Simple Practice Problems & Solution for Electric and Hybrid Vehicle Component sizing

Vehicle Specifications:

Gross Vehicle Weight = 1500 Kg

Tyre Specifications = 195/55 R 16

Transmission Gear Ratio =

Final Drive Ratio =

Rolling Resistance Coefficient = 0.013

Air density = 1.184 Kg/m^3 @ 25 deg Celsius

Vehicle Dimensions = L | B | H = 4445 mm*1770 mm*1550 mm

Frontal Area = 1.77m*1.55m = 2.7435 m^2

Drag Coefficient = 0.28

Basic Unit Conversions

1N = 1 Kg*m/s^2

1 Watt = 1 N*m/s = 1 Kg*m^2/s^3

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1. What is the wheel power in kW required for acceleration of an electric vehicle from 0 to 100 Kmph in 11.5 seconds?

   Now for a vehicle accelerating from rest, the following resistance will be applicable

   Rolling Resistance + Acceleration Resistance + Drag resistance

   Formulae Applied:

   Total Wheel Force Required = Rolling Resistance + Acceleration Resistance + Drag resistance

   Acceleration Resistance Force = mass(kg) * acceleration(m/s^2)

   Rolling Resistance Fr = m*g*μ_r = 1500*9.8*0.013 = 191 N

   Drag resistance Force Fd = ½ (air density * Frontal Area*Drag Coefficient*((Vehicle speed – Wind speed) ^2)

   Solution:

   Final speed = 100 Kmph = 27.77 m/s

   Wheel Power Required = Force (N) * Velocity (m/s)

   Acceleration Resistance Force = mass(kg) * acceleration(m/s^2)

   = mass * ((Final Velocity (m/s) – Initial Velocity(m/s)) / Acceleration Time(s))

   = 1500 * ((27.77 – 0)/11.5)

   = 3622.17 Kg*m/s^2 = 3622 N

   Drag resistance Force Fd =

   ½ (air density * Frontal Area*Drag Coefficient*((Vehicle speed – Wind speed) ^2)

   = 0.5 * 1.184 Kg/m^3 * 2.7435m^2 * 0.28 * (20.83) ^2

   = 197.3 N

   Total Force Required = Rolling Resistance + Acceleration Resistance + Drag resistance

   = 191 + 3622 + 197.3 = 4010 N

   Distance Travelled for Acceleration from 0-100 Kmph in 11.5 seconds = s = ut + (1/2) × at2

   = 0 + (0.5*2.414*11.5*11.5) = 159 m

   Required Wheel Power = Force (N) * Distance travelled (m) = 4010 N * 159 m = 637590 Nm = 637590 J

   Now 637590 J energy has been spent for 11.5 seconds

   Then Power delivered = 55442 J/s = 55442 Watt = 55 kW

   Required wheel Power for accelerating from 0 to 100 Kmph in 11.5 seconds = 55 kW

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2. What is the wheel power in kW required in an electric vehicle for negotiating a gradient of 20 % when cruising at a speed of 40 Kmph for 30 seconds?

   Now for a vehicle negotiating a gradient of 20 % when cruising at a speed of 40 Kmph for 30 seconds, the following resistance will be applicable

   Total Resistance = Rolling Resistance + Drag resistance + Gradient Resistance

Formulae Applied:

Wheel Power Required = Force (N) * Velocity (m/s)

Force Required for Gradient climbing = m*g*Sin Θ

Solution:

Rolling Resistance Fr = m*g*μ_r = 1500*9.8*0.013 = 191 N

Drag resistance Force Fd = 0.5 * 1.184 Kg/m^3 * 2.7435m^2 * 0.28 * (11.11) ^2

= 56.13 N

Gradient resistance Force = m*g*Sin Θ

Convert the gradient from percentage to degree

Slope in Degrees = [Tan^{-1} (Slope in % / 100)] – If you have percentage value

= Tan^-1(20/100) = Tan^-1(0.2) = 11.3 Deg

F = 1500 kg * 9.8 m/s^2 * Sin (11.30)

