# Assignment 1 – Selecting an Electric Vehicle Powertrain

## 2. Studied Vehicle

*2.1 Dynamic Model*

$$m\frac{dv}{dt} = F_w - F_d$$

$m$ is the mass of the vehicle, $v$ is forward velocity, $F_w$ is the accelerating force generated by the driving wheels, and $F_d$ is the force that resists the motion. The resistive force $F_d$ depends on the forward velocity $v$, and it can be modelled as

$$F_d = (C_d v^2 + C_r mg)sign(v)$$

where $C_d$is the drag coefficient and $C_r$ is the rolling resistance coefficient.

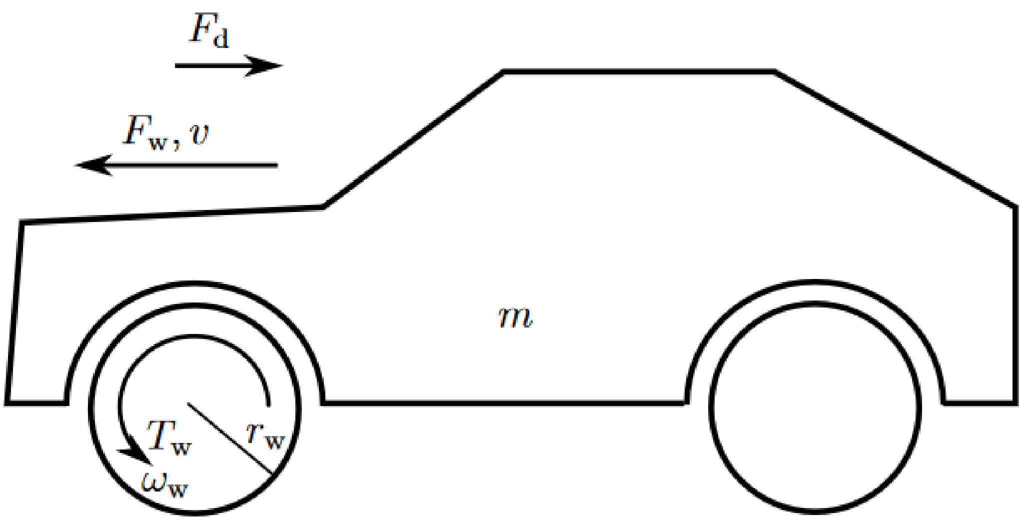


**Figure 1:** Vehicle model.

**Table 1:** Vehicle-model parameters.

| | |
|---|---|
| Mass of the chassis $m$ | 1 500 kg |
| Radius of the driving wheels $r_w$ | 0.295 m |
| Reduction-gear ratio $i$ | 8 |
| Drag coefficient $C_d$ | 0.65 kg/m |
| Rolling-resistance coefficient $C_r$ | 0.015 |
| Gravitational acceleration $g$ | 9.81 m/s$^2$ |

*2.2 New European Driving Cycle Velocity Profile*

1. Open MATLAB and create a script that loads the downloaded datafile `NEDC.mat` into the workspace and then plots the NEDC velocity profile $v$ (see Figure 2). Include the figure in your report. You can use the command `whos` to sort out the name of the time-series variable inside the loaded datafile.

1. A script that loads the downloaded datafile NEDC.mat into the workspace in MATLAB and then plots the NEDC velocity profile $v$ can be seen below.

```
% 2.2 New European Driving Cycle Velocity Profile

% Load a data file data file.mat into the workspace

load('NEDC.mat')

t = velocity.Time;
% Data y values
y = velocity.Data;
y_ms1 = y./3.6; % Velocity in m/s

%  Plot velocity in km/h

plot(t,y,'-b','LineWidth',1.25);
grid on;
xlabel('Time [s]')
ylabel('Velocity [km/h]')
title('New European Driving Cycle (NEDC) Velocity Profile')
set(gca,'fontsize',12)

% Plot velocity in m/s

plot(t,y_ms1,'-b','LineWidth',1.25);
grid on;
xlabel('Time [s]')
ylabel('Velocity [m/s]')
title('New European Driving Cycle (NEDC) Velocity Profile')
set(gca,'fontsize',12)
```

**Code 1.** MATLAB code to load the downloaded datafile NEDC.mat into the MATLAB workspace and then plot the NEDC velocity profile with respect to time. Two plots are created, one, where velocity is expressed in km/h and the other, where it is expressed in m/s.

Plots of the NEDC velocity profile with respect to time can be seen below in Figures 1 & 2.

