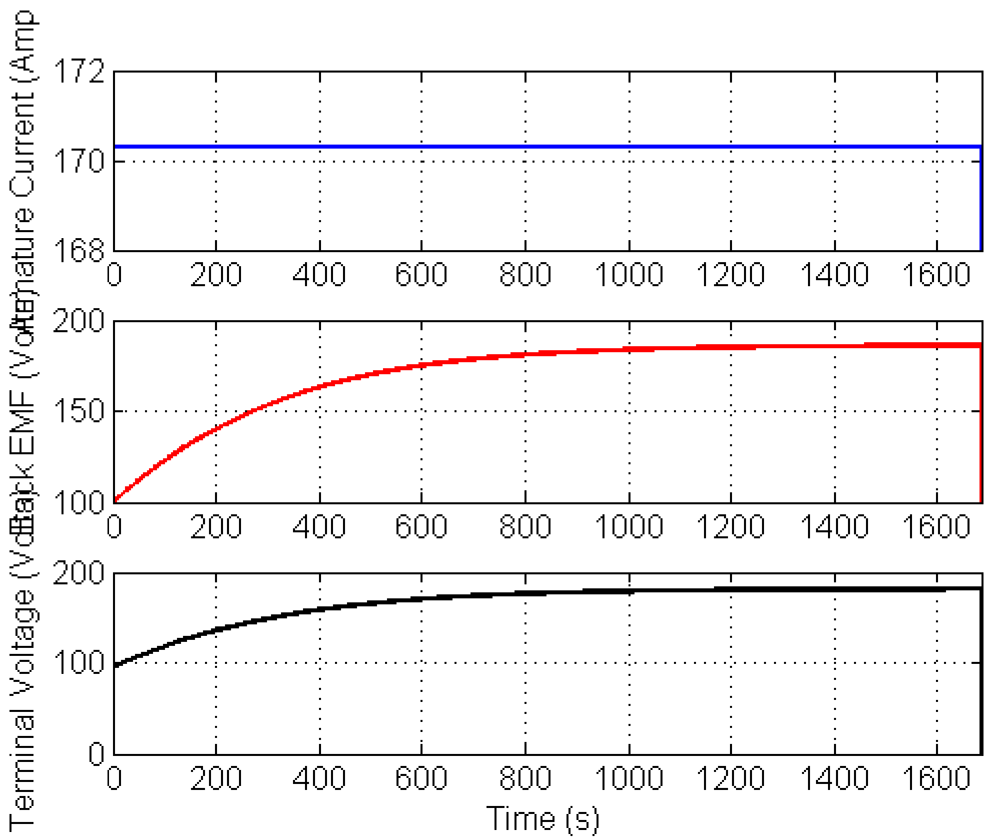
```
plot(t,acceleration,'b -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Acceleration (m/s^2)');

subplot(3,1,2);
plot(t,velocity*3.6,'r -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Velocity (km/h)');

subplot(3,1,3);
plot(t,position,'k -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
xlabel('Time (s)');
ylabel('Position (m)');
```



part III-(iii)

```
figure;
subplot(3,1,1);
plot(t,Ia,'b -','Linewidth',1.5);
grid on;
```

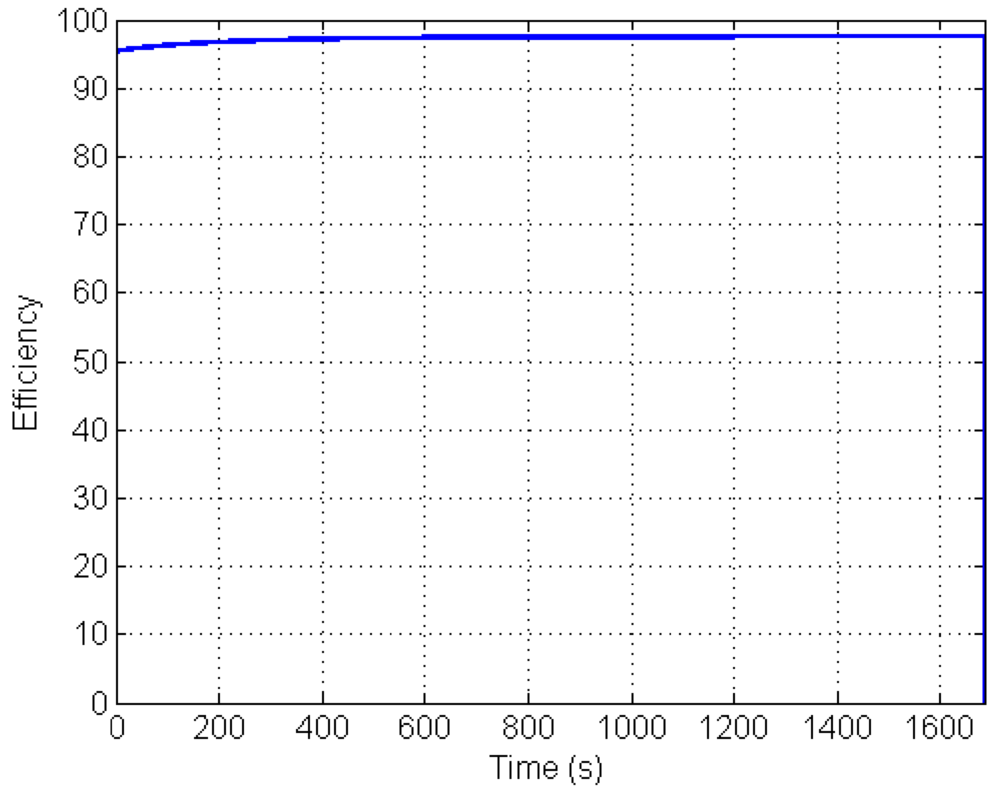
```
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Armature Current (Amps)');

subplot(3,1,2);
plot(t,Ea,'r -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
ylabel('Back EMF (Volts)');

subplot(3,1,3);
plot(t,Vt,'k -','Linewidth',1.5);
grid on;
set(gca,'FontSize',12);
xlim([0,t(final)]);
xlabel('Time (s)');
ylabel('Terminal Voltage (Volts)');
```



part III-(iv)

```
figure;
plot(t,efficiency,'b -','Linewidth',1.5);
grid on;
xlim([0,t(final)]);
set(gca,'FontSize',12);
xlabel('Time (s)');
```

```
ylabel('Efficiency');
ylim([0 100]);
```



part III-(v)

```
time_length = t(final);
disp(time_length);
```

```
        1686
```

part III-(vi)

The traction machines are operated in generating mode (braking)

Ia is in negative direction

Vt and Ea have positive polarity

```
%publish('solution_hw5.m', 'pdf')
```

Published with MATLAB® R2013a