= 1500*9.8*0.1959

= 2879.73 kg* m/s^2 = 2880 N

Total resistance = 191 + 56 + 2880 = 3127 N

Total Power Required to negotiate the Gradient @ 40kmph (11.11 m/s)

= Force (N) * Velocity (m/s) = 3127 N * 11.11 m/s

= 34740.97 Nm/s = 34741 Watt = 34.741 kW

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3. What is the wheel power required in kW to maintain a constant cruising speed of 150 Kmph in an electric vehicle?

A vehicle running at a top speed need to overcome the rolling resistance and aerodynamic resistance.

Rolling resistance Force = F_r = m * g * μ_r * COS α

= 1500 kg * 9.8 m/s^2 * 0.013 * Cos 0°

= 191.1 kg m/s^2 = 191 N

Power Required to overcome rolling resistance = 191 N * 41.66 m/s

= 7957.06 Watt = 8 kW

Aerodynamic Resistance Force $F_w = \frac{1}{2}\rho A_f C_D (V - V_w)^2$

= ½ (air density * Frontal Area*Drag Coefficient*((Vehicle speed – Wind speed) ^2)

= 0.5 * 1.184 Kg/m^3 * 2.7435m^2 * 0.28 * (41.66 – 0) ^2

= 789.26 kg* m/s^2 = 790 N

Power Required to overcome aerodynamic resistance = 790 N * 41.66 m/s

= 32953.06 Watt = 32.94 kW

Total Power Required to travel at 150 Kmph

= 8 kW + 32.94 kW = 40.94kW

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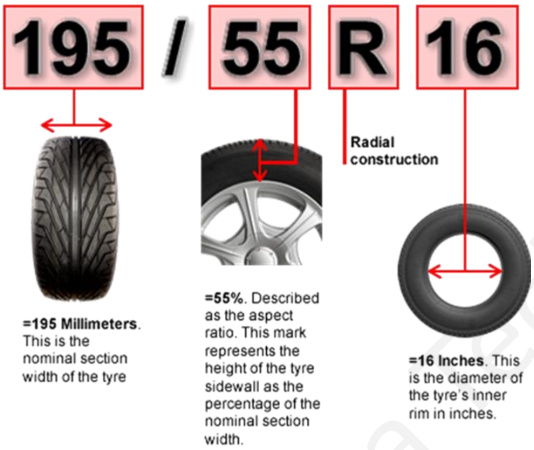
4. What is the wheel radius in metres of an electric passenger car with the following tyre and wheel rim specifications 195/55 R 16

Wheel Radius Calculation:



Wheel specification → 195/55 R16 means

Wheel radius = Wheel Diameter / 2 = [(2*Sidewall height in m) + Rim Diameter in m]/2

= Side wall height = 55% of section width = 0.55*0.195m = 0.10725 m

Rim Diameter = 16 inches = 0.4064 m

Wheel radius = [(2*0.10725 in m) + 0.4064 in m]/2 = 0.31045 m

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5. What is the electric motor speed in rpm required for achieving a top speed of 180Kmph in an electric vehicle?

   Let us first calculate the Wheel speed in rpm

   Vehicle speed = 180 Kmph = 50 m/s

   To convert m/s to rpm = Vehicle speed (m/s) * (60/ (2*pi*Wheel radius))

