# M3_BSC_9

IIT #9
Bosch EV Simulation

# TARGETS

- Design and Simulate an Electric Vehicle
- Vehicle segment: 2-wheeler
  - Growing EV 2-wheeler market in India
  - More focus on powertrain
- Set performance benchmarks
- Achieve set baselines
- Compute results and compare with targets

# BASELINING

# PERFORMANCE BENCHMARKS

Data available on popular electric two wheelers was utilised to set the targets

| PARAMETERS | TARGETS |
| --- | --- |
| Acceleration (0-40 km/h) | <3.3s |
| Top Speed | ≈ 80 km/h |
| Overtaking (40-60 km/h) | <3.5s |
| Gradability | >20% |
| Braking Distance (60-0 km/h) | <30m |

# SIMULATION METHODOLOGY

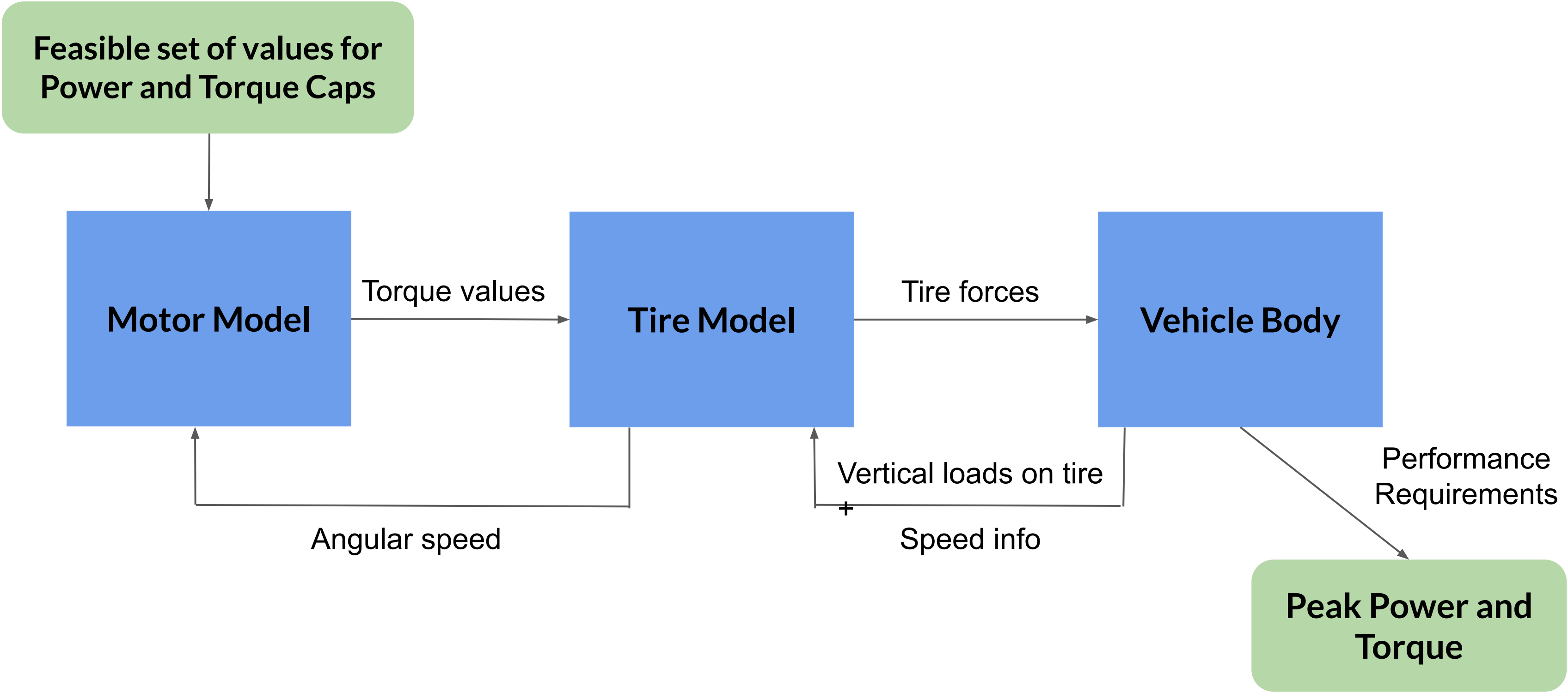
1. Run simulations for Acceleration and Top speed
2. Peak Torque and Power values required to design the motor calculated
3. Verify that other design targets are met

Transient vehicle model accounting for suspension loads, dynamic load transfer, aerodynamics and Pacejka tire model used for simulations.

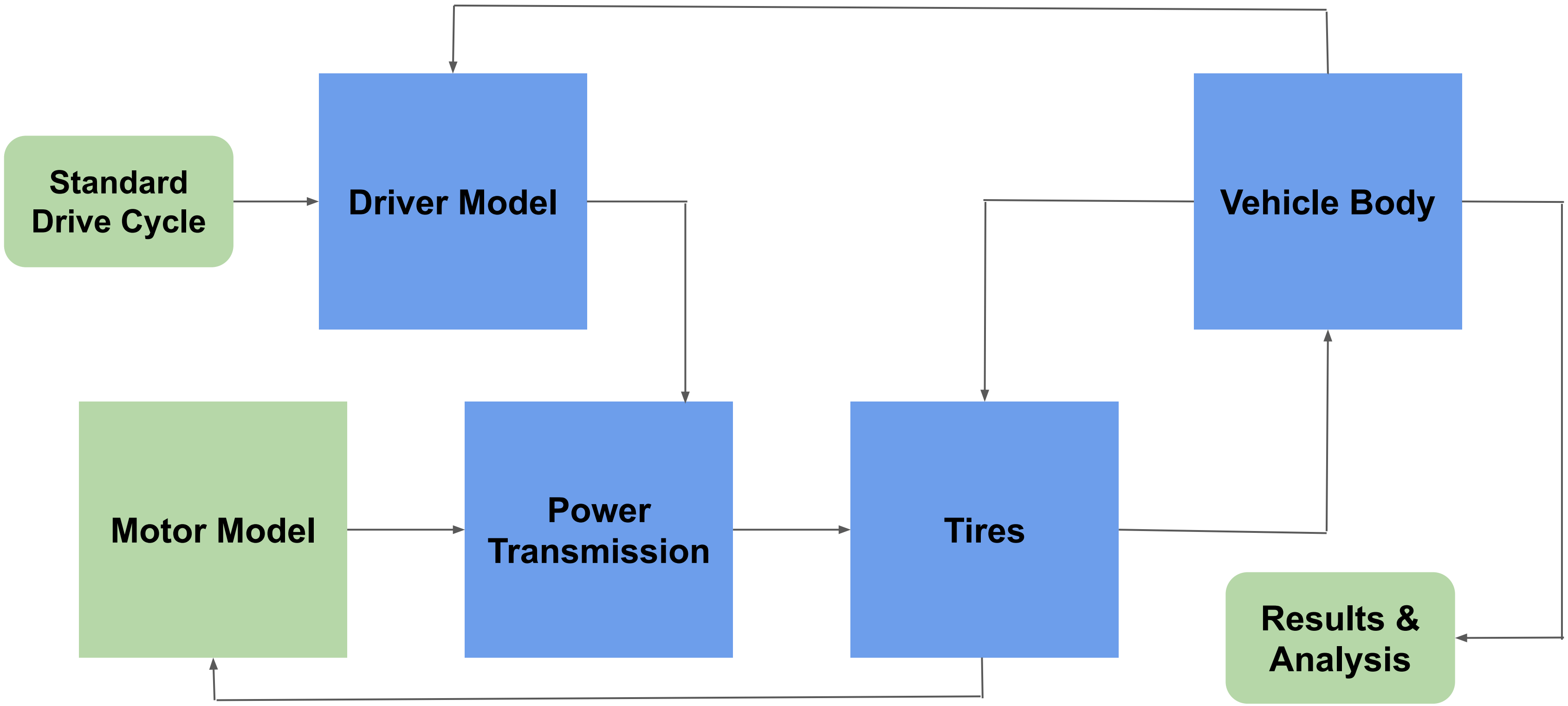
For battery sizing, regenerative braking and efficiency calculations, similar model with a longitudinal driver was used.

