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CHEMNITZ

Advanced Range Estimation Of An e-Bike

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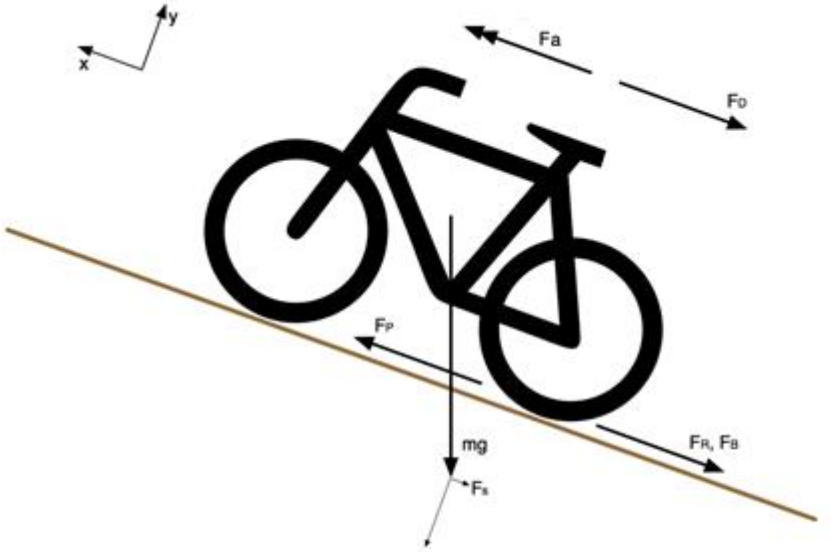
Contents

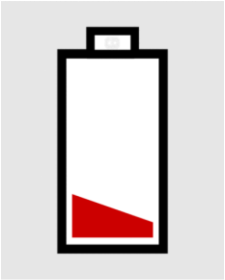
Introduction

- Heterogeneous modelling of a Pedelec (mechanical and electrical domain) that estimates the total energy required for the track.

.gpx file provides coordinates and elevation.