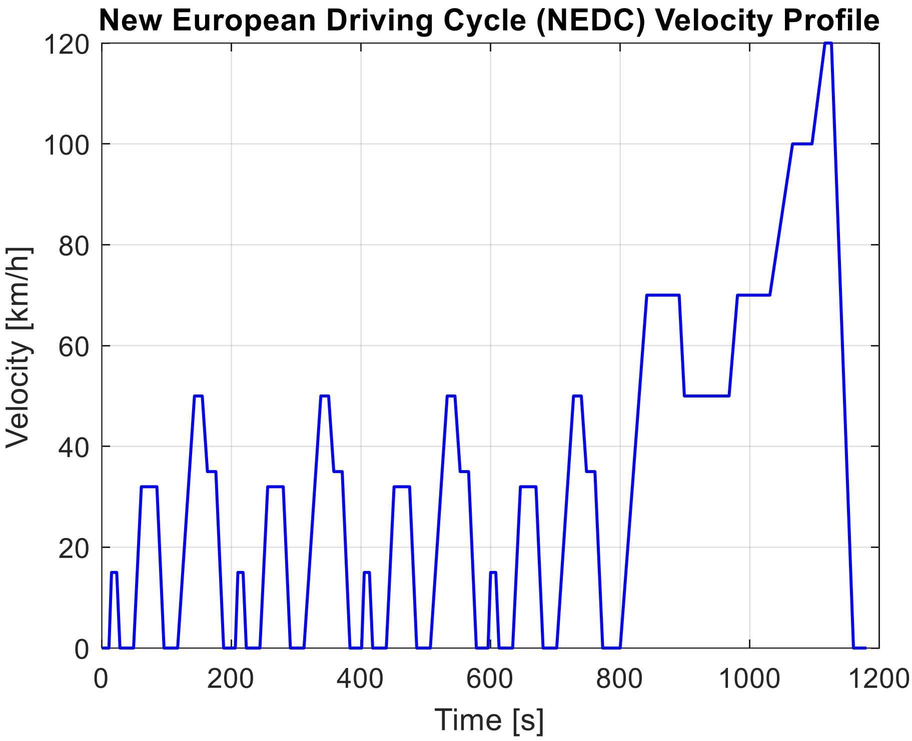


*Figure 1: Plot of NEDC velocity profile with respect to time. Units for velocity are km/h.*

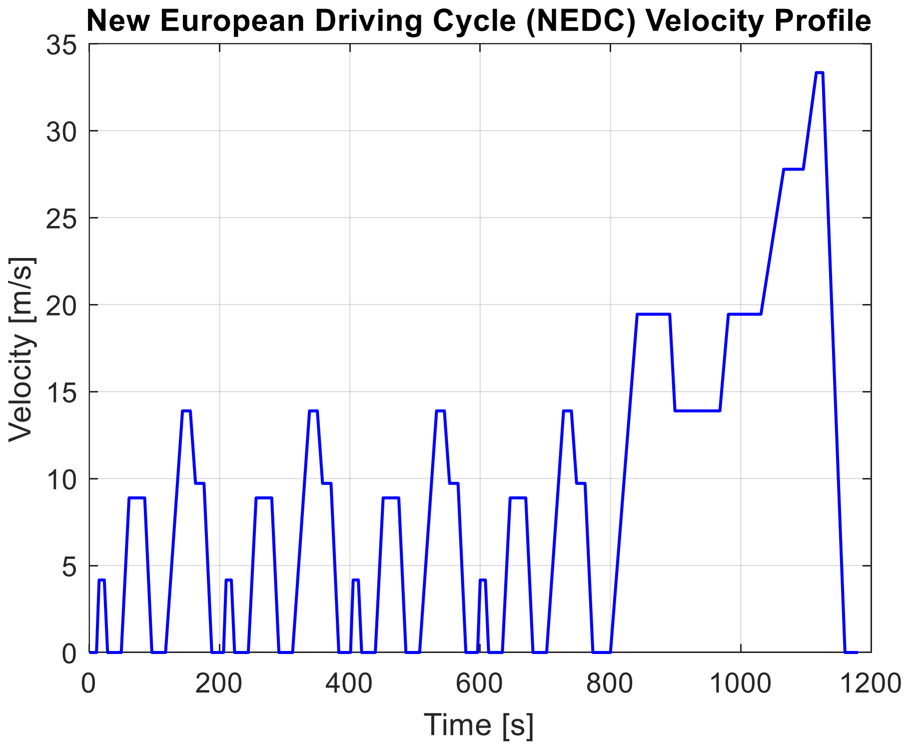


*Figure 2: Plot of NEDC velocity profile with respect to time. Units for velocity are m/s.*

### *2.3 Acceleration and Wheel Force of the Vehicle*

2. Calculate the longitudinal acceleration $\mathrm{d}v/\mathrm{d}t$ of the vehicle based on the NEDC velocity profile $v$. You may use the previously listed example to complete this task. Then, plot the obtained acceleration profile as a function of time $t$.
3. Use (1) together with the velocity $v$ and the acceleration profile $\mathrm{d}v/\mathrm{d}t$ to define the required wheel force $F_{\mathrm{w}}$ as a function of time. Plot the result.