# MODELING

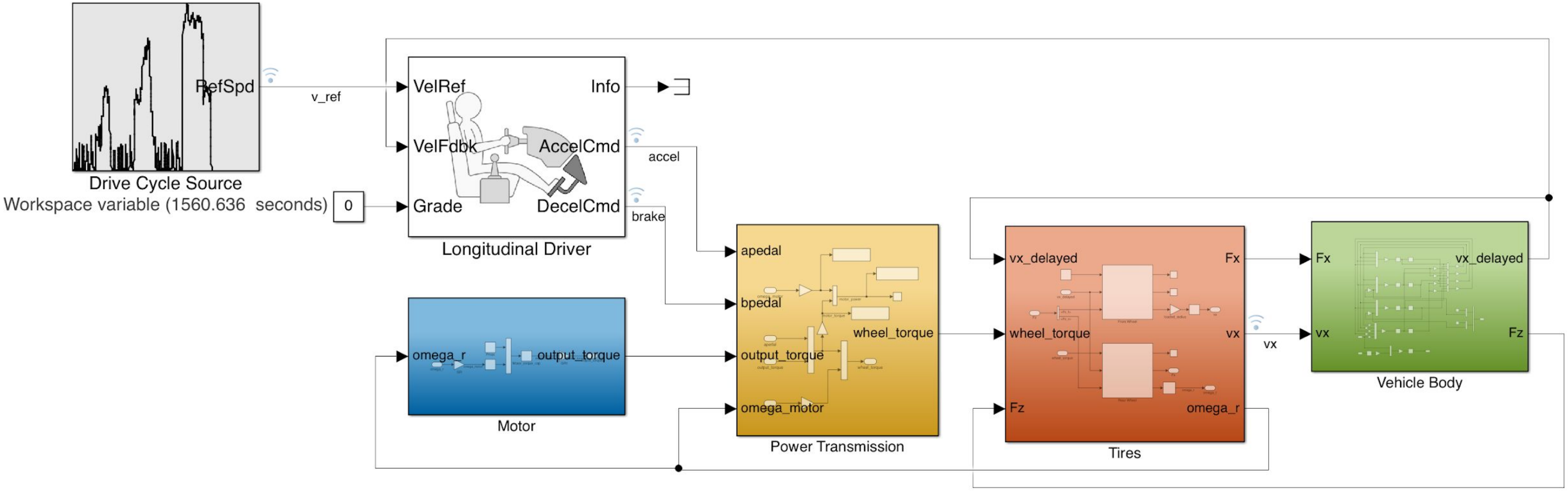
# SIMULATION MODEL



# SIMULATION MODEL WITH DRIVER

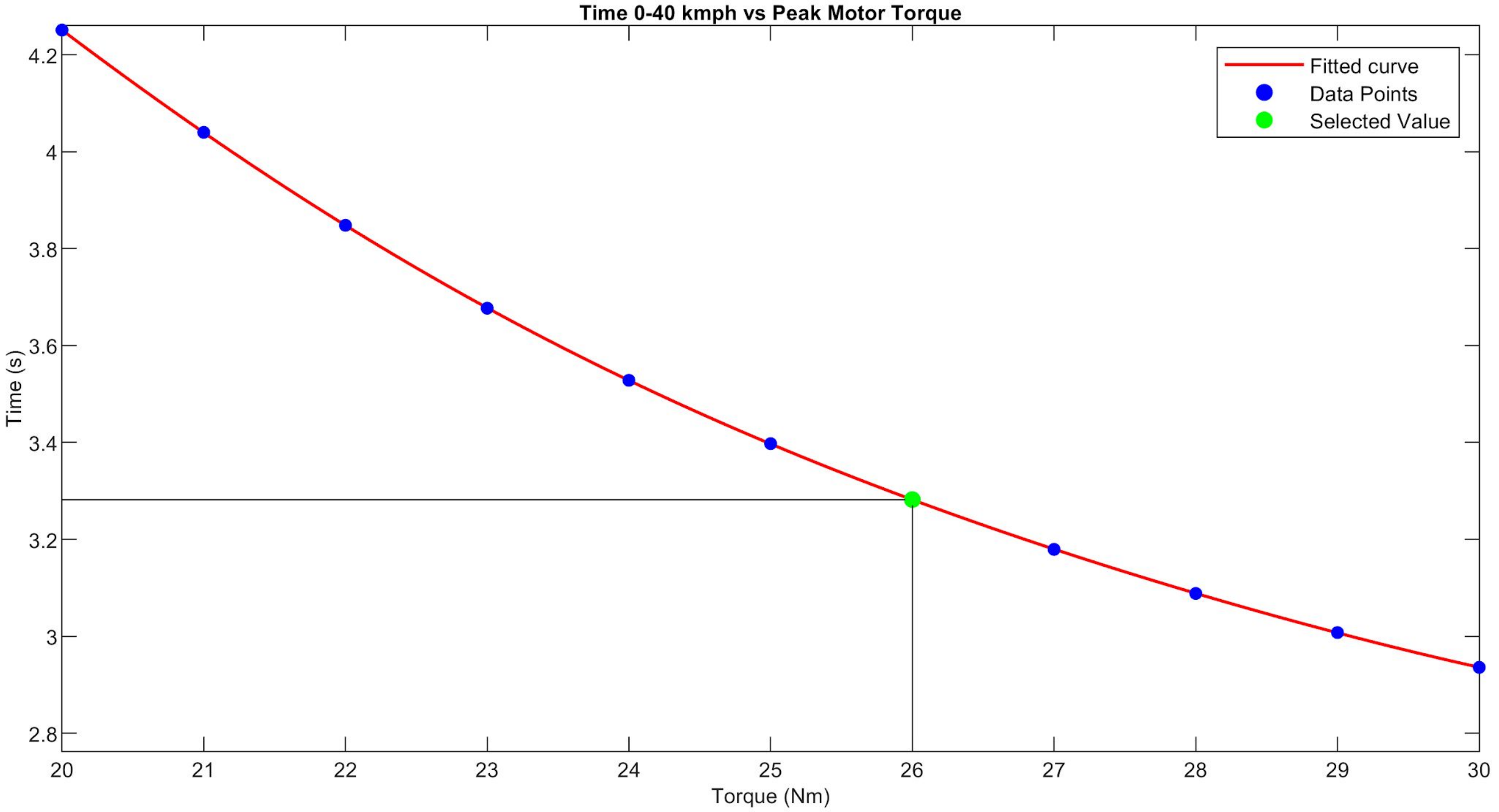


# SIMULINK MODEL

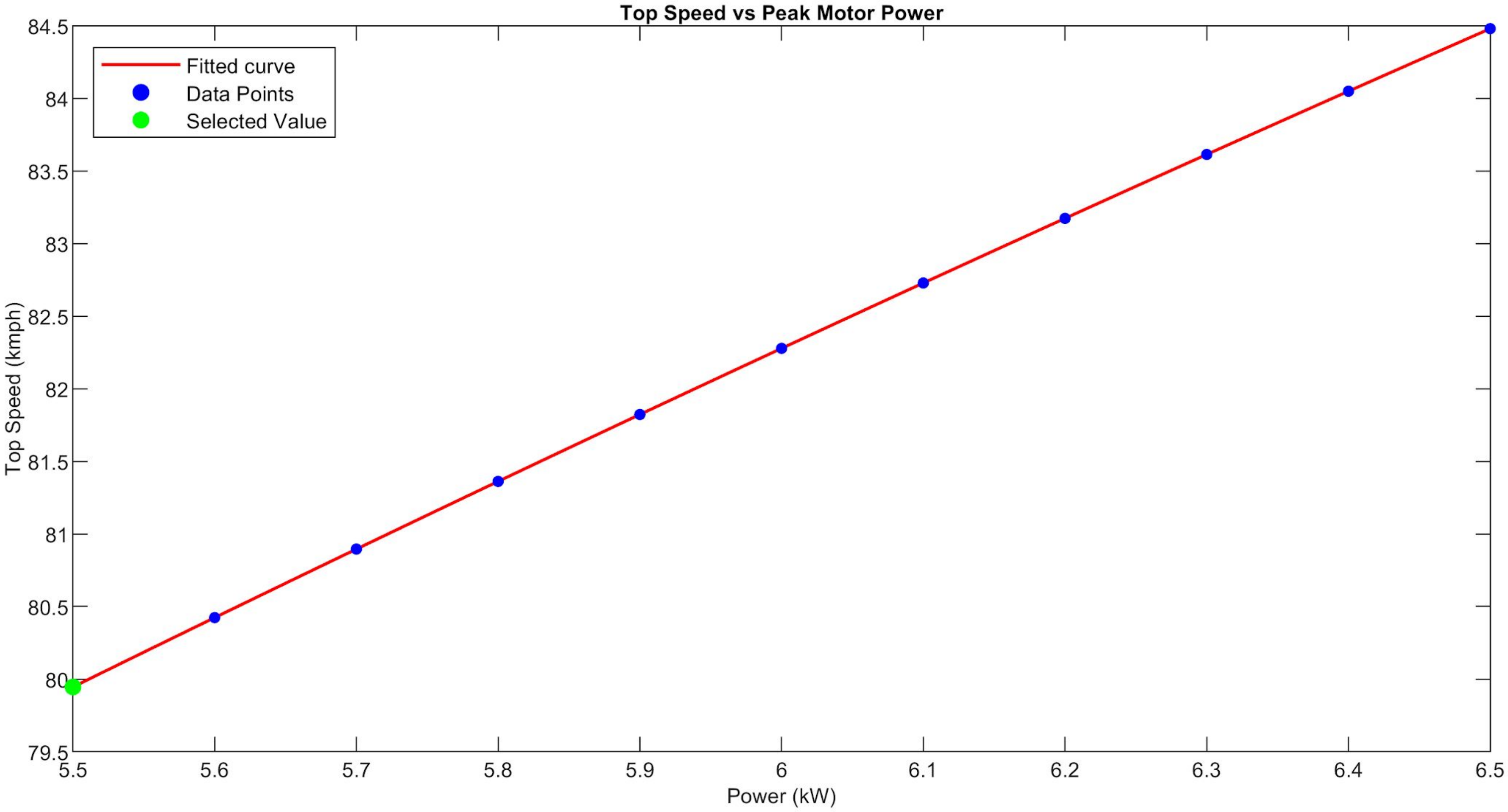


# MODEL RESULTS

# Plot for Acceleration



# Plot for Top Speed



# Baselining Results

| PARAMETERS | TARGET | ACHIEVED |
|---|---|---|
| Acceleration (0-40 km/h) | <3.3s | 3.282s |
| Top Speed | ≈ 80km/h | 79.95km/h |
| Overtaking (40-60 km/h) | <3.5s | 3.1685s |
| Gradability | >20% | 24.5% (≈11º) |
| Braking Distance (60-0 km/h) | <30m | 24.8m |

# MOTOR DESIGN

# INPUT DESIGN PARAMETERS

- ❑ Power and Torque requirements upper-limited to 5.5 kW and 26 Nm respectively (by the mechanical design team).
- ❑ Voltage rating upper limited to 83.14 V (by battery design team).
- ❑ Maximum rated current is limited to 100 A.