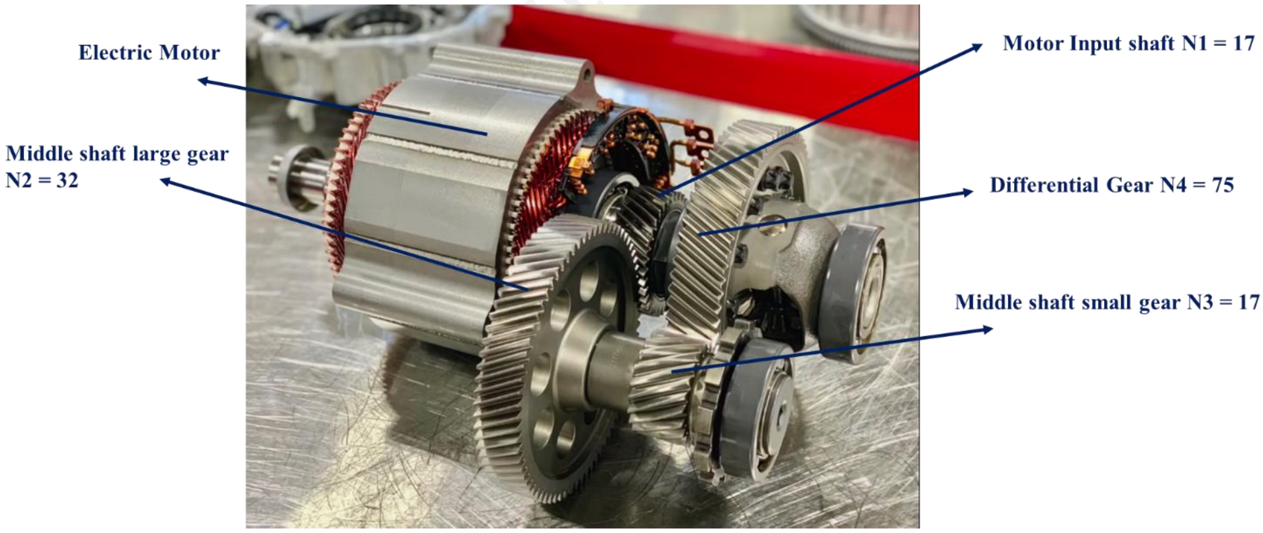
   Wheel speed in rpm = Vehicle speed (m/s) * (60/ (2*pi*Wheel radius))

   = 50 m/s * (60/ (2*3.14*0.31045m))
   = 50 * 30.78

   = 1500 rpm

   Now the wheel needs to rotate at 1500 rpm to operate at 180 Kmph

   Now consider the following drivetrain assembly.



   Total Gear Ratio = $i_g + i_o$ = N2/N1 + N4/N3 = (32/17) + (75/17) = 1.8823 + 4.41 = 6.29

   Motor speed = (Wheel speed * $i_g * i_o$)

   = 1500*1.88*4.41 = 12436 rpm

   For the vehicle to operate @ 180 Kmph, the motor needs to operate @ 12436 rpm

   So to reach the target top speed, the motor selected should have a capability to operate at a maximum speed of 12436 rpm

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6. What is the continuous power for an electric vehicle required for the following drive cycle?

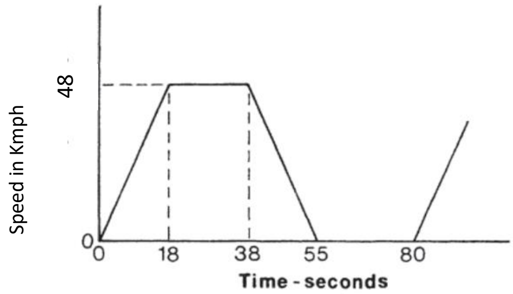
   Firstly, the Rms Power is the average power required over a driving cycle. It considers all the varying torque values used during operation as well as the time duration each torque value is needed

   Acceleration, 0–18 s

   Cruise, 18–38 s (including 5 s climbing a 10% grade);

   Coast and brake, 38–55 s

   Idle, 55–80 s



Solution:

Now for the ease of calculation, let us divide the driving cycle into different sections