2. Script used to calculate the longitudinal acceleration $\frac{dv}{dt}$ based on the NEDC velocity profile $v$, can be seen below.

```
% 2.3 Acceleration and wheel force of the vehicle

N = length(t);

% Calculate the acceleration with the use of a for loop, where velocity in
% m/s is used.

for k = 1:N-1
    dyt(k) = (y_ms1(k+1)-y_ms1(k))/(t(k+1)-t(k)); % Acceleration in m/s

end

% Adding an extra zero in the end to make dyx the same length as y and

dyt = [dyt 0];

figure 3
plot(t,dyt)
grid on;
xlabel('Time [s]')
ylabel('Acceleration [m/s^2]')
title('Longditudinal Acceleration as a Function of Time')

figure 4
plot(t,dyt) % Plot acceleration in m/s^2
hold on
plot(t,y_ms1,'-b','LineWidth',1.25); % Plot velocity in m/s
grid on;
```

**Code 2.** MATLAB code to calculate the longitudinal acceleration of the vehicle based on the NEDC velocity profile.

Plot of the obtained acceleration profile as a function of time $t$ can be seen in Figure 3

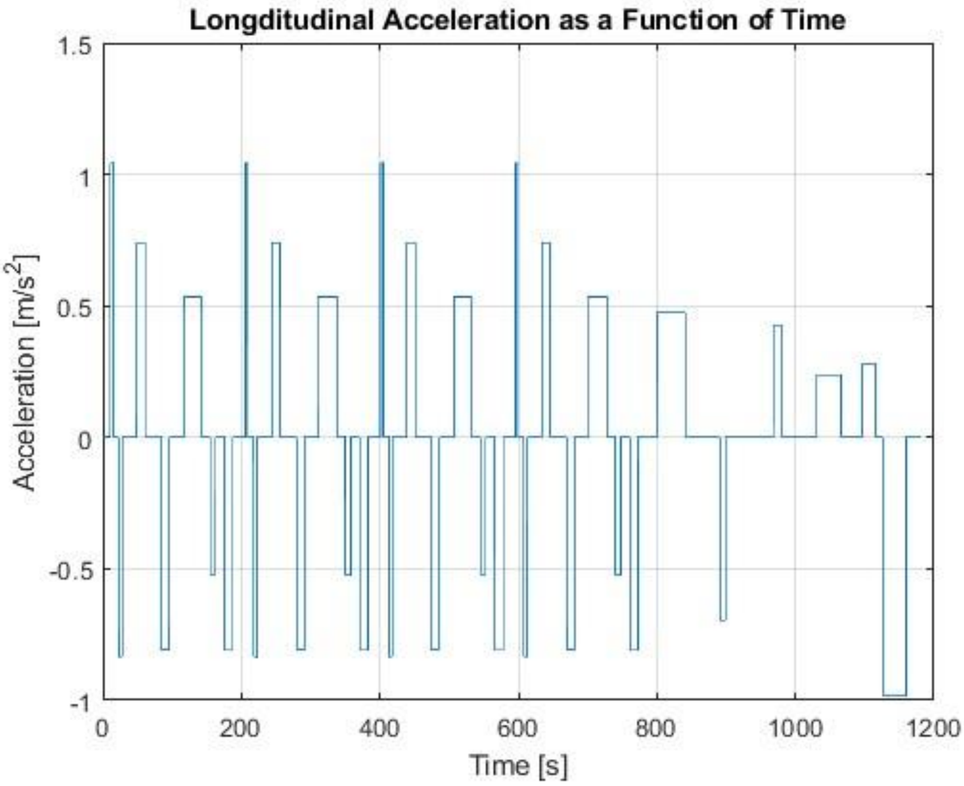


*Figure 3: Plot of Longitudnal Acceleration of Vehicle with respect to time. Units for longitudnal acceleration are m/s^2.*