## Motor parameter need to be decided:

- Rated Voltage (V): 48
- Number of Poles: 18
- Thickness of Magnet : 1.4mm
- Mechanical Pole Embrace: 0.9
- Number of Conductors = 1
- Type of Magnet: NdFe35

➔ Higher number of poles considered to increase the linkage flux to meet torque requirement.

➔ Number of conductor and pole embrace decided to keep the Q and D axis Inductances high

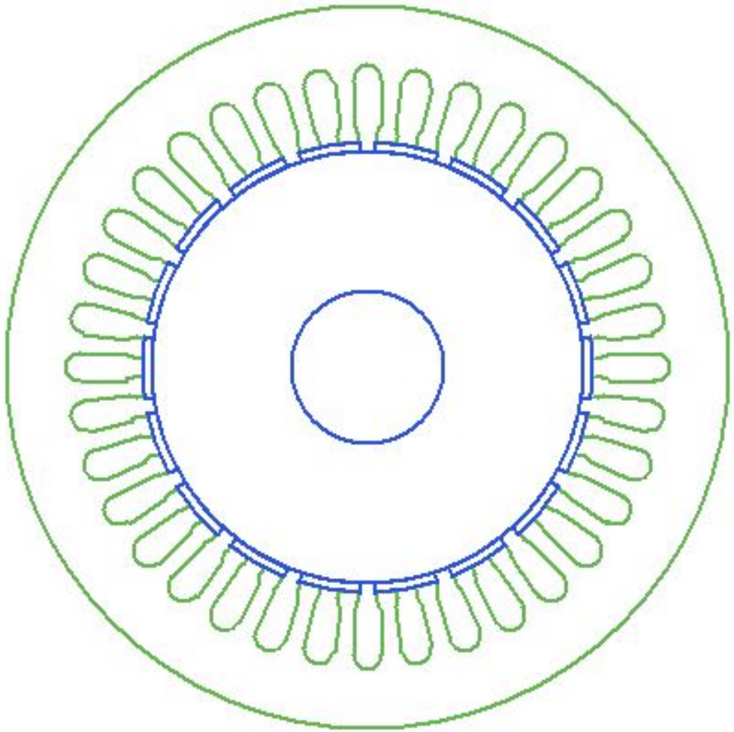
# MOTOR EFFICIENCY CALCULATION

## Required motor parameters

- Q-Axis Reactive Inductance $L_q$ = **160$\mu$H**
- D-Axis Reactive Inductance $L_d$ = **181$\mu$H**
- Armature Phase Resistance $R_a$ = **19.7 mΩ**
- Base Speed $n_{base}$ = **2000 rpm**
- Flux Linkage λ = **19.33 mWb**
- Reference speed for Frictional and Windage Losses

  $n_{ref}$ = **2400 rpm**
- Frictional Loss at reference speed = **11 W**
- Windage Loss at reference speed = **11 W**

## Motor stator and rotor design



# Analytical calculations

## 1st quadrant: ($T_{load}$ > 0, ω > 0)

Equations for the motor operation in 1st quadrant:

($T_{load} > 0, \omega > 0$)

$T_{load} + T_f + B\omega^2 = 1.5*P*[\lambda*I_q + (L_d - L_q)*I_d*I_q]$

$V_q = R*I_q + P\omega*L_d*I_d + P*\omega*\lambda$

$V_d = R*I_d - \omega*L_q*I_q$

$\mathbf{P_{in} = 1.5(V_q *I_q + V_d *I_d) + P_{core}}$

$\mathbf{P_{out} = T_{load}*\omega}$

$P_{Core} = 1.5*(V_q^2 + V_d^2)*n*n/R_f$

**Efficiency** = $\mathbf{T_{load}*\omega/P_{in}}$

## 4th quadrant: ($T_{load}$ > 0, ω < 0)

Equations for the motor operation in 4th quadrant:

($T_{load} > 0, \omega < 0$)

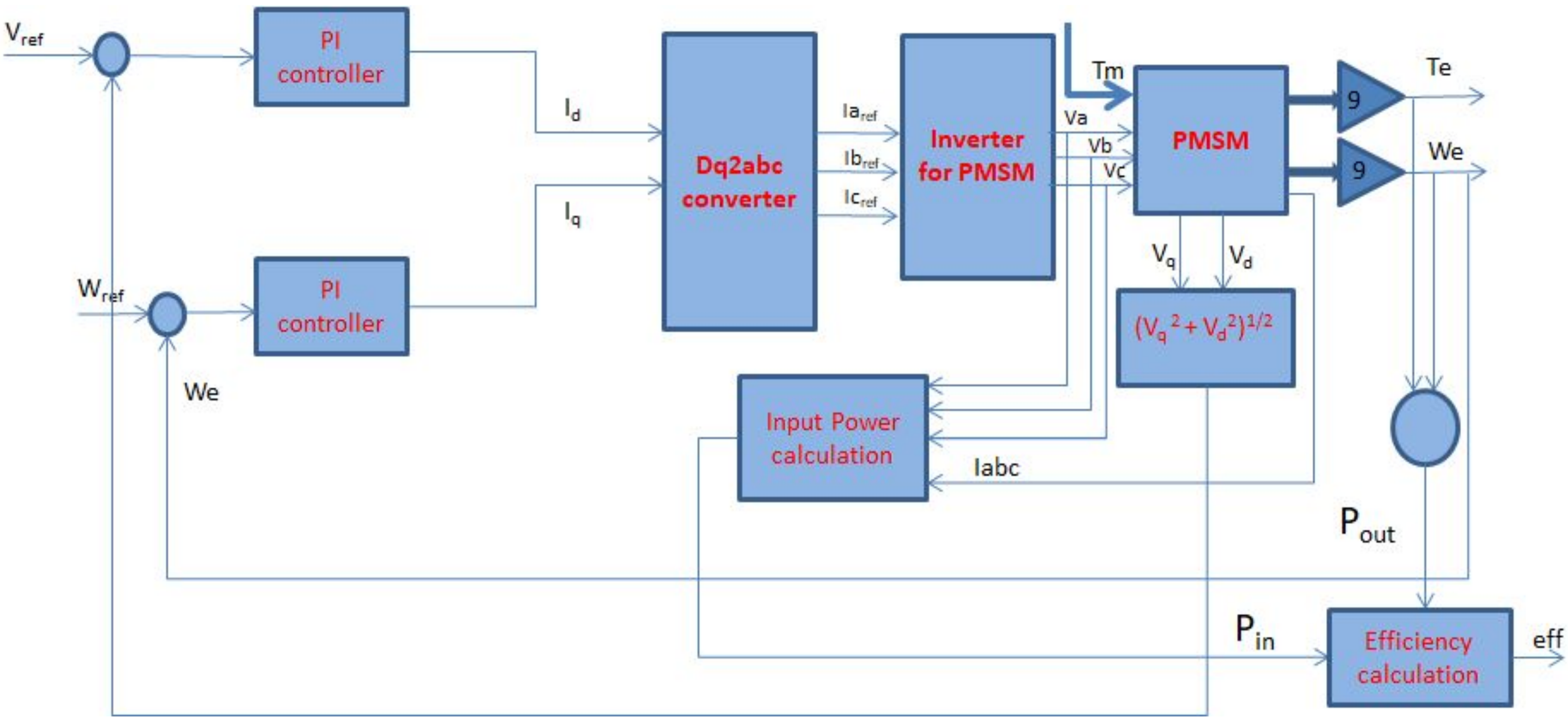
Here the power output is at electrical side will be:

$\mathbf{P_{out} = 1.5(V_q *I_q + V_d *I_d) + P_{core}}$

★ Same calculations for 2nd and 3rd quadrant operation of machine and the sign of $T_{load}$, ω will change accordingly

