BOSCH’S ELECTRIC VEHICLE SIMULATION

Vehicle Selection

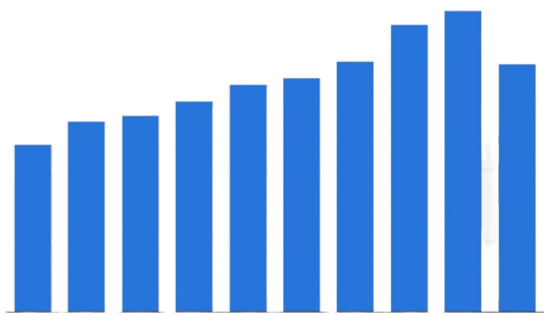
The vehicle segment chosen here is 2- wheeler.

Reasons for choosing this segment:

01 The Indian road conditions that are narrow and congested make the two-wheelers preferable to avoid traffic congestion.

02 Two-wheelers sales are skyrocketed and they are more preferred by Indian Market (Proof)

03 In major Indian cities, two-thirds of pollution load is due to two-wheelers. They give out 30% of the particulate matter load, 10% points more than the contribution from cars.

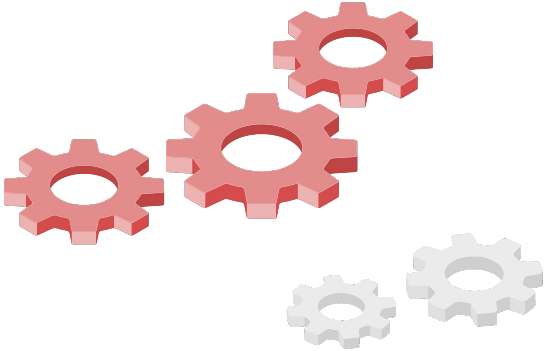


Two wheeler sales in India from financial year 2011-2020

Performance Baselining

Equations and Assumptions

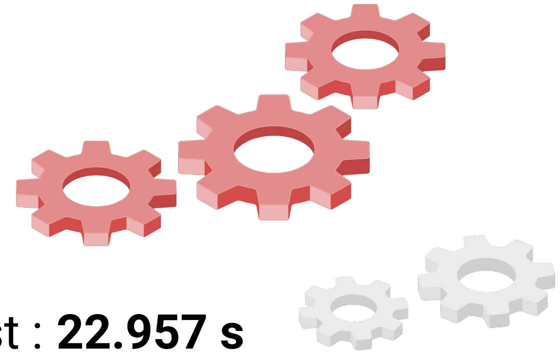
- 1. Vehicle weight with one passenger(M): **200 kg** (Normal curb weight of 120 kg + passenger of 80 kg)
- 2. Gradeability : **5%** (for urban driving)
- 3. Considered speed(V): **50 km/h** (maximum allowable for scooter in city)
- 4. Frontal area(A_f): **0.65 m^2**
- 5. Coefficient of rolling resistance(μ_r): **0.004** (tyre on asphalt road)
- 6. Drag coefficient(C_D): **0.68**
- 7. Air density(ρ): **1.2** (dry air density)
- 8. Wheel radius(r) : **8 in** (0.2032 m)
- 9. Torque provided by wheel at maximum speed : **36.33 N-m**
- 10. Single speed reduction ratio : **1.563**



Performance Baselining

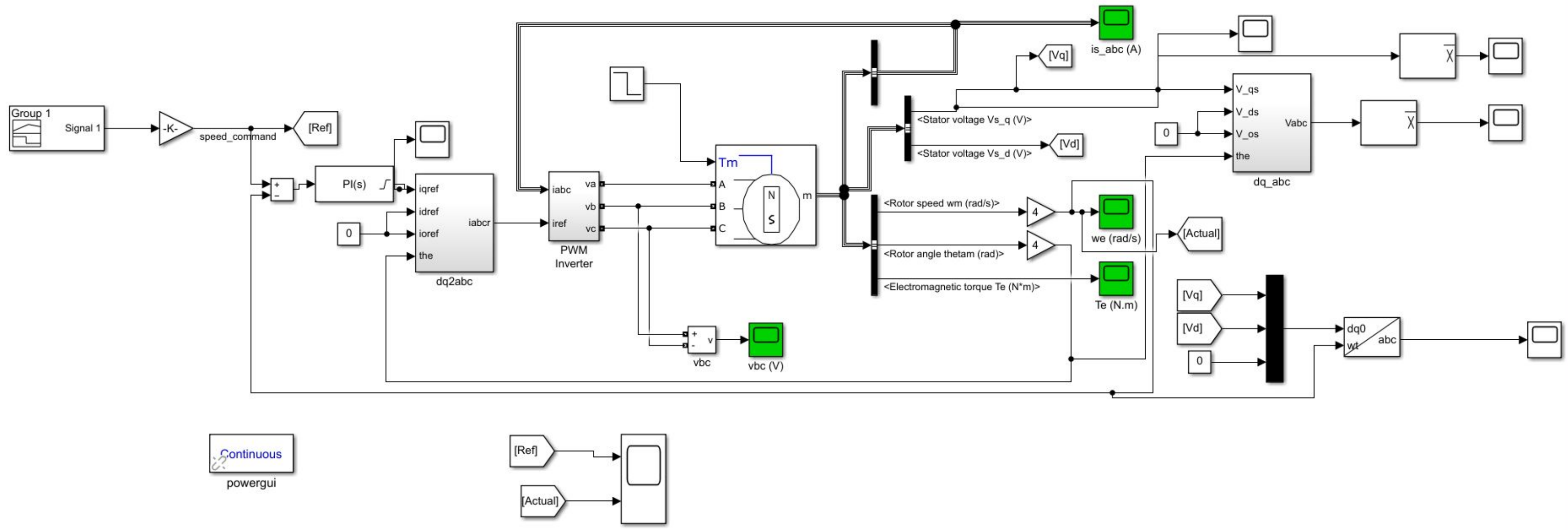
Calculated values:

- Gradient resistance: **M*g*sin(α) = 98 N**
- Rolling resistance: **μ_r*M*g = 7.848 N**
- Aerodynamic resistance: **0.5*C_D*A_f*ρ*V^2 = 49.57 N**
- Total drag: **155.48 N** *(sum of the above three resistances)*
- Angular velocity of wheel: **68.3 rad/s**
- Time taken for reaching a speed of 50 km/h from rest : **22.957 s**



Modelling and Analysis

Simulink Model of the Motor Control System (Download here)



Modelling and Analysis

A brief description about each of the subsystems used:

1. **PI controller**: Controller used to reduce the error between reference speed and measured speed. The controller gains are estimated using the following expressions:

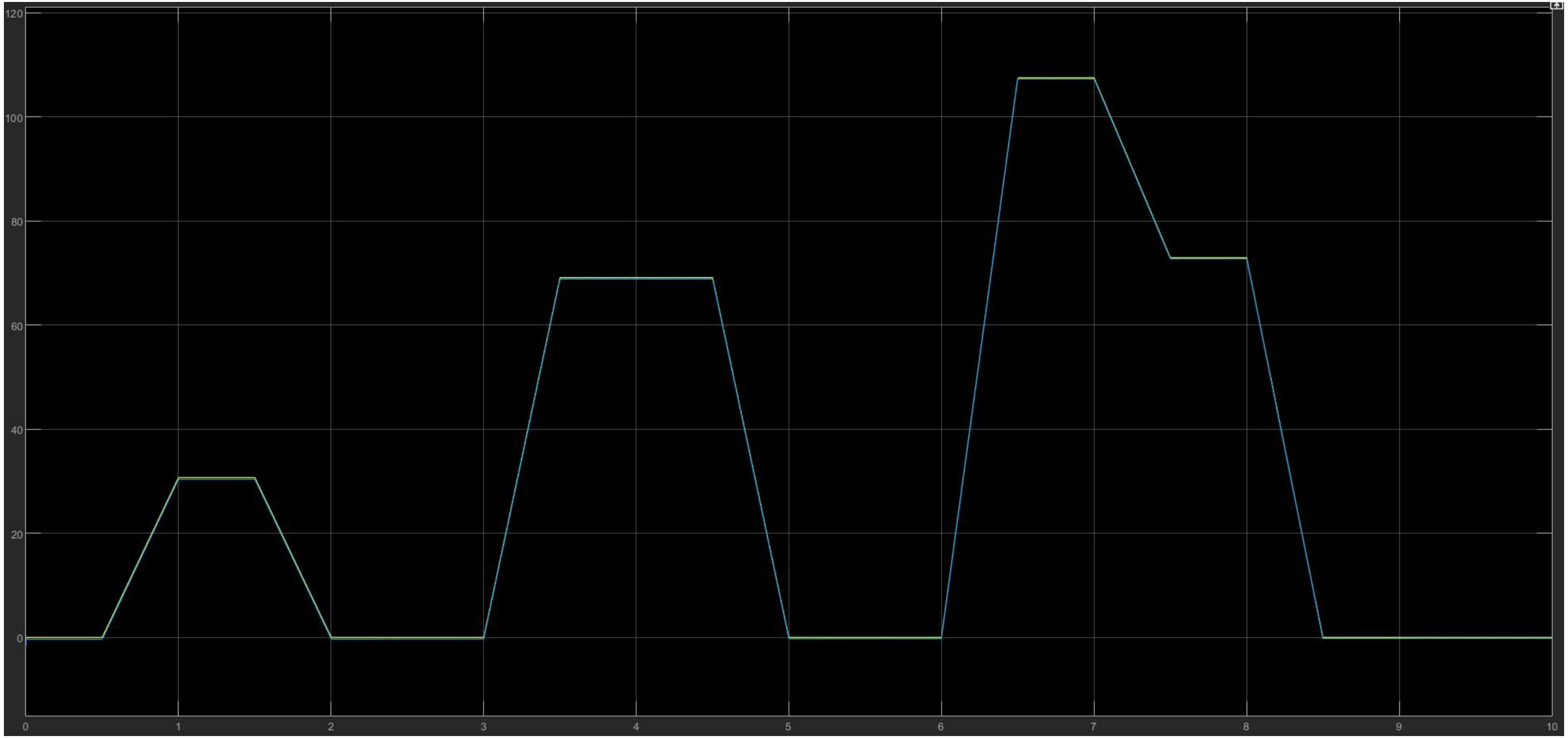
$$\mathbf{Kp = 2\xi\omega_0 L - R}$$

$$\mathbf{Ki = \omega_0^2 L}$$

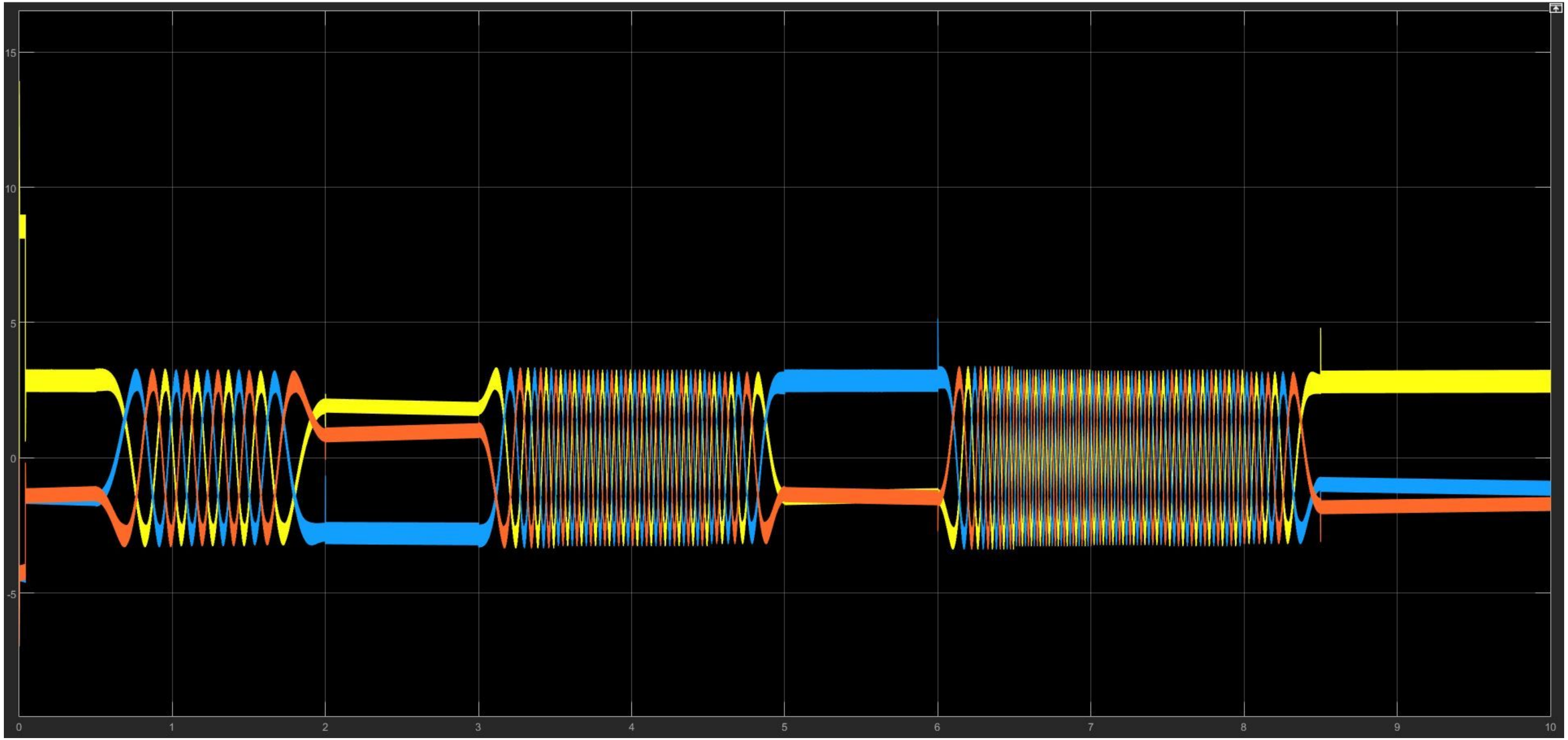
Where ω_0 is the natural frequency of the current closed-loop system (loop bandwidth) and ξ is the current loop attenuation.