3. Script used for defining the required wheel force $F_w$ as a function of time using velocity $v$ and longitudinal acceleration $\frac{dv}{dt}$ profile, can be seen below.

```
% Calculate the resistive force in order to define the required wheel
% force as a funciton of time

% To calculate a power function x^(n), where n is an arbitrary power
v_2 = y_ms1.^2;
sign_velocity = sign(y_ms1);

F_d = (C_d.*v_2+(C_r*m*g)).*sign_velocity; % Calculation of resistive force

F_w = m.*dyt'+F_d; % Calculation of required wheel force, dyt is transposed

% Plot of required wheel force, Fw, as a function of time based on NEDC
% velocity profile

figure
plot(t,F_w,'MarkerFaceColor',"#0072BD",'LineWidth',1.1)
grid on;
xlabel('Time [s]')
ylabel('Wheel force [N]')
title('Required Wheel Force as a Function of Time')
set(gca,'fontsize',10)
```

**Code 3.** MATLAB code to calculate the required wheel force $F_w$ as a function of time using velocity $v$ and longitudinal acceleration $\frac{dv}{dt}$ profile

Plot of the obtained wheel force $F_w$ can be seen in Figure 4

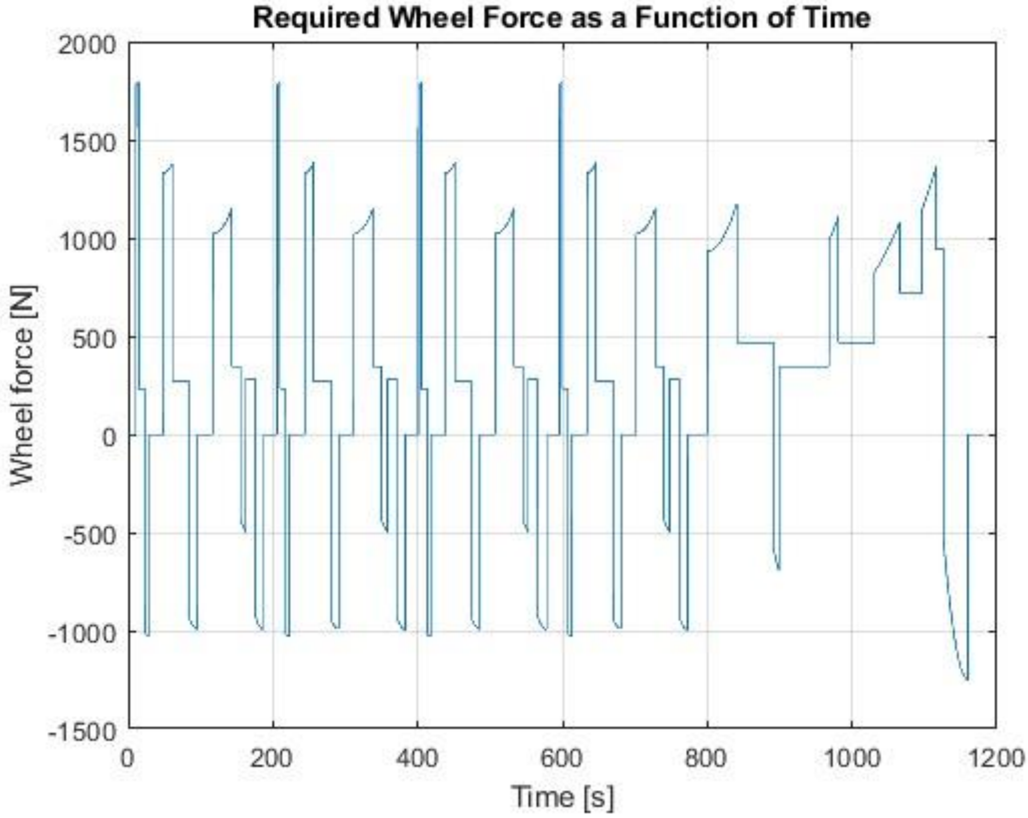


*Figure 4: Plot of Required Wheel Force with respect to time. Units for Wheel Force are N*

## *2.4 Maximum Performance*

The maximum performance of the vehicle is defined based on the required top speed of the vehicle $v_{max}$ and the required 0–100 km/h acceleration time $t_{100}$. These values are given in Table 2.

**Table 2:** Performance specifications.

| | |
|---|---|
| Top speed $v_{\max}$ | 150 km/h |
| 0–100 km/h acceleration time $t_{100}$ | 8 s |

4. Based on the values given in Table 2, calculate the maximum torque $\tau_{\mathrm{w,max}}$ and the maximum rotational speed $\omega_{\mathrm{w,max}}$ required from the driving wheels. For simplicity, assume constant motion resistive force $F_{\mathrm{d}} = 500$ N in this task.