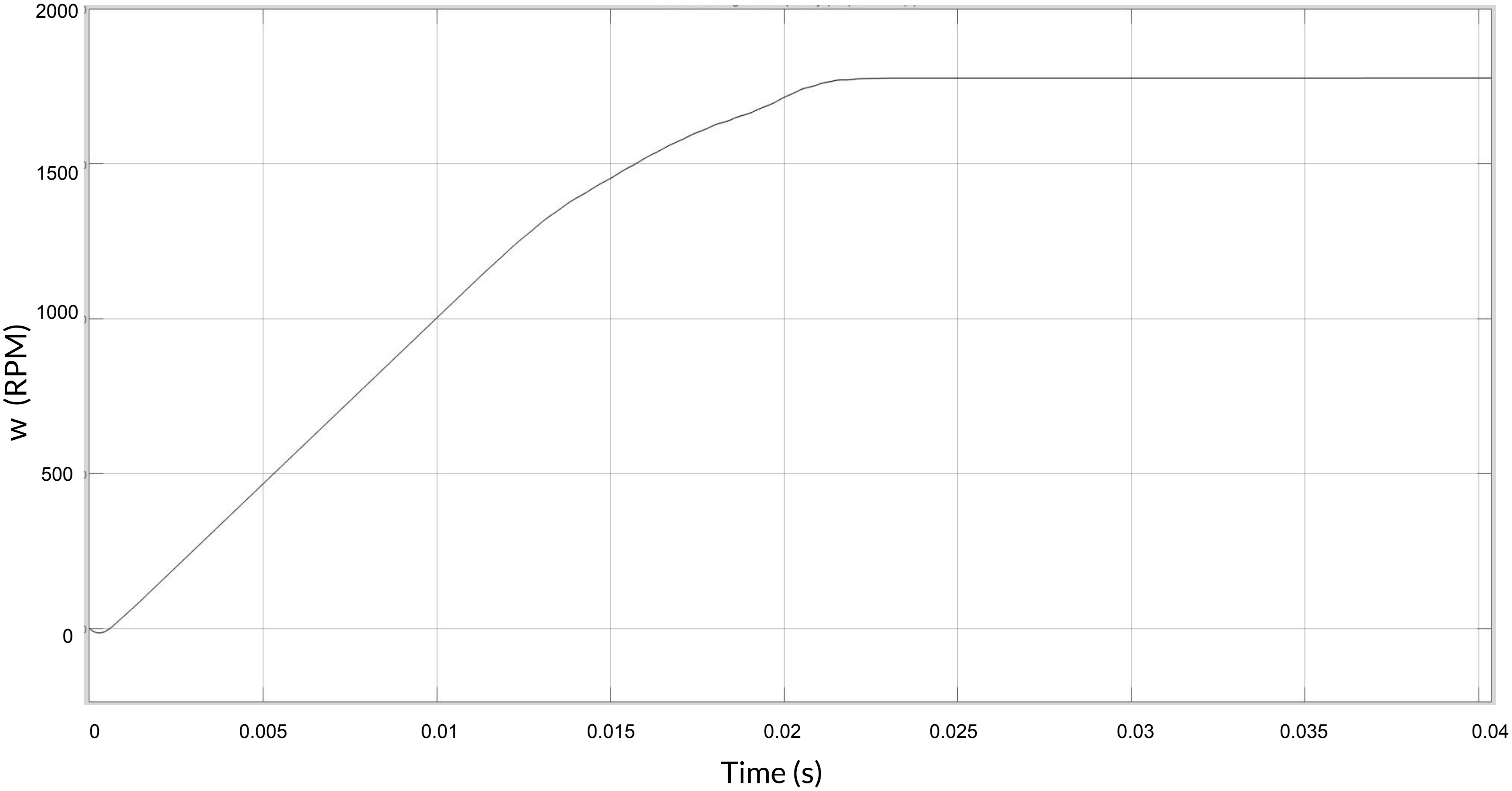
# SIMULATION MODEL OF MOTOR

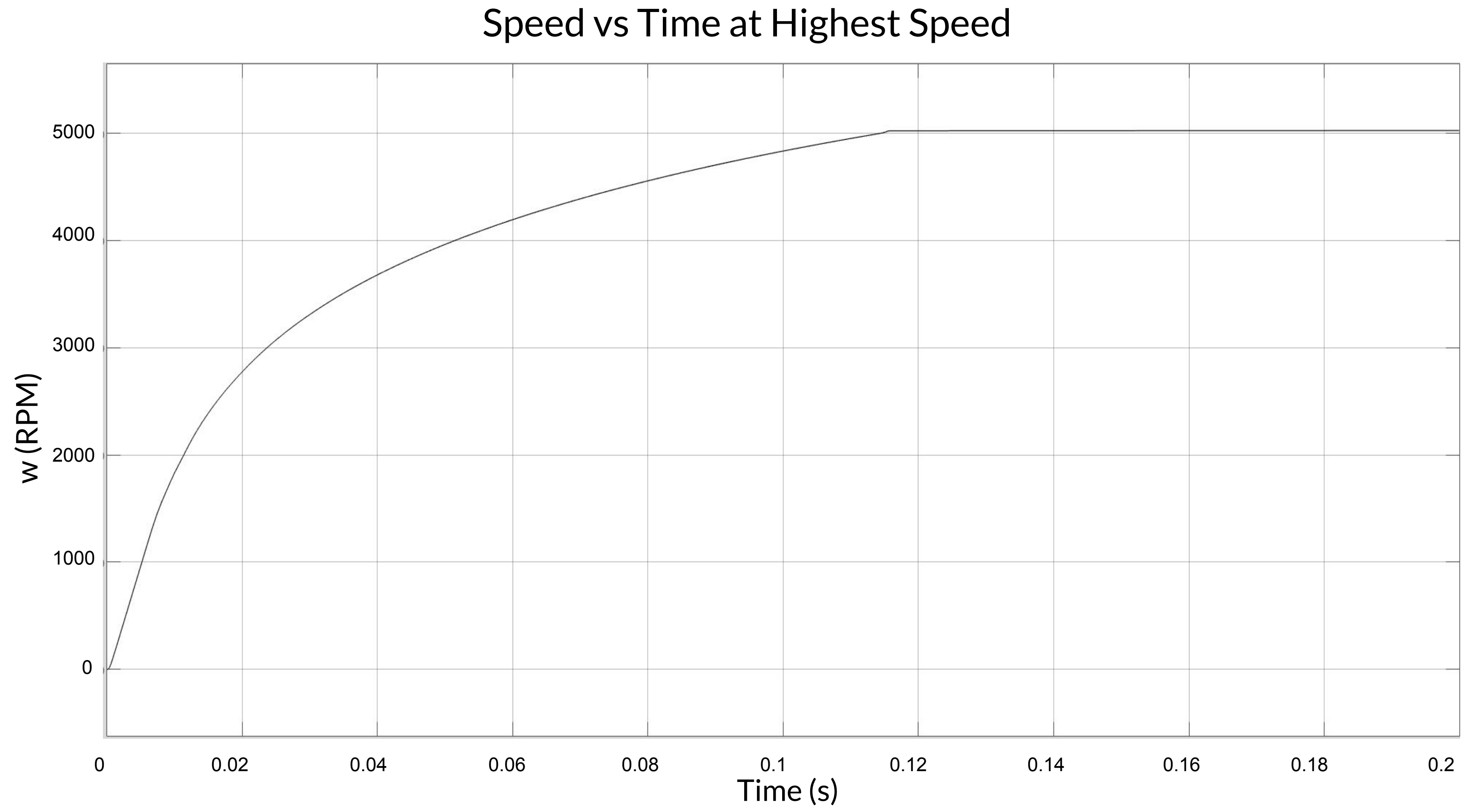
# Simulation Model Block Diagram



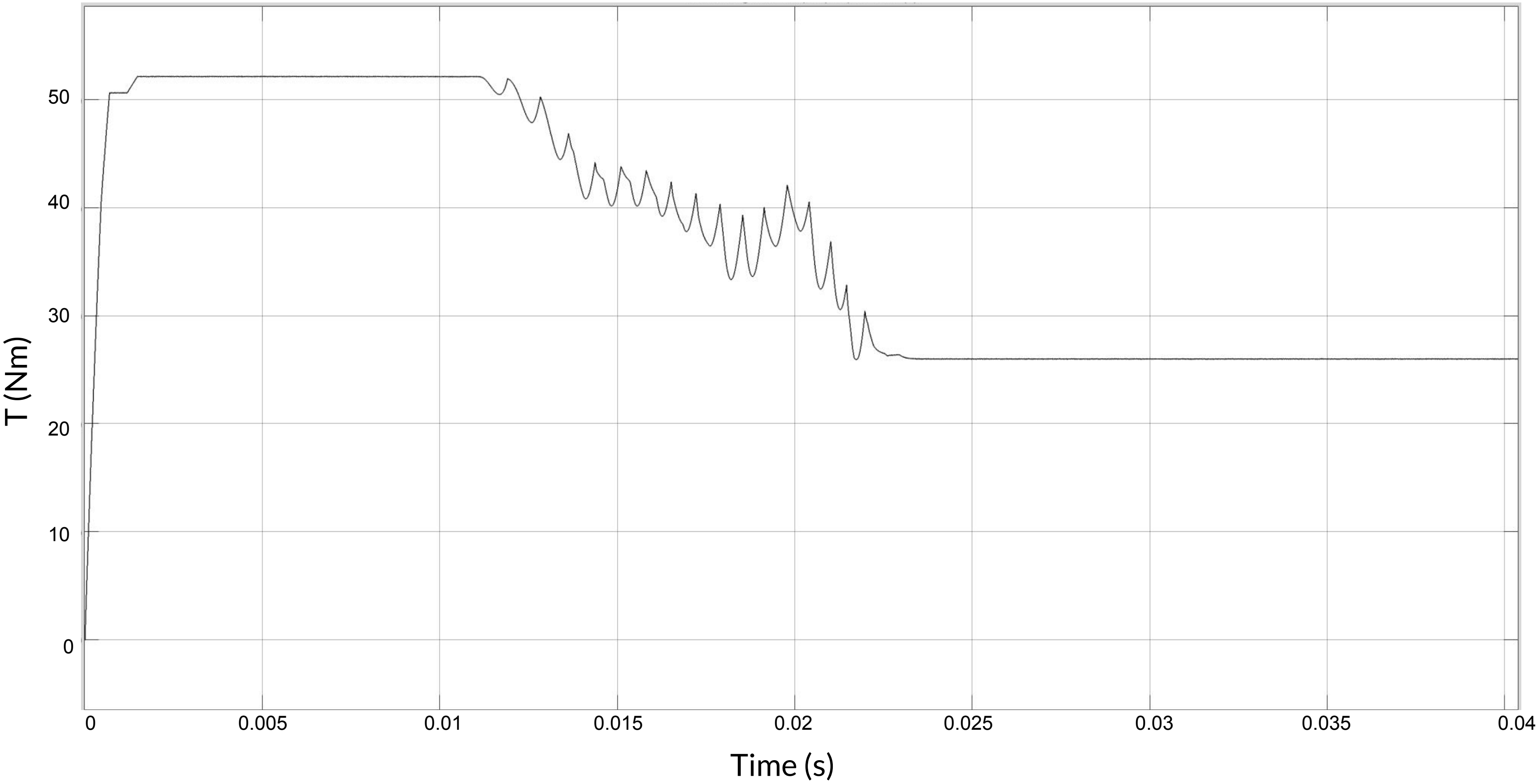
# MOTOR RESULTS

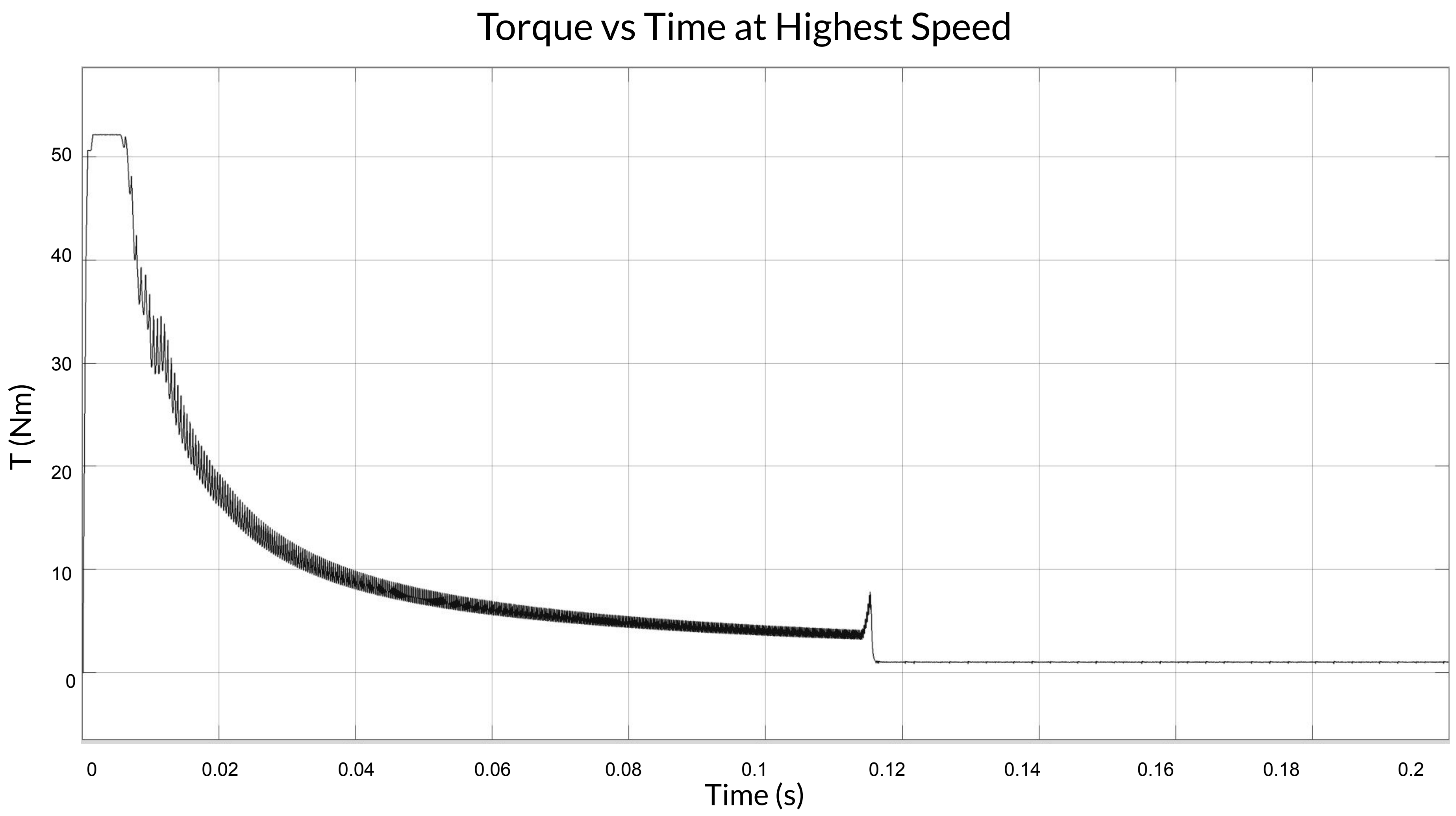
## Speed vs Time at Base Speed



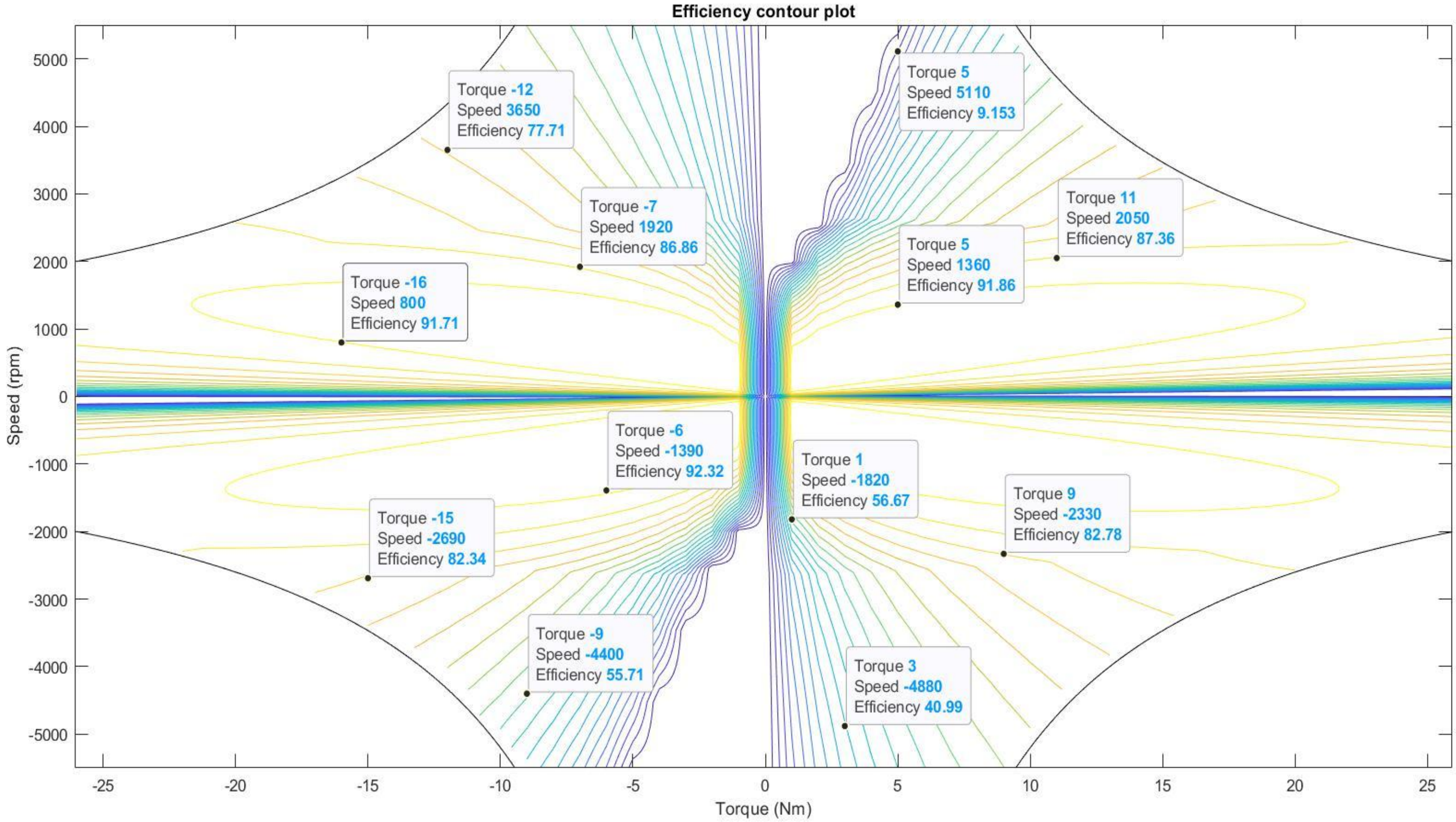

Speed vs Time at Highest Speed
w (RPM)
5000
4000
3000
2000
1000
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Time (s)

# Torque vs Time at Base Speed




Torque vs Time at Highest Speed
T (Nm)
50
40
30
20
10