2. **dq2abc**: Park and Clarke transformation

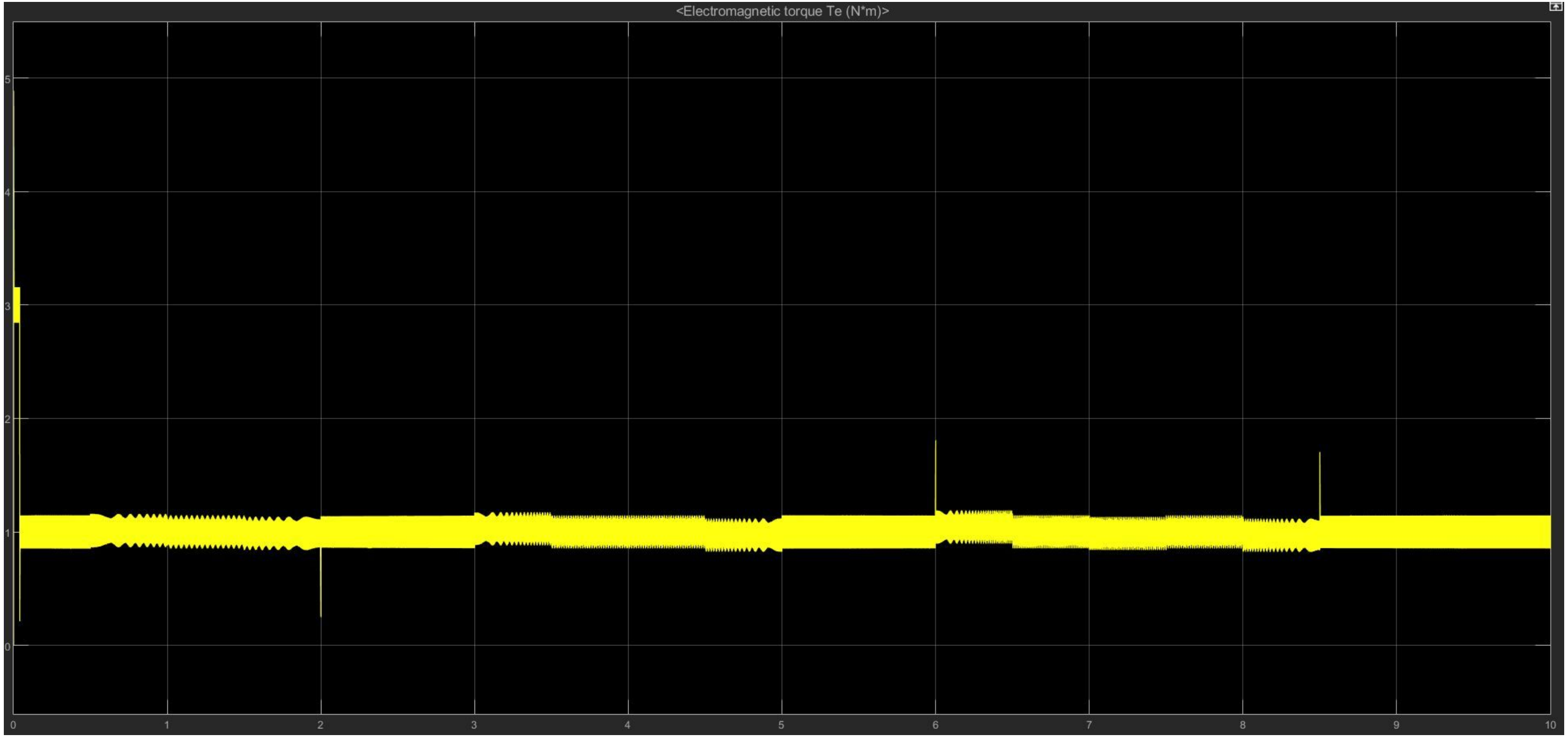
Modelling and Analysis: Speed Tracking



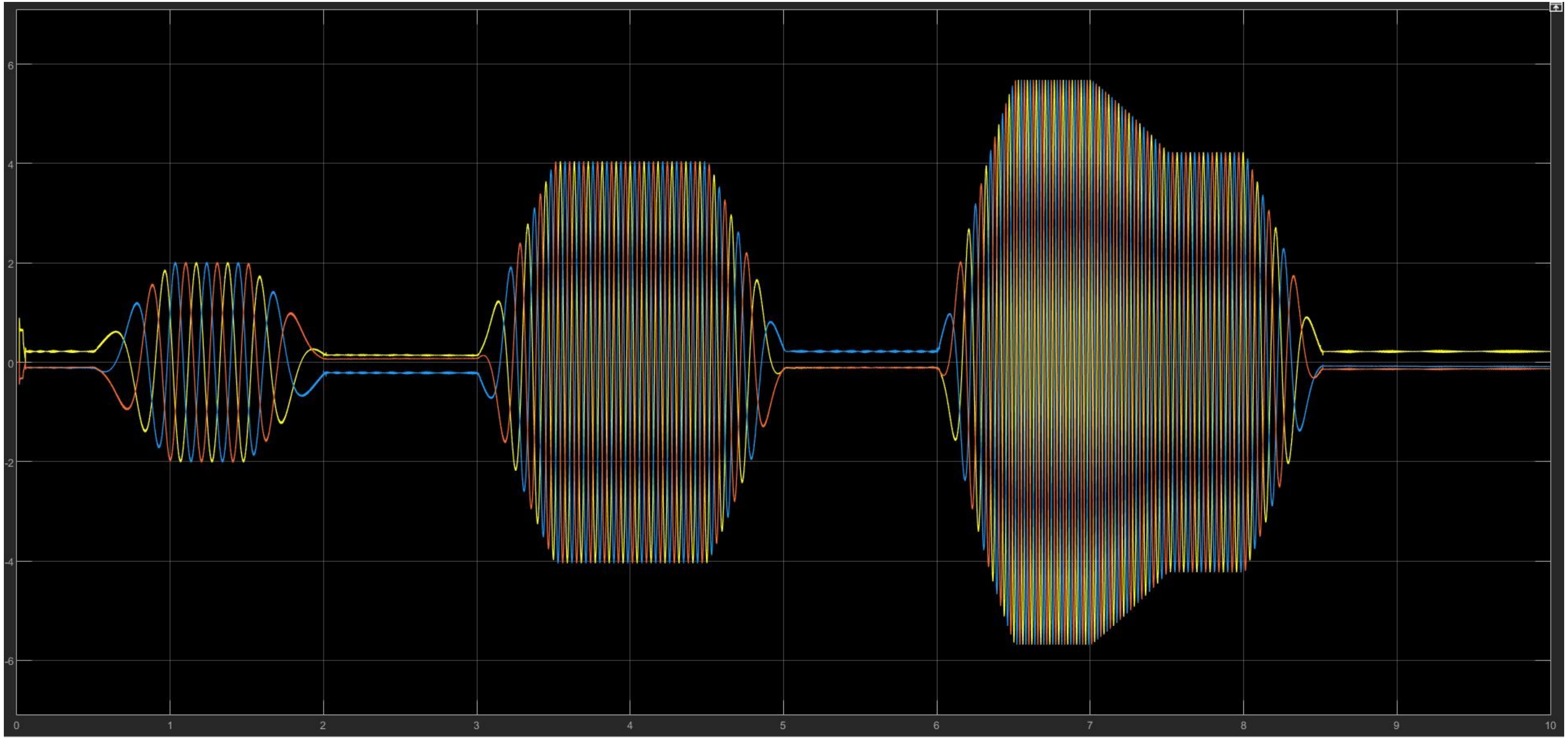
Modelling and Analysis: 3 Phase Currents