4. Script used for calculating the maximum torque $\tau_{w,max}$ and the maximum rotational speed $\omega_{w,max}$ required from the driving wheels, can be seen below.

```
% 2.4 Maximum performance of the vehicle

vmax = 150/3.6; % Vehicle's top speed in m/s
t100 = 8; % Vehicle's acceleration time to 100 km/h
amax = (100/3.6)/t100; % Vehicle's maximum acceleration, where average acceleration =
(vf-vi)/t
F_dC = 500; % Constant motion resistive force

F_wmax = m*amax+F_dC; % Calculation of required maximum wheel force at two wheels when
accelerating to 100 km/h in 8s
F_wmax_1 = F_wmax/2; % Calculation of maximum wheel force at 1 wheel
Twmax = r_w*F_wmax; % Calculation of required maximum torque at the driving wheels
Twmax_1 = r_w*F_wmax_1; % Calculation of required maximum torque at one driving wheel
Pmax = F_wmax*vmax; % Calculation of maximum power required at vmax
w_wmax = Pmax/Twmax; % Calculation of maximum rotational speed * Dependent on max speed
only and radius of wheel
```

```
Twmax_1 =                w_wmax =

  841.9792                 141.2429
```

**Code 4.** MATLAB code for calculating the maximum torque $\tau_{w,max}$ and the maximum rotational speed $\omega_{w,max}$ required from the driving wheels along with their results.

## 3. Traction Motor

### *3.1 Speed and Torque of the Motor*

5. Use the velocity profile (given in Section 2.2) and calculate the motor speed $\omega_M$ as a function of time. Plot the result.
6. Furthermore, use the wheel force $F_w$ (defined in Section 2.3) to calculate the motor torque $\tau_M$ as a function of time. Plot the result. As an example, the motor torque (with an undefined reduction-gear ratio) is shown in Figure 3. Then, calculate the required mechanical power $p_M$ as a function of time and plot the result.

5. Script used to calculate the motor speed $\omega_m$ as a function of time and then plotting it against time, can be seen below.

```
3.1 Speed and torque of the motor

ww = y_ms1./r_w; % Angluar speed of wheel
wm = ww.*i; % Calculate angular speed of motor

% Plot motor speed wm based on given velocity profile

figure
plot(t,wm,'-r')
grid on;
xlabel('Time [s]')
ylabel('Motor speed [rad/s]')
title('Motor Speed as a Function of Time')
```

**Code 5.** MATLAB code to calculate the motor speed $\omega_m$ as a function of time and its result

Plot of the obtained motor speed $\omega_m$ as a function of time can be seen in Figure 5