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Time (s)

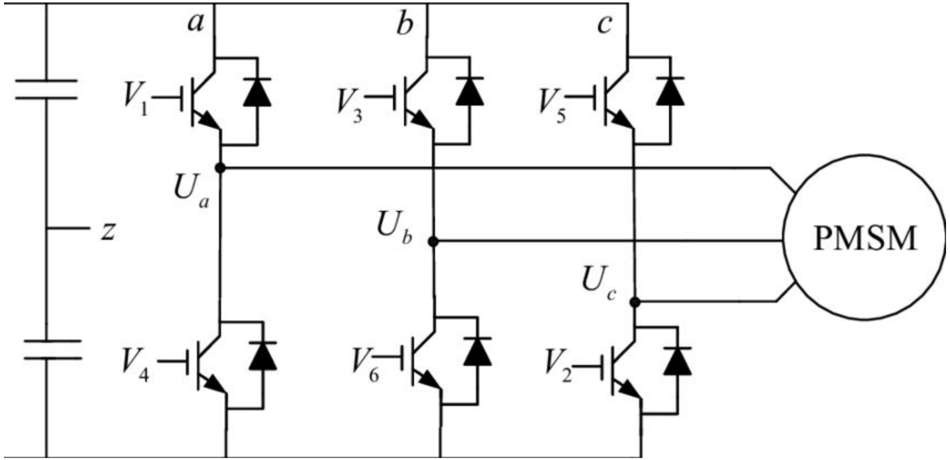
# MOTOR EFFICIENCY CONTOUR



# INVERTER DESIGN

# DESIGN REQUIREMENTS

1. To supply **48V** peak phase-neutral three phase supply.
2. To provide a variable frequency supply ranging **0 Hz - 825 Hz** to reach the required maximum speed of the motor




So, to get this we need variable voltage variable frequency inverter.

We have used a typical three phase voltage source inverter to get the three phase output required for the motor, along with a DC link capacitor.