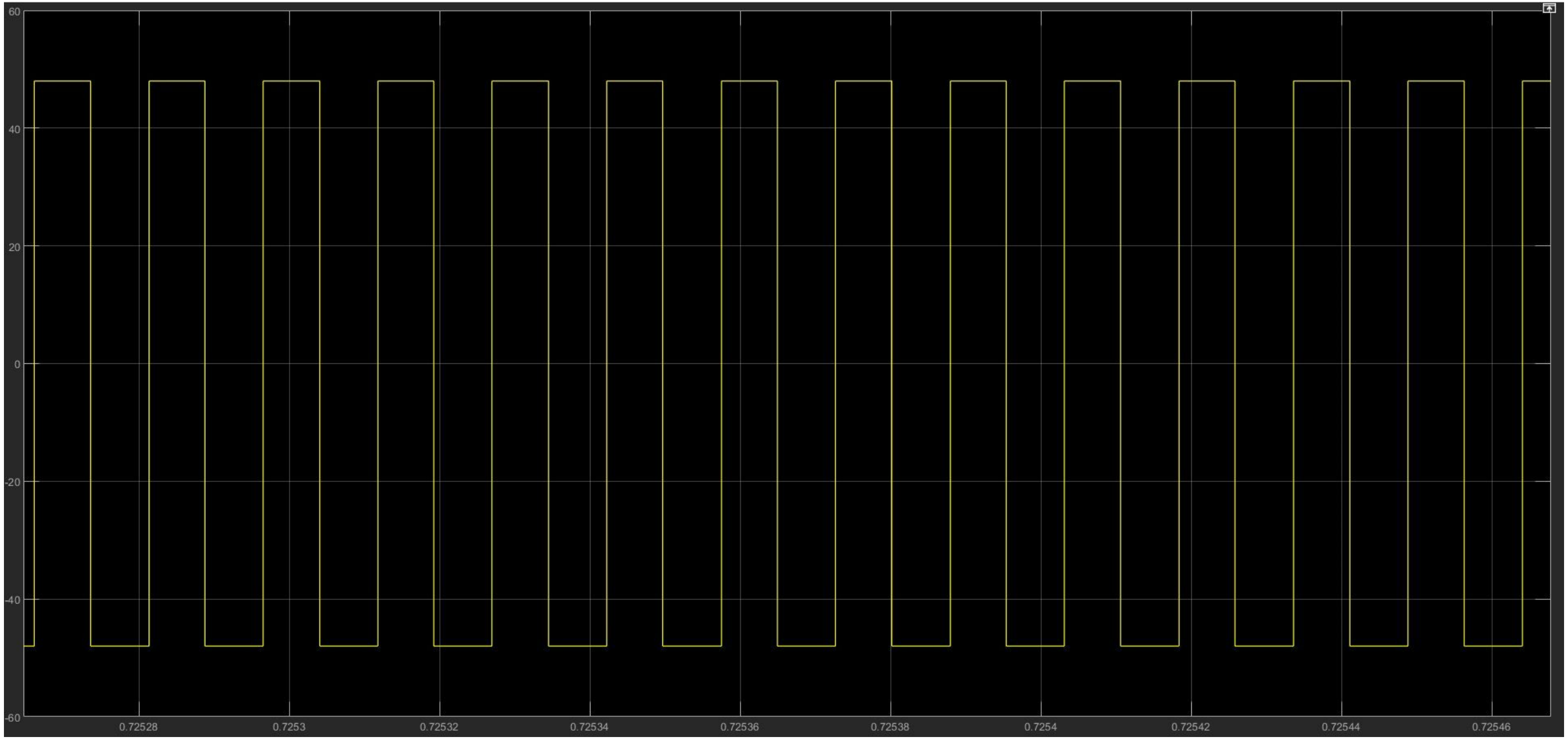
Modelling and Analysis: Torque



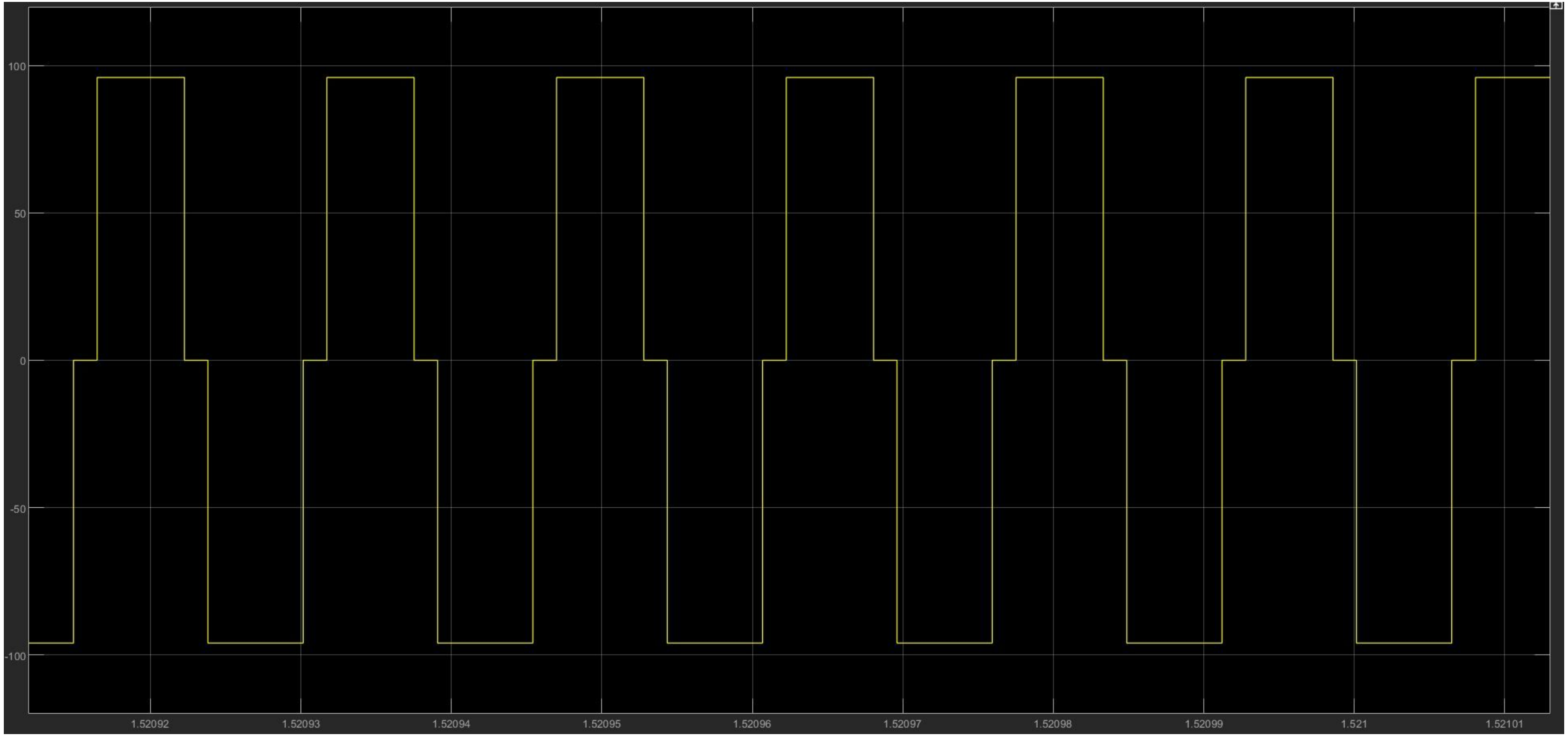
Modelling and Analysis: Avg Line Voltages