Section 1 → 0 to 18 seconds – Vehicle accelerating from 0 to 48 Kmph

Section 2 → 18 to 33 seconds - Vehicle cruising @ 48 Kmph

Section 3 → 33 to 38 seconds - Vehicle negotiating a grade 10%

Section 4 → 38 to 55 seconds – Vehicle deceleration from 48 Kmph to 0

Section 1 → 0 to 18 seconds – Vehicle accelerating from 0 to 48 Kmph

Now for a vehicle accelerating from rest, the following resistance will be applicable

Rolling Resistance + Acceleration Resistance + Drag resistance

Rolling Resistance Fr = m*g*μ_r = 1500*9.8*0.013 = 191 N

Drag resistance Force Fd =

= ½ (air density * Frontal Area*Drag Coefficient*((Vehicle speed – Wind speed) ^2)

= 0.5 * 1.184 Kg/m^3 * 2.7435m^2 * 0.28 * (6.66) ^2

= 20 N

Acceleration Resistance Force = mass(kg) * acceleration(m/s^2)

= mass * ((Final Velocity (m/s) – Initial Velocity(m/s)) / Acceleration Time(s))

= 1500 * ((13.33 – 0)/18) = 1110.8 Kg*m/s^2 = 1111 N

Total Force Required = Rolling Resistance + Acceleration Resistance + Drag resistance

= 191 + 20 + 1111 = 1322 N

Distance Travelled for Acceleration from 0-48 Kmph in 18 seconds = s = ut + (1/2) × at2

= 0 + (0.5*0.740*18*18) = 120 m

Energy Required = Force * Distance **= 1322 N * 120m = 158640 J = 158.6 kJ**

Section 2 → 18 to 23 seconds - Vehicle cruising @ 48 Kmph

Now for a vehicle cruising, the following resistance will be applicable

Total Force Required = Rolling Resistance + Drag resistance

Rolling Resistance Fr = m*g*μ_r = 1500*9.8*0.013 = 191 N

Drag resistance Force Fd =

= ½ (air density * Frontal Area*Drag Coefficient*((Vehicle speed – Wind speed) ^2)

= 0.5 * 1.184 Kg/m^3 * 2.7435m^2 * 0.28 * (13.33) ^2 = 80.8 N

Total Force Required = 191 N + 80.8 N = 271.8 N

Distance travelled = Speed * Time = 13.33 m/s * 15 s = 200 m

Required Energy = Force * Distance **= 271.8 N * 200m = 54360 J = 54.36 kJ**

Section 3 → 33 to 38 seconds - Vehicle negotiating a grade 10%

Now for a vehicle negotiating a gradient of 10 % when cruising at a speed of 48 Kmph for 5 seconds, the following resistance will be applicable

Total Resistance = Rolling Resistance + Drag resistance + Gradient Resistance

Rolling Resistance Fr = m*g*μ_r = 1500*9.8*0.013 = 191 N

Drag resistance Force Fd =

= ½ (air density * Frontal Area*Drag Coefficient*((Vehicle speed – Wind speed) ^2)

= 0.5 * 1.184 Kg/m^3 * 2.7435m^2 * 0.28 * (13.33) ^2 = 80.8 N

Gradient resistance Force = m*g*Sin ϴ

Convert the gradient from percentage to degree

Slope in Degrees = [Tan^{-1} (Slope in % / 100)] – If you have percentage value

=Tan^-1(10/100) = Tan^-1(0.1) = 6°

F = 1500 kg * 9.8 m/s^2 * Sin (6°) = 1500*9.8*0.1045 = 1536.15 kg* m/s^2 = 1536 N

Total Force Required = 191 N + 80.8 N + 1536 N = 1808 N

Distance travelled = Speed * Time = 13.33 m/s * 5 s = 66.65 m

Required Energy = Force * Distance **= 1808 N * 66.65 m = 120503 J = 120.5 kJ**

Section 4 → 38 to 55 seconds – Vehicle deceleration from 48 Kmph to 0

Stopping distance = reaction distance + braking distance

For example, Reaction Time for 48 Kmph ≈ 15 m

Deceleration d = $v^2 – u^2 / 2s = 0^2 - 13.33^2 / 2*s = - 0.40\ m/s^2$

Stopping distance = $v^2 / 2d = (13.33^2 / 2*0.40) = 222$ m

Peak power dissipated during braking = Braking Force N * Velocity m/s

Required Braking Force = Rolling Resistance + Deceleration Resistance + Drag resistance