# SWITCHING STRATEGY

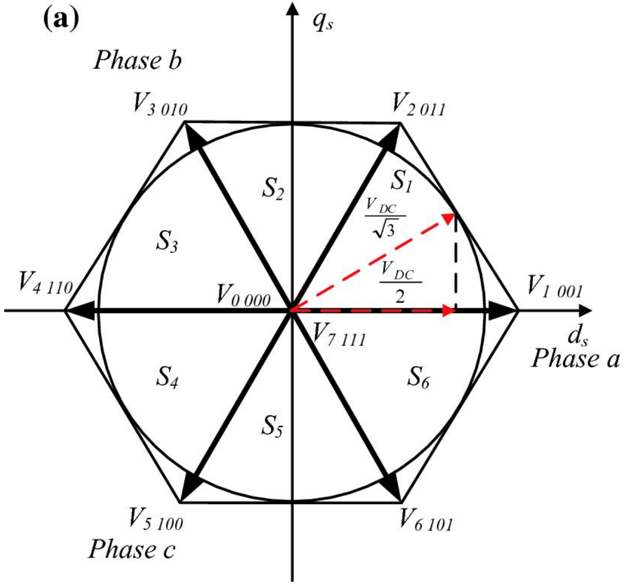
## Conventional Space Vector Pulse Width Modulation

The output peak voltage and frequency can be controlled using the modulation factor M

$$M = M_a / \sqrt{3} \times \sin(\omega t) \quad \left(0 \leqslant M_a \leq 1\right)$$

$$V_{ph-n,a} = M \times V_{DC}$$

- High DC bus utilization - 0.577 $V_{DC}$
- Low power losses
- Low Harmonic Distortion



# ELECTRICAL SPECIFICATIONS

To prove the required $V_d$, $V_q$, $I_d$ and $I_q$ values required by the motor through the range of frequencies, we get the following electrical specifications

## Electrical Specifications:

1. DC input voltage: **83.14 V**
2. Peak rms current: **101.5 A**
3. DC link capacitance to limit ripple to 2%: 4000 μF 100 $V_{DC}$ Aluminium electrolytic capacitor

# SWITCHING DEVICE

## Switch requirements

- Blocking voltage > $V_{DC}$ = 83.14 V
- Max Drain current $I_d$ > 100 A

Due to the lower blocking voltage, we prefer a MOSFET switch over an IGBT.

This also allows us to operate our inverter at higher switching frequencies.

We have taken a switching frequency, **$f_s$=25 kHz** - to get sufficiently low losses while also maintaining low harmonic distortion

# Switch Parameters (IPT030N12N3 G)

| Parameter | Value |
|---|---|
| Voltage Rating ($V_{DS\text{-}break}$) | 120V |
| Current Rating ($I_{D\text{-}max}$) | 237A |
| $V_{0,T}$ | 0V |
| $V_{0,d}$ | 0.9V |
| $R_{f,T}$ | 2.5mΩ |
| $R_{f,d}$ | 3mΩ |
| $t_{swon}$ | 41ns |
| $t_{swoff}$ | 74.7ns |
| $Q_{rr}$ | 115nC |

$$P_{cond,T} = \frac{V_{0,T} I_m}{2}\left(\frac{1}{\pi} + \frac{M\cos(\varnothing)}{4}\right) + r_{F,T} I_m^2 \left(\frac{1}{8} - \frac{5\sqrt{3}}{64} + \frac{M\cos(\varnothing)}{4} - \frac{5\sqrt{3}}{192\pi}\cos(2\varnothing)\right)$$

$$P_{sw,T} = \frac{V_{DC}}{\pi} I_m f_{sw}\left(t_{swon} + t_{swoff}\right)$$

$$P_{sw,D} = V_{DC} Q_{rr} f_{sw}$$

*For 6 switches,*

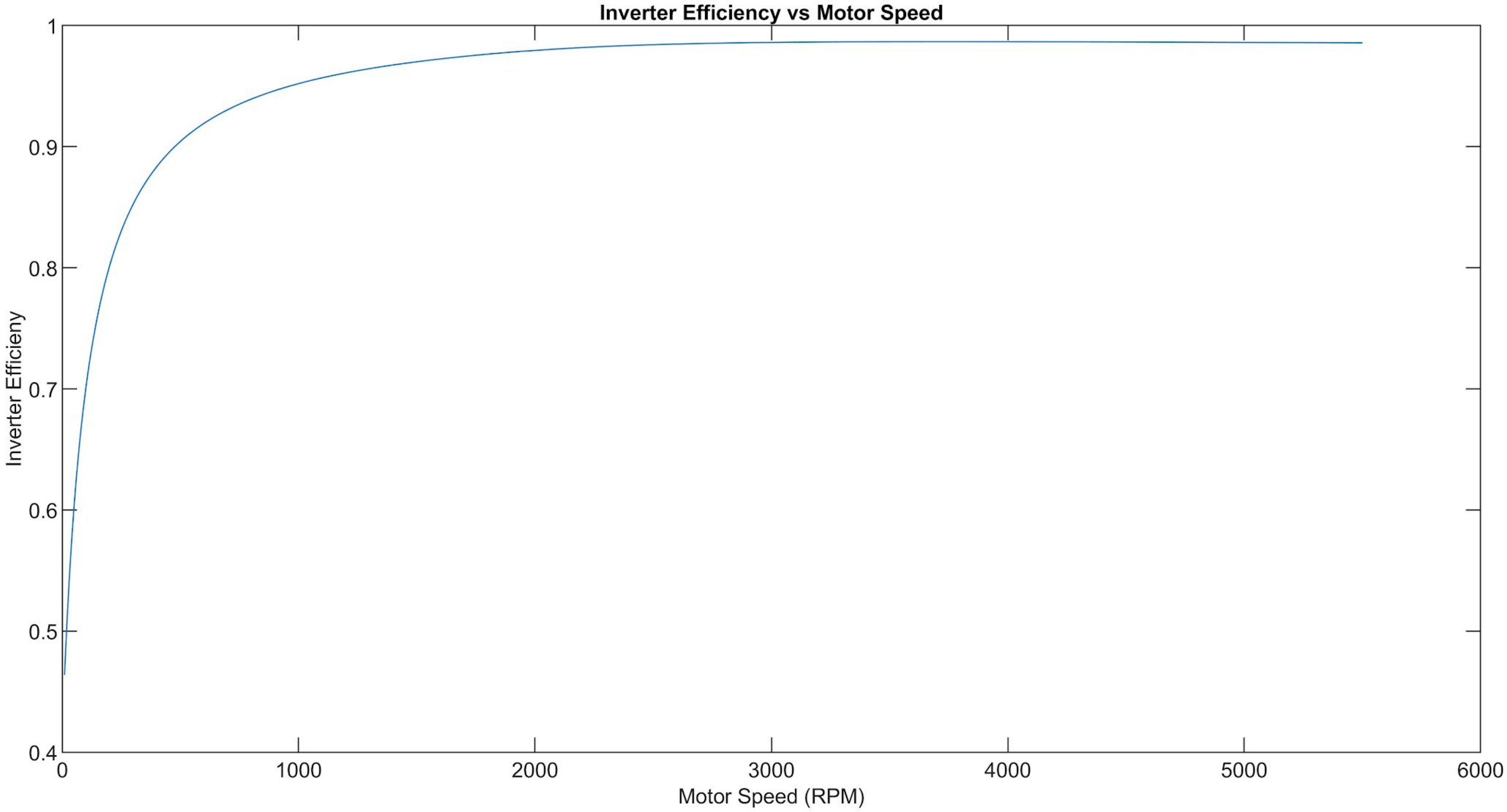
$$P_{cond} = 6 \times \left(P_{cond,T} + P_{cond,D}\right)$$

$$P_{sw} = 6 \times \left(P_{sw,T} + P_{sw,D}\right)$$

$$P_{loss} = P_{cond} + P_{sw}$$

$$Efficiency = 1 - \frac{P_{loss}}{P_{in}}$$

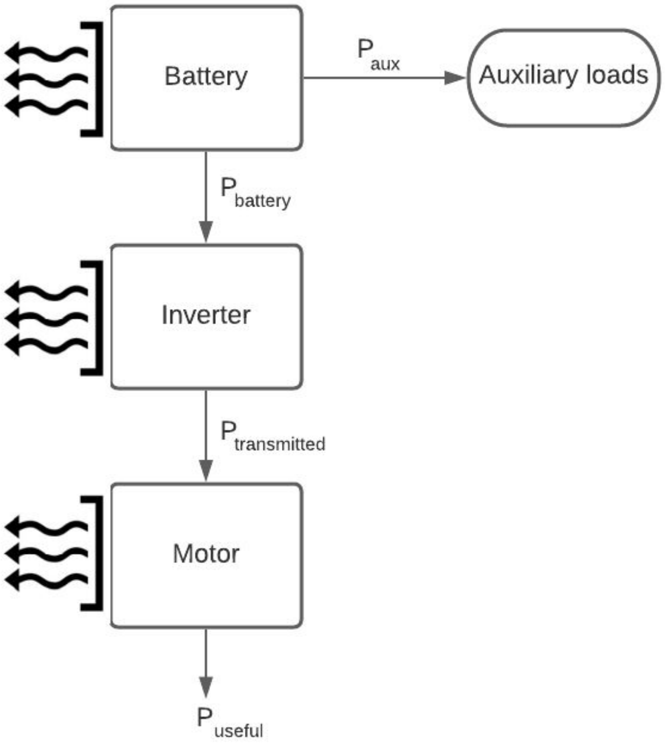
# PLOT FOR INVERTER EFFICIENCY



# BATTERY SIZING

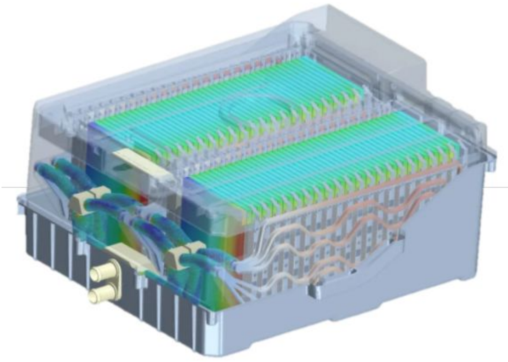
# BATTERY SIZING

- Target Range: 85 km
- Indian Drive Cycle
- Methodology:
    1. Compute useful power
    2. Estimate power losses due to inefficiencies
    3. Estimate auxiliary power consumption