Modelling and Analysis: Line Voltage Vc



Modelling and Analysis: Phase Voltage



Electric Drive Dimensioning

Motor Design: Assumptions

The following values have been assumed for the design of PMSM motor:

- Battery voltage(V): 48V
- Number of Poles(P): 8
- Diameter of stator bore(D): 75 mm
- Stator length(L): 52 mm
- Magnetic Field Strength(B_{1g}): 0.4 T
- Electrical Frequency(f): 50 Hz
- Winding factor(k_w): 0.933
- Length of air gap(l_g): 0.5 mm
- Length of magnet(l_m): 2 mm
- Carter coefficient(C): 1.7
- Relative permeability of NdFeB(μ_r): 1.05
- Slot Width Factor(SWF): 0.5
- Slot Depth(SD): 12.3 mm
- Slot space factor(f_s): 0.5

Electric Drive Dimensioning

Motor Design: Governing Equations

- Rms value of linear current density $K_{1s} = (P_{out} . 2p)/(\pi B_{1g} D^2 L \omega_s)$
  where p = number of pole pairs = 4 and $\omega_s = 2\pi f = 100\pi$
- Ampere turns per phase - $N_{ph} I_{ph} = (K_{1s} .\pi D)/(6.k_w)$
- Current density $J_c = K_s/f_s$.SWF.SD
- $E_{ph}(rms) = \epsilon.V/\sqrt{3}$
- $N_{ph} = 2E_{ph}/(k_w B_{1g} D L \omega_s)$
- $I_{ph} = N_{ph} I_{ph} / N_{ph}$

Electric Drive Dimensioning

Motor Design: Governing Equations

- Cross-sectional area of conductor $A_c = I_{ph}/J_c$
- $L_d = 1.125\pi\mu_0(N_{ph}/P)^2(DL/g_d)$

  (where $g_d = C.l_g + l_m/\mu_r$ and $L_d = L_q$)
- $\lambda_m = (2N_{ph}B_{1g}DL)/(P/2)$
- $R_s = 2N_{ph}.(\rho L/A_c)$

  (where $\rho = 0.0171\ \Omega\text{-m/mm}^2$ assuming copper conductors)

Electric Drive Dimensioning

Motor Design: Lookup Table

Motor Parameter	Value
R_s	0.0775 Ω
L_d	0.5523 mH
L_q	0.5523 mH
λ_m	0.0585 Wb turns