= (1500*9.8*0.013) + 1500*(-0.40) + 0.5 * 1.184 Kg/m^3 * 2.7435m^2 * 0.28 * (6.66) ^2

= 191.1 - 600 + 20.17 = -388.73 N

Braking energy required = (-388.73) N * 222m = -86298 Nm = -86298 J for 17 seconds

Consider 15% of the braking energy is recovered by regenerative braking, then the

Total energy utilised in one drive cycle = 158.6 kJ + 54.36 kJ + 120.5 kJ + (86.298kJ *0.85) = 406.8133 kJ

Average Power consumed for the complete driving cycle = 211.8 kJ / 55 seconds = 3.85 kW

Total distance covered = 120 m + 200 m + 67 m + 222 m= 608 m = 0.608 Km / cycle

Consider the following battery specifications for this vehicle

Battery Voltage = 360 V

Battery Capacity = 66 Ah

So now consider a Battery energy available = (360 V * 66 Ah * 3600) = 8,55,36,000 J

No. of drive cycles = 85536000 J / 406813 J = 210 cycles

Travel Range of the vehicle = 210 * 0.608 Km = 127 Km

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Battery Related sample Calculations

1. What is the Total number of cells required to design a battery pack with following specifications?
   Nominal Voltage per cell = 3.8 V
   Nominal Capacity per cell = 33.1 Ah
   Required energy of the battery pack = 24 kWh

   Required energy per cell = Nominal Voltage per cell * Nominal Capacity per cell
   = 3.8 V * 33.1 Ah = 125.78 Watthour

   Total number of cells required = 24000 / 125.78 = 192

2. What is the peak power capability of the battery cell with the following specifications?
   Open circuit voltage of each cell = 3.8 V
   Internal Resistance of each cell = 2 mOhm

   $$\text{Peak Power (in kW)} = V^2_{\text{Open Circuit}} / 4R$$

   Peak power per cell = (3.8^2 / 4*2) = 1800 Watt

3. What is the energy consumed by an electric vehicle operating at a constant speed of 50 & 100 Kmph with a battery operating voltage of 360 V. The current consumption values are approximately considered from the test results of Nissan leaf 2011.

   Wh/km = ((Current Drawn / Vehicle speed) * (Battery Voltage))

   Wh/km @ 50 Kmph = (14.44 A / 50 Kmph) *360 V = 104.4 Wh/km

   Wh/km @ 100 kmph = (50 A / 100 kmph) * 360 V = 180 Wh/km

4. What is the range of the electric vehicle operating at a constant speed of 50 Kmph with a following battery specifications?

   Wh/km @ 50 Kmph = 104.4 Wh/km

   Range of the electric vehicle = (Usable Pack size / Wh/km)

   = (22000 (Wh) / 104.4 (Wh/km)) = 210 Km

5. What is the charging time required for an electric vehicle with a 24-kWh battery specification?

   Formula Used:

   Charging Time in Hours = Battery Capacity in kW / Charging Power Delivered in kWh

Case 1: On Board Slow Charging

Consider the Vehicle is charged with the on-board charger operating at 230 V AC & 15 A

Then the rate of charging = 230 V *15 A = 3.4 kWh

Charging Time = 24 kW/3.4 kWh = 7.05 Hours

Case 2: Fast Charging

Consider the Vehicle is charged with an off-board fast charger operating at 360 V DC & 100 A

Then the rate of charging = 360*100 = 36 kWh

Charging Time = 24 kW/36 kWh = 0.66 Hours = Approx. 40 Minutes