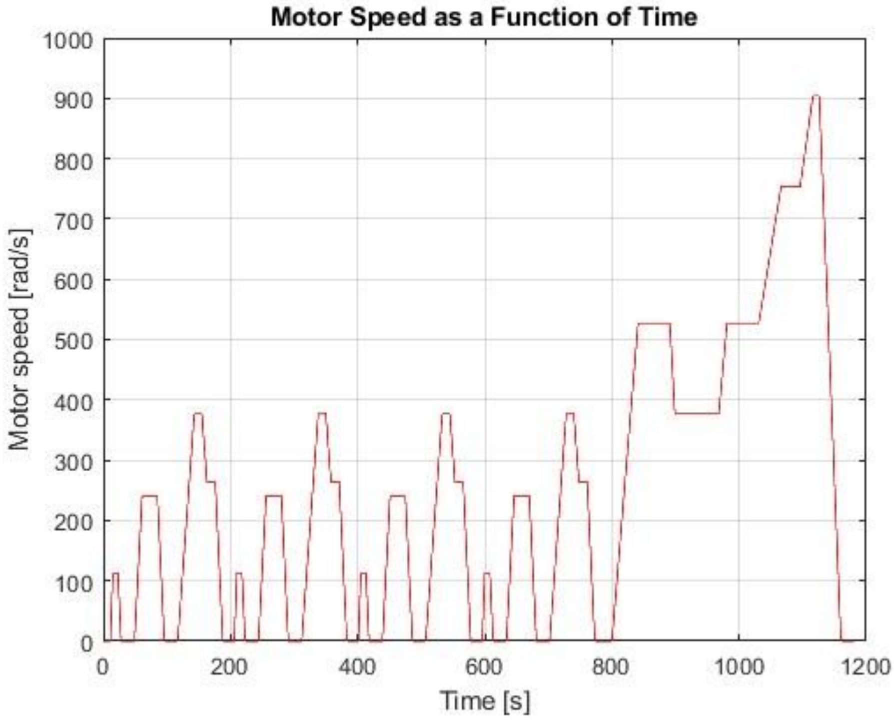


*Figure 5: Plot of Motor Speed with respect to time. Units for speed are rad/s.*

6. Script used to calculate the motor torque $\tau_m$ as a function of time using the wheel force $F_w$ and then plotting it against time along with the calculation of mechanical power $p_m$ with respect to time and its plot, can be seen below.

```
% Calculate the motor torque t_m as a function of time from wheel force F_w

T_w = F_w*r_w; % Calculate the wheel torque based on the wheel force and the wheel
radius. *Note* the motor should 'see' all of the torque
T_m = T_w./i; % Calculate the motor torque based on the gear ratio

% Plot motor torque as a function of time
figure
plot(t,T_m,'-r')
grid on;
xlabel('Time [s]')
ylabel('Motor torque [Nm]')
title('Motor Torque as a Function of Time')

% Calculate the motor power P_m as a function of time

P_m = wm.*T_m; % Calculate motor power in terms of motor torque and motor speed

% Plot motor power as a function of time
figure
plot(t,P_m,'-k')
grid on;
xlabel('Time [s]')
```

```
ylabel('Motor Power [W]')
title('Motor Power as a Function of Time')
```

**Code 6.** MATLAB code to calculate the motor torque $\tau_m$ as a function of time using the wheel force $F_w$ and then plotting it against time along with the calculation of mechanical power $p_m$ with respect to time and its plot

Plot of the obtained motor torque $\tau_m$ and mechanical power $p_m$ as a function of time can be seen in Figure 6 and Figure 7