Electric Drive Dimensioning

Inverter Design

3 Phase PWM Inverter has been used here with the following specifications:

DC Supply: 48V

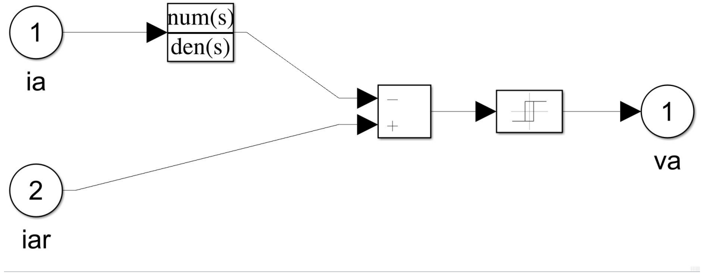
Relay switching operation-

Switch on point: 0.05

Switch off point: -0.05

Output when on: 48

Output when off: -48

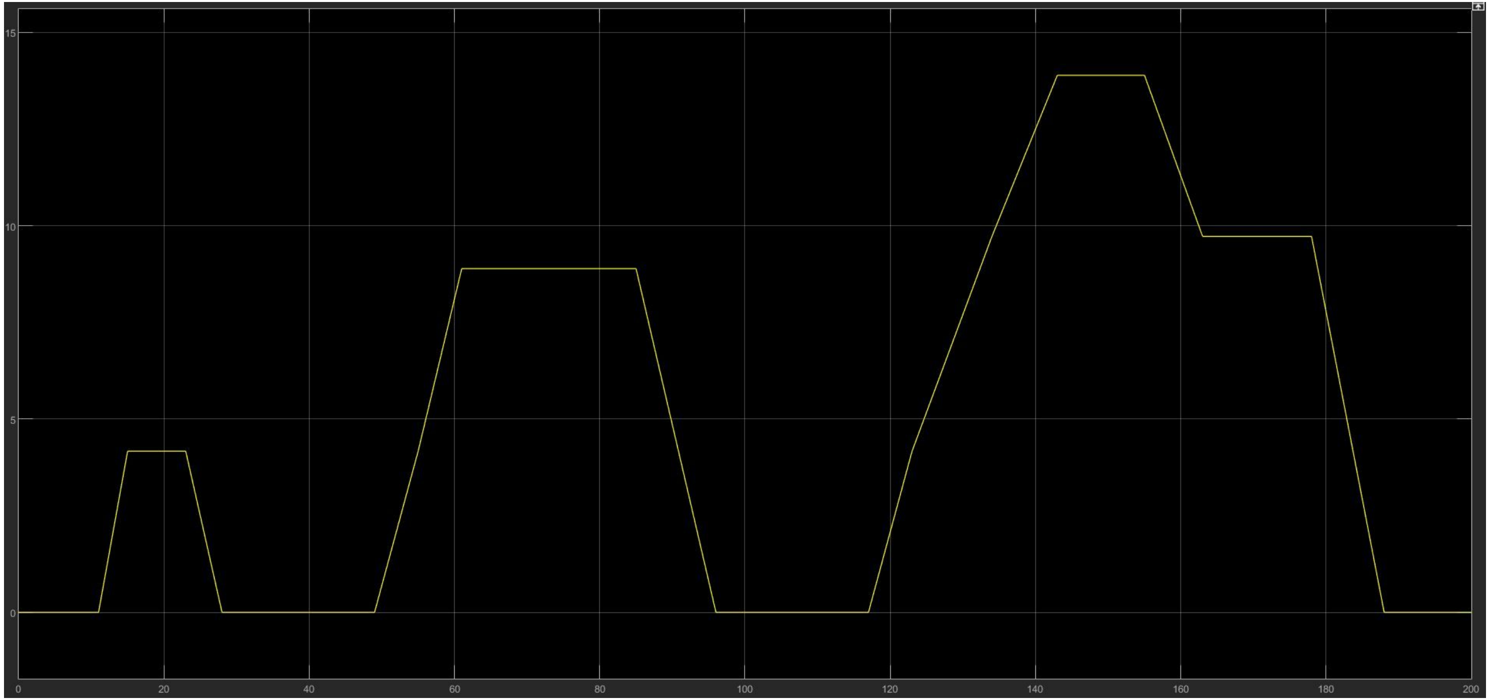


Battery Dimensioning and Optimization: Driving Cycle

We will be considering the ECE R15 driving cycle for calculating the average energy per driving cycle. The parameters of the driving cycle are as follows:

Duration: 200s
Distance: 1.017 km
Max Speed: 13.88 m/s (50 km/h)
Average Speed: 5.085 m/s (18.306 km/h)
Min acceleration: 1.042 m/s
Max acceleration: -0.972 m/s^2

Battery Dimensioning and Optimization: Driving Cycle ECE R15



Battery Dimensioning and Optimization: Energy Consumption

- The energy consumption is calculated based on the road loads. The total road load F_{tot} is the sum of the inertial force, road slope force, road load (friction) force and aerodynamic drag force.

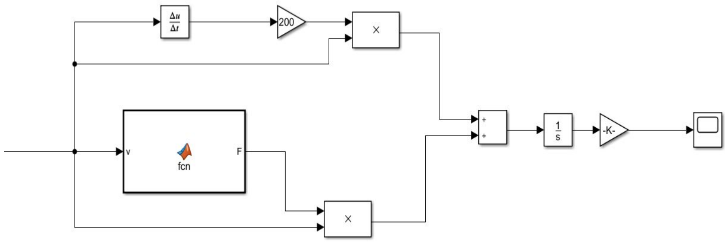
- The inertial force is the mass times instantaneous acceleration and the rest of the force expressions where calculated earlier.

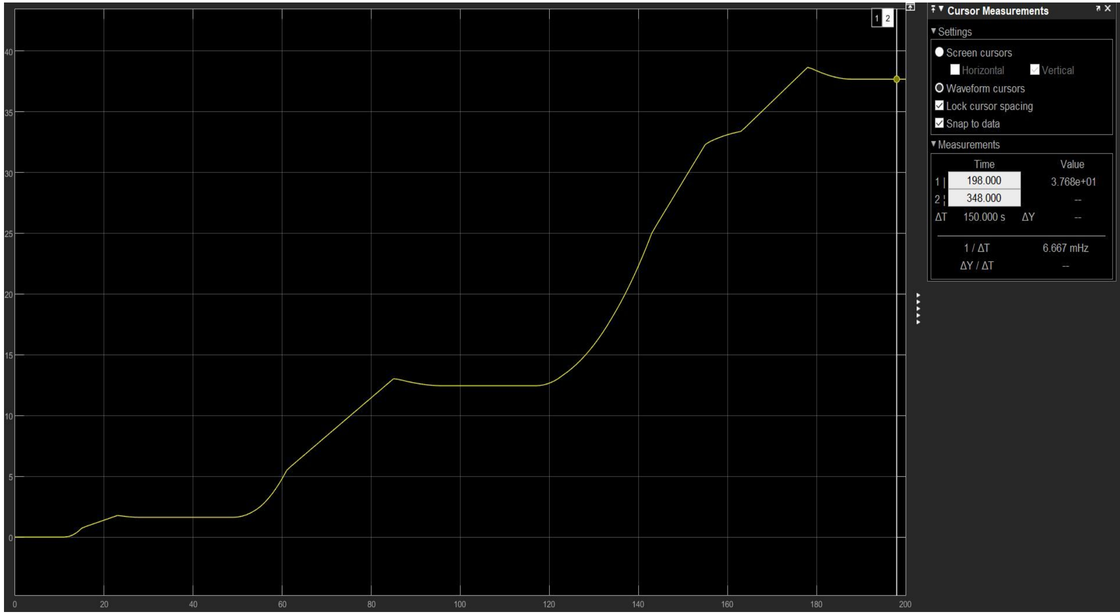
Total Power P_{tot} $= F_{tot} \cdot v$

Total energy consumption over the cycle E_{tot} $= \int F_{tot} \cdot v \, .dt$
(where v is the instantaneous vehicle speed)