# BATTERY SPECIFICATIONS

| PARAMETERS | SPECS |
|---|---|
| Usable battery capacity | 3 kWh |
| Average energy per driving cycle | 35 Wh/km |
| Auxiliary power consumption | 12 % |
| Obtained Range | 85 km |
| Battery unit's weight | 18 kg |



# REGENERATIVE BRAKING

# PARAMETERS

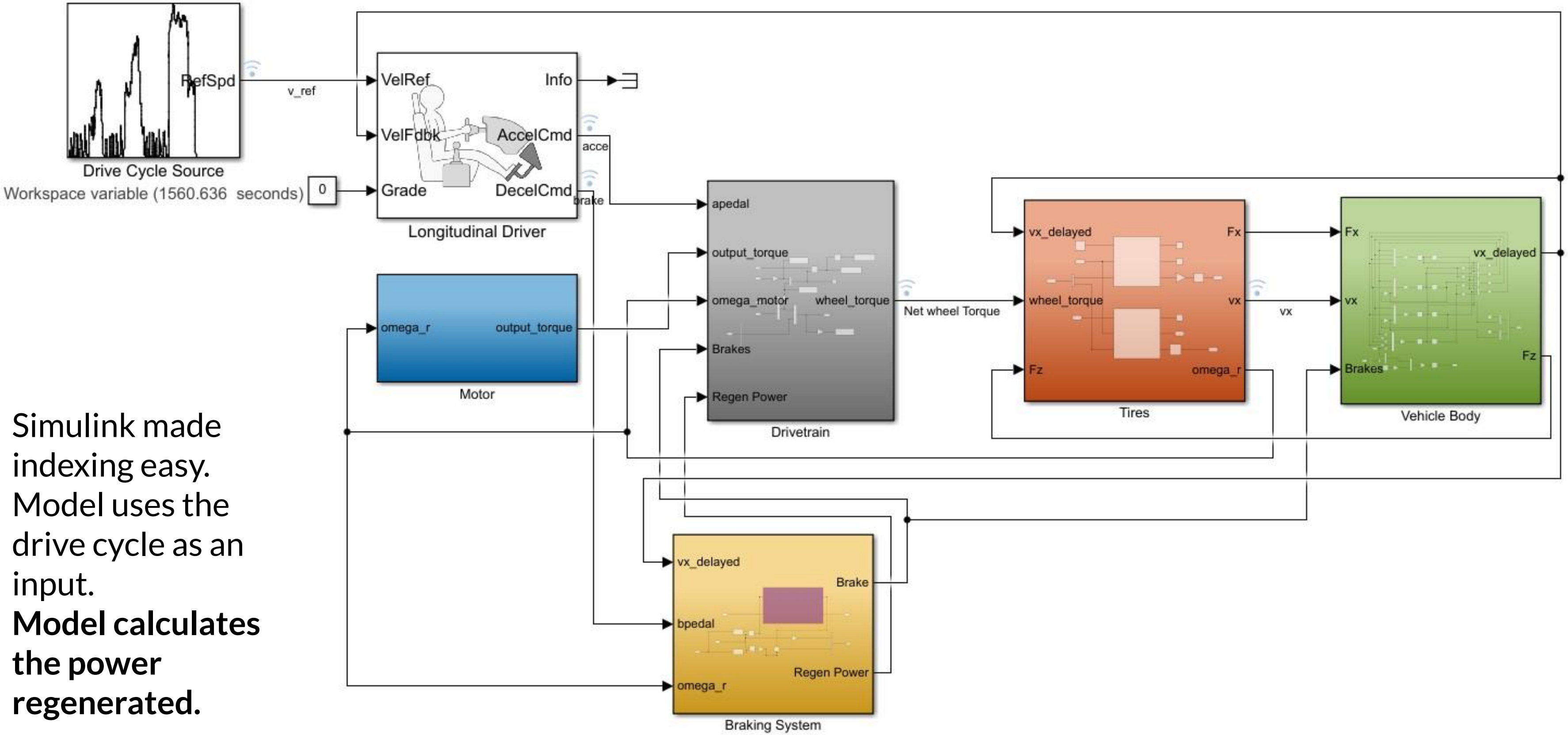
## 01 Charging Power Capacity Limited

- Charging capacity = 4.9kW
- Limits the usable Torque
- Ditch the Supercapacitors

## 02 Assumptions & Considerations

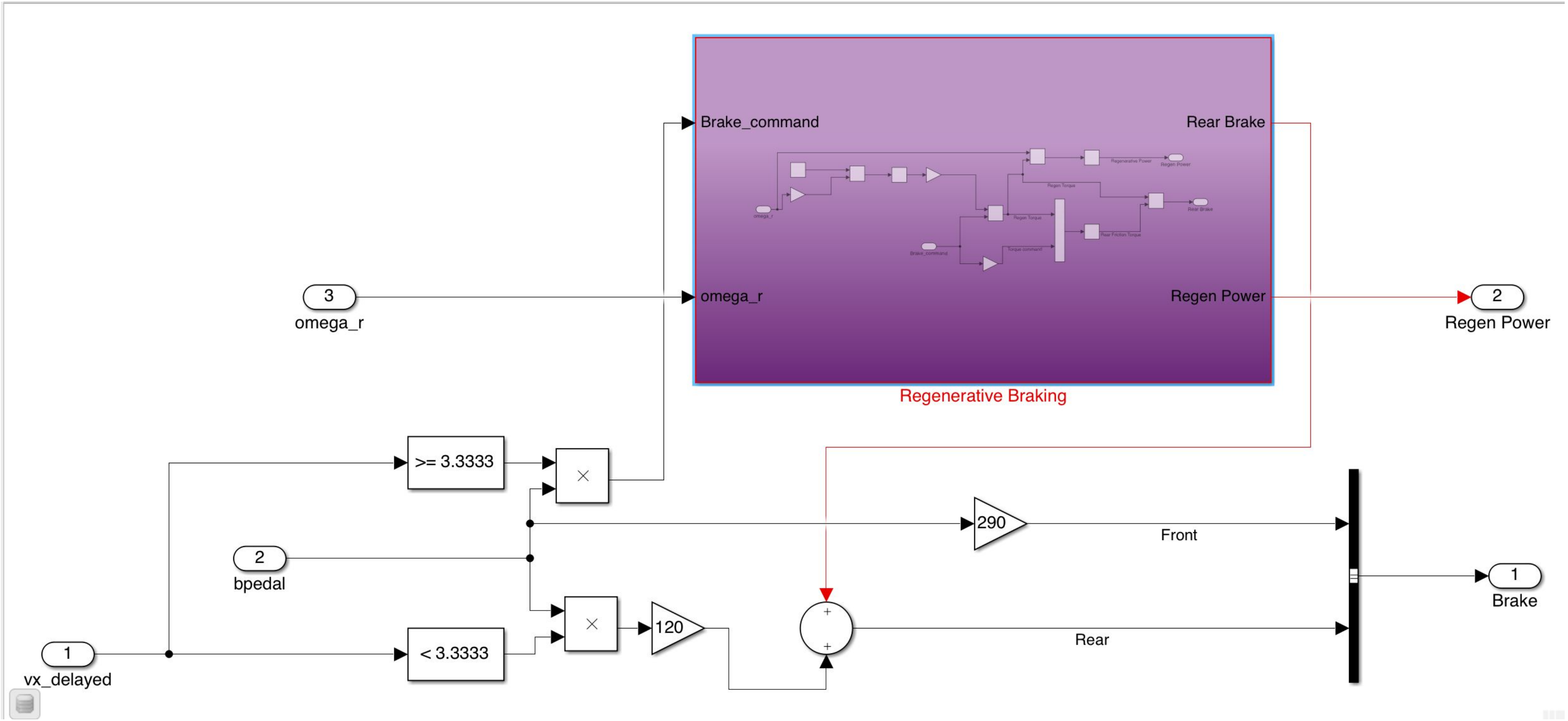
- Regenerative Braking disables if Speed is below 12 km/h
- Maintaining Braking Distance

# SIMULINK MODEL




- Simulink made indexing easy.
- Model uses the drive cycle as an input.
- **Model calculates the power regenerated.**