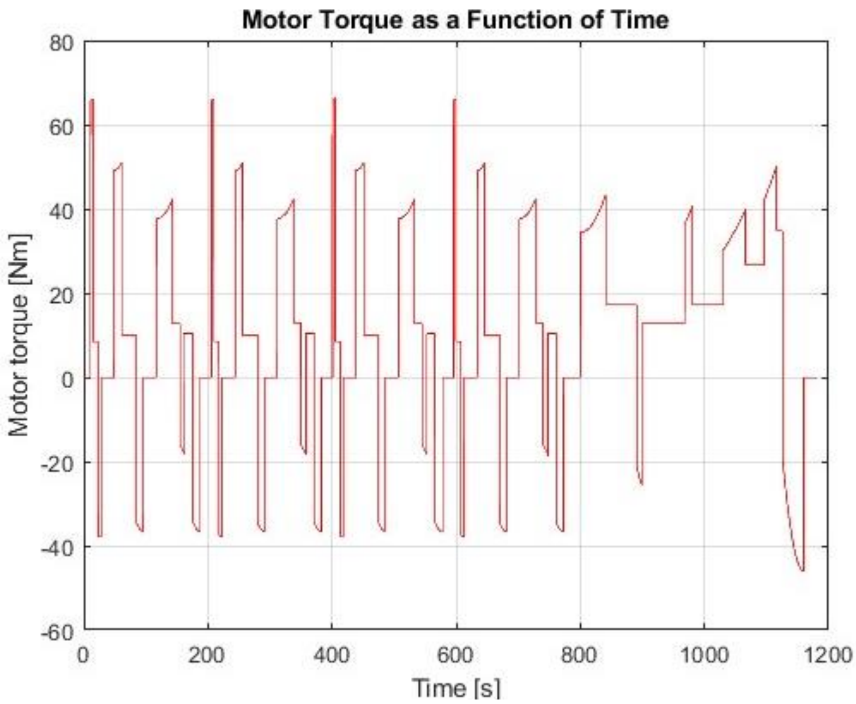


*Figure 7:Plot of Motor Torque with respect to time. Units for Torque are Nm.*

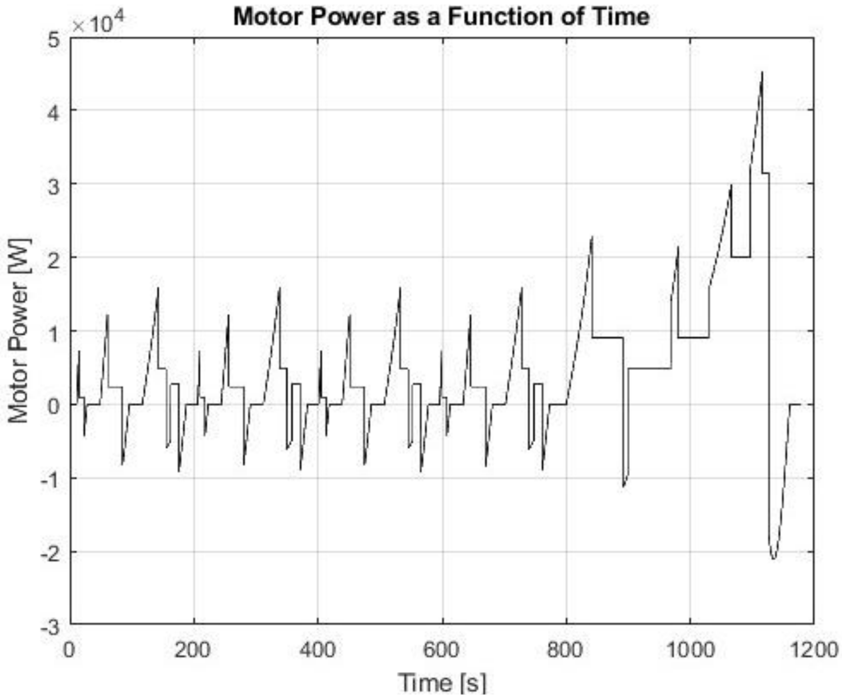


*Figure 6: Plot of Motor Power with respect to time. Units for Power is Watt.*

### *3.2 Maximum Performance*

> 7. Use the values defined in Section 2.4 and calculate the maximum torque $\tau_{\mathrm{M,max}}$ and maximum speed $\omega_{\mathrm{M,max}}$ required from the traction motor.

7. Script used to calculate the maximum torque $\tau_{M,max}$ and maximum speed $\omega_{M,max}$ , can be seen below.

```
% 3.2 Determine motor's maximum performance

Tm_max = Twmax./i; % Calculate the maximum torque required from the traction motor
based on the gear ration and maximum torque required at the wheels
w_m_max = w_wmax.*i; % Calculate the maximum speed required from the traction motor
based on the gear ratio and the maximum speed required at the wheels
```

```
Tm_max =                w_m_max =

  210.4948               1.1299e+03
```

**Code 7.** MATLAB code for calculating the maximum torque $\tau_{M,max}$ and the maximum rotational speed $\omega_{M,max}$ required from the driving wheels along with their results.

### *3.3 Effective Torque of the Motor*

If the traction motor operates in the full-field region ($|\omega_{\mathrm{M}}| \leq \omega_{\mathrm{N}}$) at $t = 0 \ldots T_1$, and in the field-weakening region ($|\omega_{\mathrm{M}}| > \omega_{\mathrm{N}}$) at $t = T_1 \ldots T$, then the effective torque of the motor is defined as

$$\tau_{\mathrm{M,ef}} = \sqrt{\frac{1}{T}\left(\int_0^{T_1} \tau_{\mathrm{M}}^2 \mathrm{d}t + \frac{1}{\omega_{\mathrm{N}}^2}\int_{T_1}^{T} p_{\mathrm{M}}^2 \mathrm{d}t\right)} \tag{3}$$

> 8. Calculate the effective torque of the traction motor based on the torque and power cycles defined in Section 3.1. The nominal speed of the motor can be assumed to be $n_{\mathrm{N}} = 4\,000$ r/min.

8. Script used to calculate the effective torque of the traction motor based on the torque and power cycles defined, can be seen below.

```
% 3.3 Effective Torque of the Motor

% Calculate the effective torque  the traction motor based on the torque
% and power cycles defined in Section 3.1

% Nominal motor speed
wn_rad = 4000/60*2*pi; % Nominal motor speed in radians/s
```

```
% Number of samples in the motor-torque data vector T_m
N = length(T_m);
% Drive-cycle end time T
T = t(end);
% Calculate the value inside the integrals in (3) at each time instant k
for k = 1:N
    if abs(wm(k)) < wn_rad
        % When the motor operates in full-field region
        TI(k) = T_m(k)^2;
    else
        % When the motor operates in field-weakening region
        TI(k) = P_m(k)^2/wn_rad^2;
    end
end

% Numerical integration can be completed using trapz command
T_m_ef = sqrt(trapz(t, TI)/T);
```

```
T_m_ef =

   31.1683
```

**Code 8.** MATLAB code for the effective torque of the traction motor based on the torque and power cycles defined along with its result.

## 4. Motor and Converter Selection

9. Select a suitable traction motor from the motor list (available at the MyCourses portal). Pay attention to the nominal torque, the maximum rotational speed, and the maximum torque. Explain briefly how you selected the motor.
10. Select a suitable converter for the motor from the converter list. Explain briefly your selection.