Battery Dimensioning and Optimization

Simulink Model for Calculating Energy Consumed





Battery Dimensioning and Optimization: Results

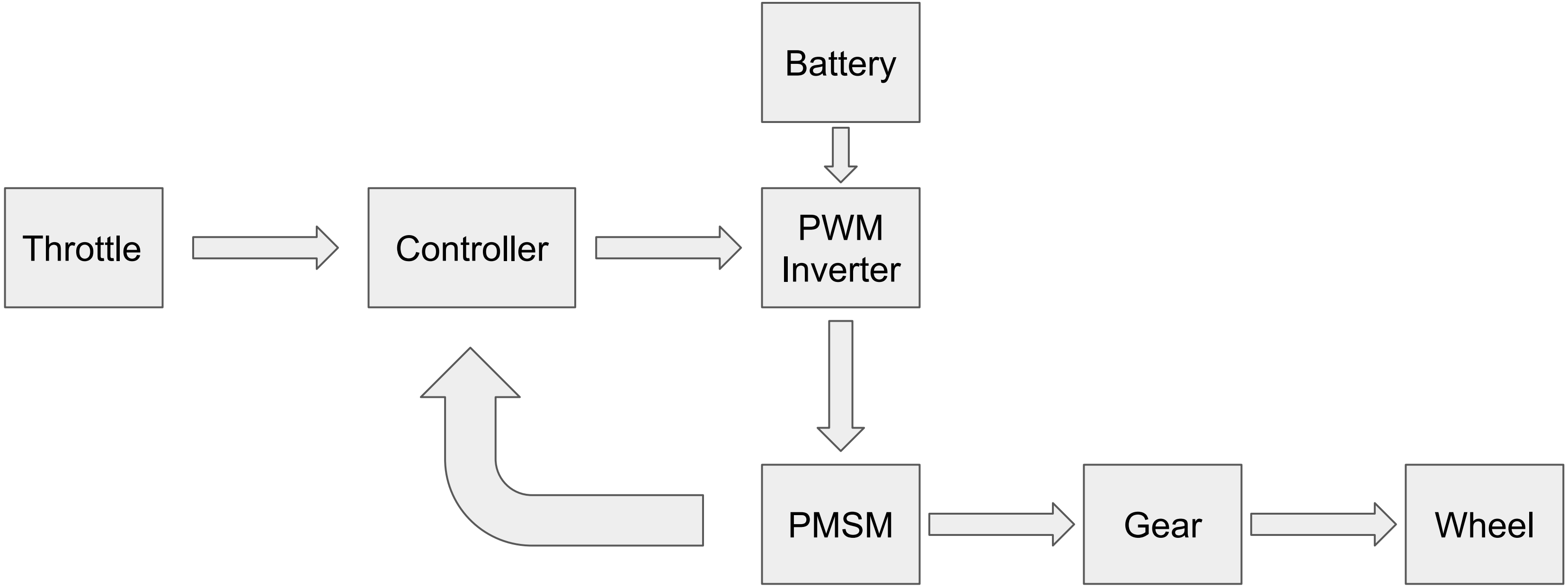
- After doing the calculations using MATLAB Simulink model shown in the previous slide, the average energy per driving cycle = **37.7 Wh/km**.

- Assuming the target range to be **70 km**, we arrive at a target battery size of **2639 Wh**.

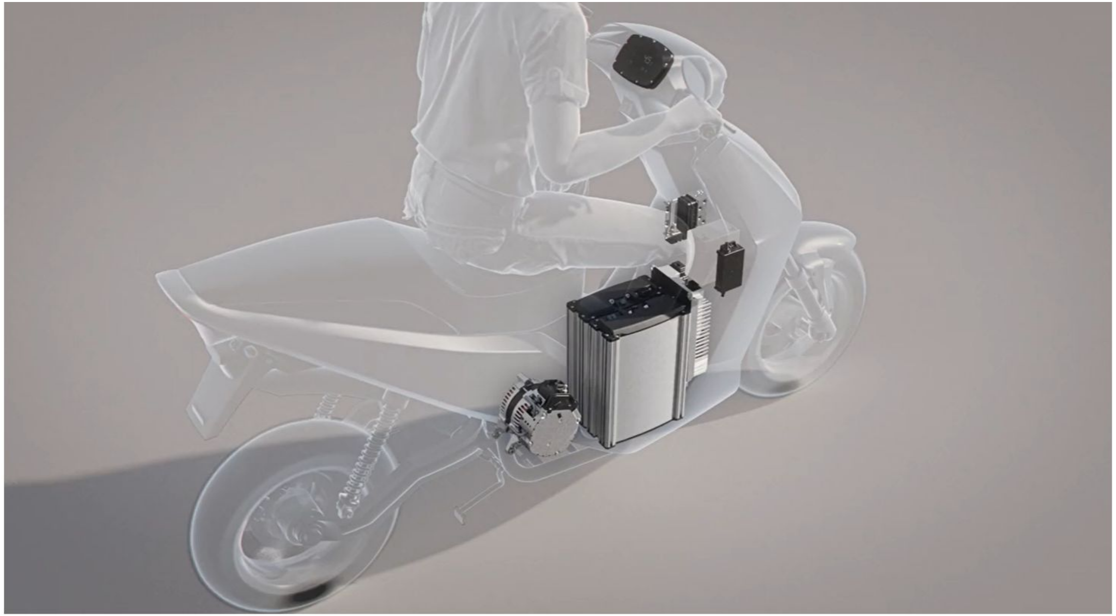
- We use a combination of **238 cells(each of 11Wh)** to make battery for our vehicle which will ensure better performance, fast charging and easy maintenance.

- We will be using Li-ion Battery for its Efficiency and applications.

E/E Architecture



E/E Architecture



THANK YOU.