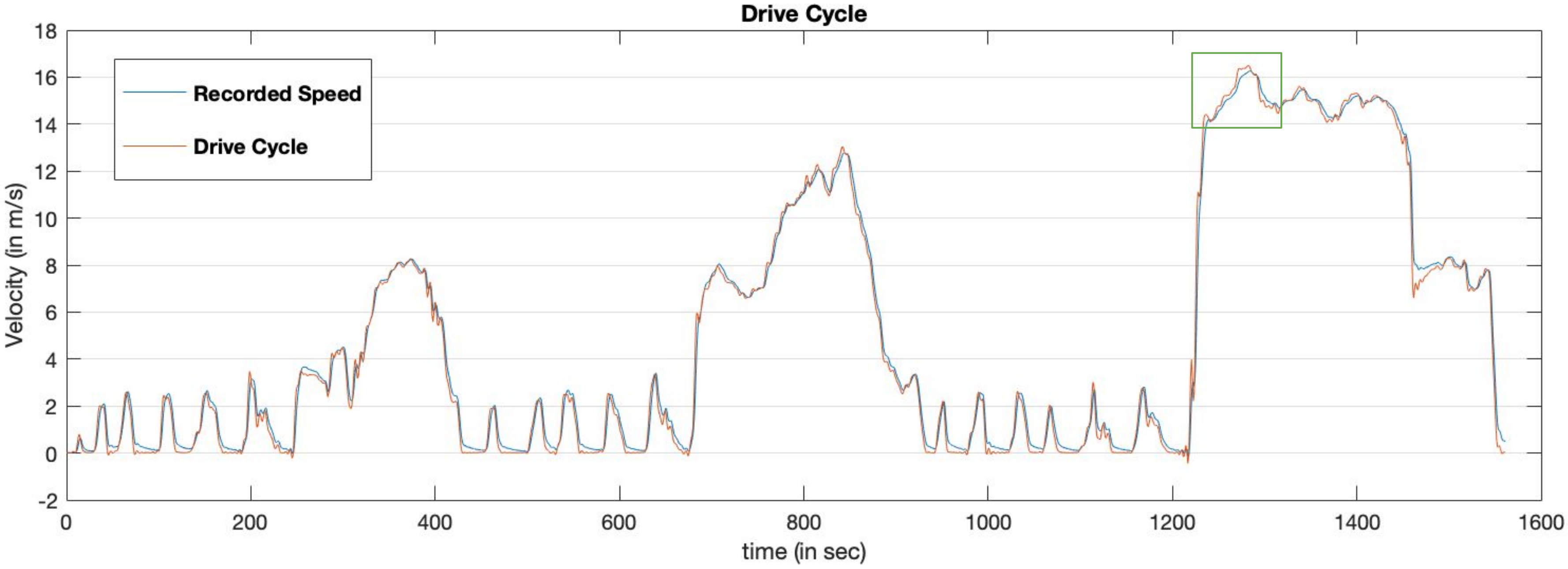
# BRAKING SYSTEM BLOCK



# PLOTS
# &
# RESULTS

# PLOT FOR SPEED vs TIME

INDIAN
URBAN
DRIVE CYCLE



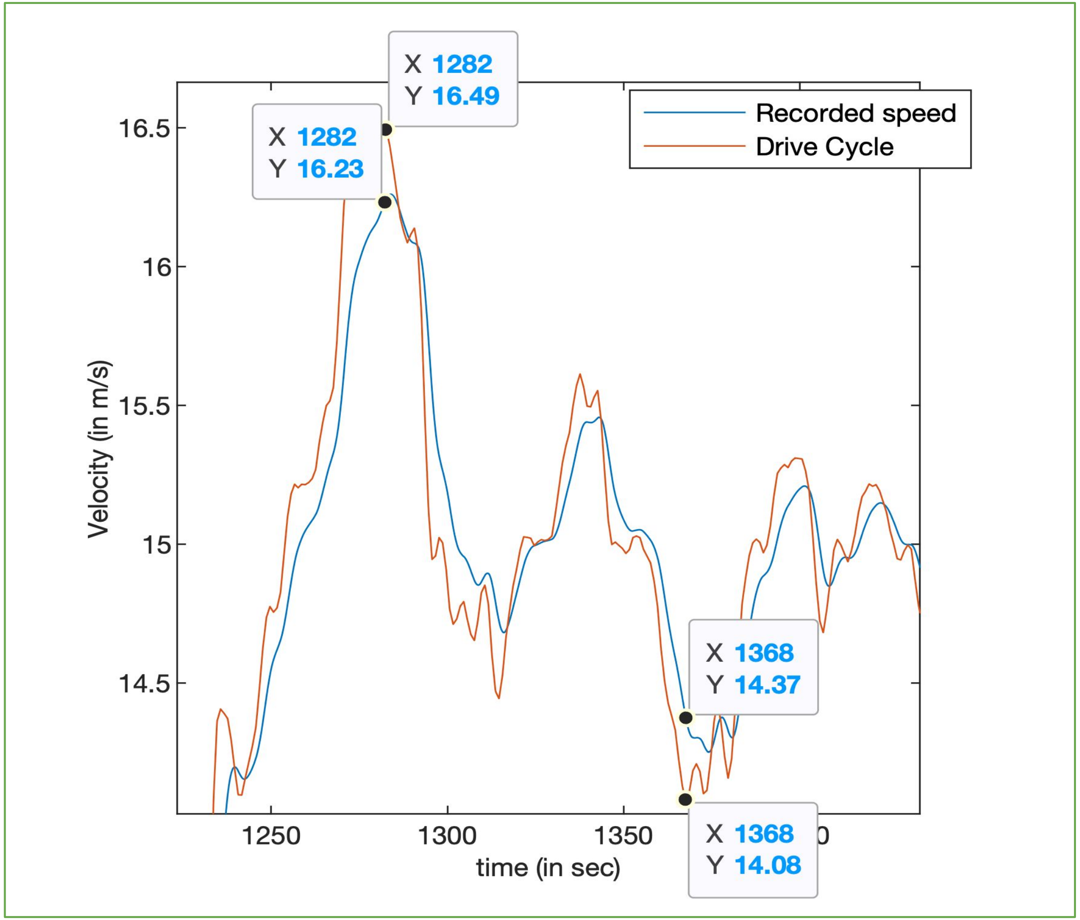
# INTERPRETATION

Notion : How Driver Model chases the Drive Cycle!

The difference is negligible.

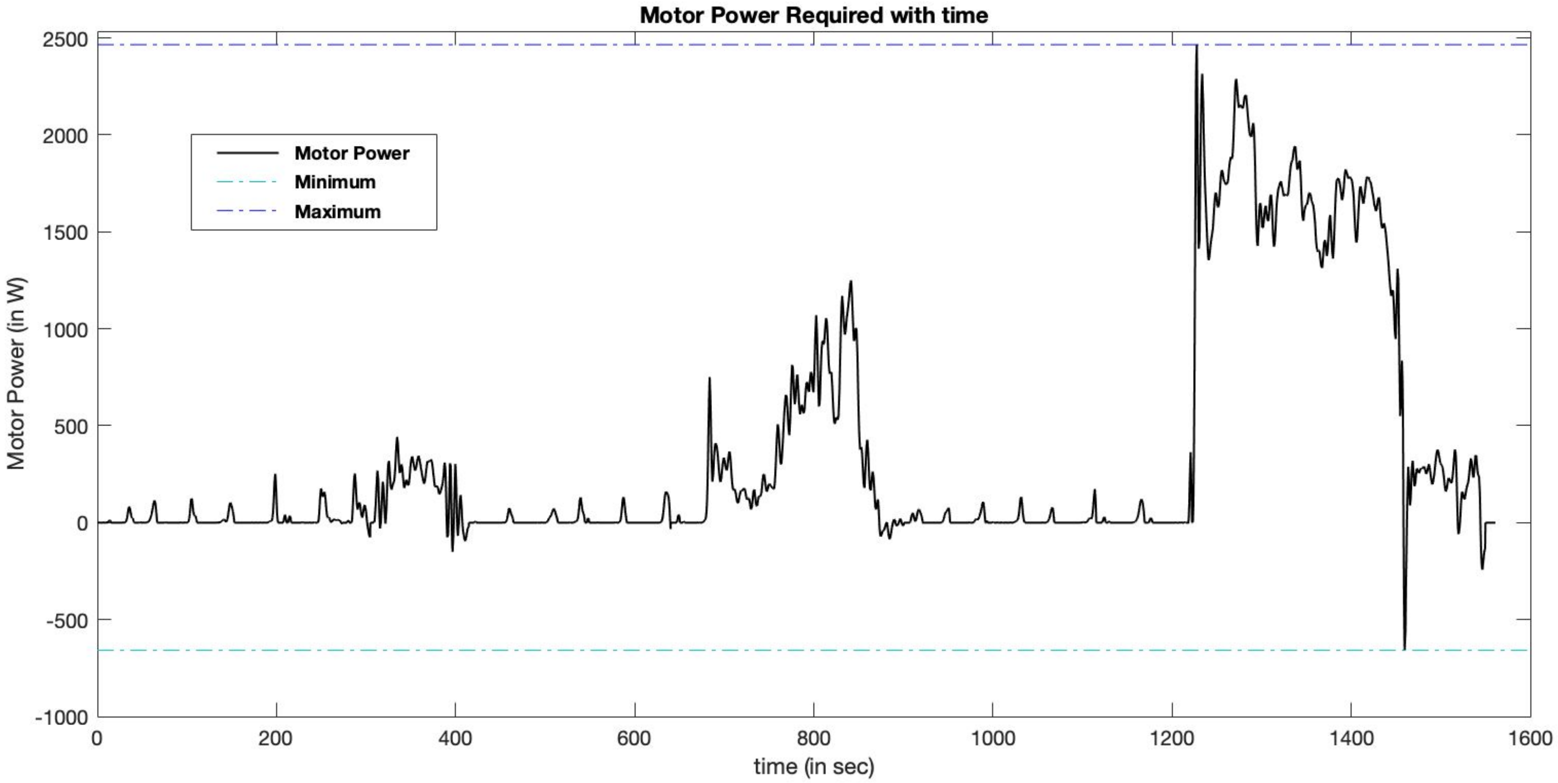
Let's say for these two points:

The average error is 1.8%



# MOTOR POWER vs TIME

Increase in Average Energy per Drive Cycle = 0.623 %



# ELECTRICAL ARCHITECTURE

# AUXILIARY SYSTEMS

## Systems

BMS

ECU

CAN

## Integration

Harness

## Safety

Fuses

Insulation Monitoring

## Sensors

Potentiometers

Temperature

Current

Inertia

## Others

Lights

Dash

Fans

# THANK YOU!