9. Traction Motor Selection

The **BRUSA HSM1-12.18.13 Hybrid Synchronous Motor** presents a comprehensive set of specifications that warrant careful evaluation in the context of our vehicle's particular requirements:

- **Nominal Speed:** The motor operates at a nominal speed of **4,800 rpm**, which notably surpasses the specified nominal speed of **4,000 rpm.**

- **Continuous Torque:** This motor offers a continuous torque of **180 Nm**, displaying a commendable level of torque thus fulfilling the nominal torque requirement of **31.16 Nm** of our motor.

- **Max. Torque:** The motor can generate a maximum torque of **250 Nm**, which is near to our specified maximum torque of **210.4948 Nm**.

- **Continuous Power:** It delivers a continuous power output of **90 kW** at 25°C, which is within the limit of our power requirement of **45.24 kW.**

- **Typical Efficiency:** With an efficiency rating of **96%**, this motor excels at converting electrical energy into mechanical power, minimizing energy loss.

- **Insulation Class:** Classified as **"H,"** this motor demonstrates high-temperature resilience, a vital characteristic for durability.

In summary, the ***BRUSA HSM1-12.18.13 Hybrid Synchronous Motor*** admirably balances exceptional torque and speed capabilities, reinforced by a noteworthy efficiency rating. Its aptitude to accommodate a wide voltage range, coupled with robust insulation and protection features, further underpin its suitability for our vehicle. With this motor at the heart of our vehicle's propulsion system, we can expect dynamic and responsive driving experience, ensuring both performance and reliability.

10. Converter Selection

Based on the specifications of the **BRUSA HSM1-12.18.13 Hybrid Synchronous Motor**, it appears that the **DMC534 High Power Inverter** is well-suited for the motor application. Here's a summary of why this converter is a suitable choice:

- **Input Voltage Compatibility:** The DMC534 converter can accept a wide range of high-voltage (HV) input voltages, from **120 V to 450 V**. This range aligns with our motor's requirements, ensuring it can efficiently power the motor.

- **Output Current and Power:** The DMC534 can provide continuous RMS current of **337 A** and continuous power of **118 kW**. These specifications comfortably match the requirements of our motor, which has a continuous power requirement of **45.24 kW.**

- **Efficiency:** The DMC534 converter boasts an impressive efficiency rating of **0.97**. This high efficiency ensures that the power conversion from the converter to the motor is highly effective, minimizing energy losses.

- **IP-Protection:** Both the DMC534 converter and the motor have an **IP67** protection rating, making them suitable for rugged and challenging environments.

- **Ambient Temperature Range:**The converter can operate in ambient temperatures ranging from -**40°C to +85°C**, which provides flexibility for various environmental conditions, ensuring reliability.

In summary, the **DMC534 High Power Inverter** exhibits excellent compatibility with the **BRUSA HSM1-12.18.13 Hybrid Synchronous Motor** in terms of input voltage range, output current and power, high efficiency, cooling, and protection features. It appears to be a well-matched choice for powering our motor and should provide the necessary electrical support for our vehicle's propulsion system.

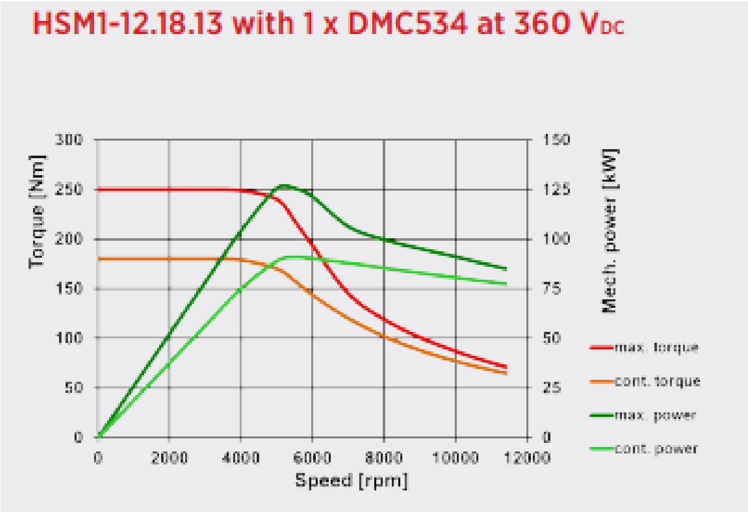


*Figure 8: Torque Speed Characteristic of HSM1-12.18.13 with DMC534 Converter*