Physical model to compute the mechanical power required



Electrical subsystem to compute energy required to run the track

Fig.1 : Heterogenous model overview

Model Implementation - Overview

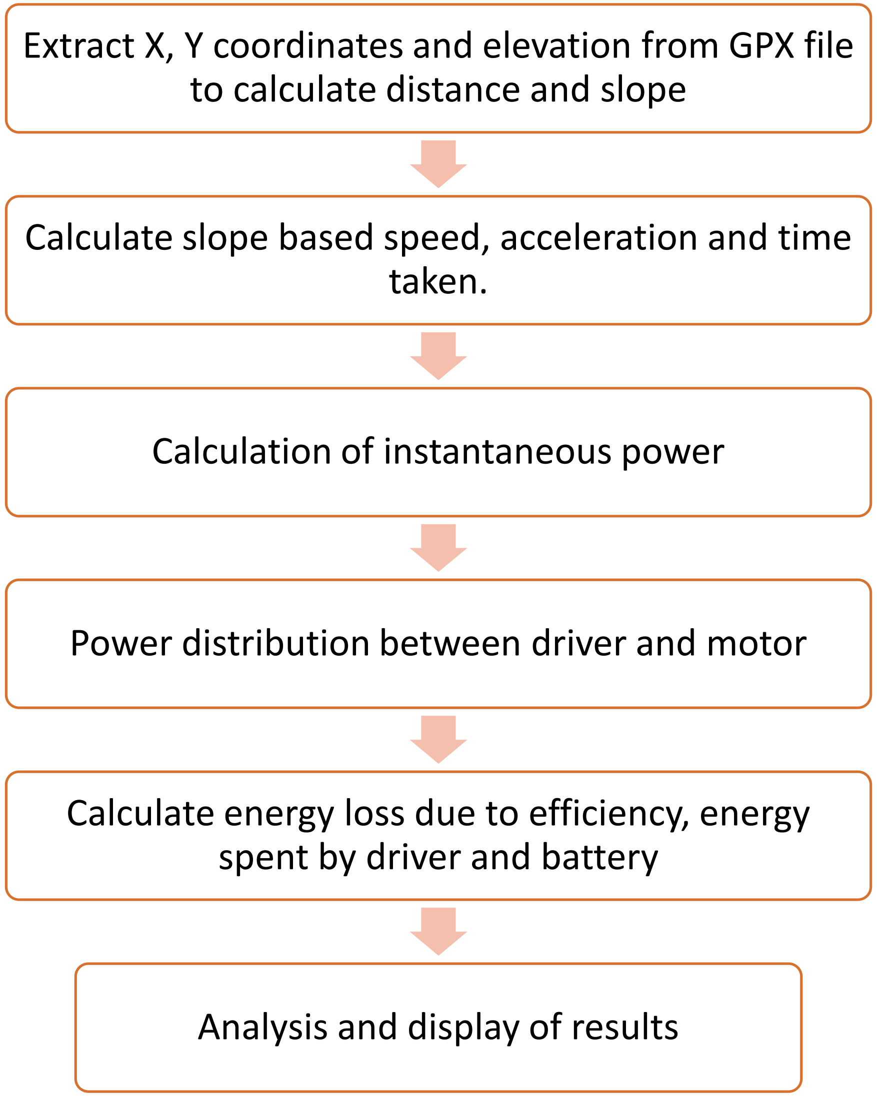


Fig.2 : Model flowchart

Model Implementation - Overview

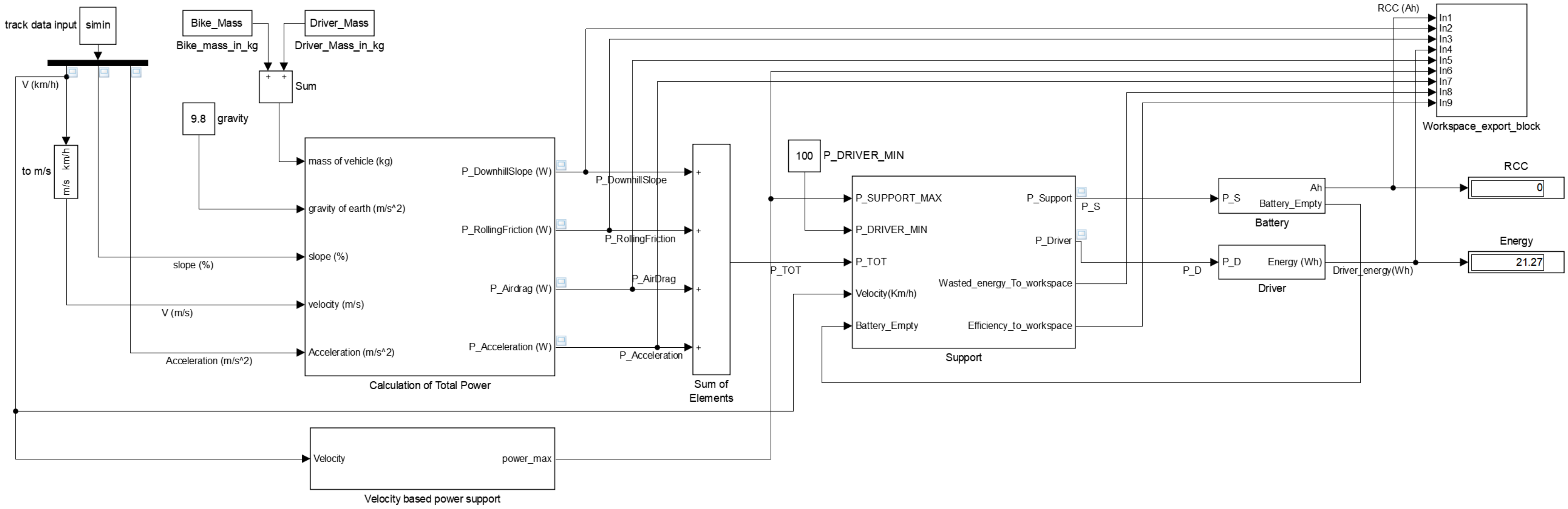


Fig.3 : Top level - Simulink model

Calculation of speed, time and acceleration

Calculation of speed

- Speed over each of the segment is assigned based on slope of the track
- Idea: Speed increases downhill and decreases uphill.
- Speed is calculated using the equation

$$Speed(s_i) = 20 - 80 * sin(angle(s_i))$$

Where:

Angle(s_i) = atan(Grade(s_i)/100).

Grade(s_i) = rise/run or elevation/distance.

s_i = segment of index ‘i’.

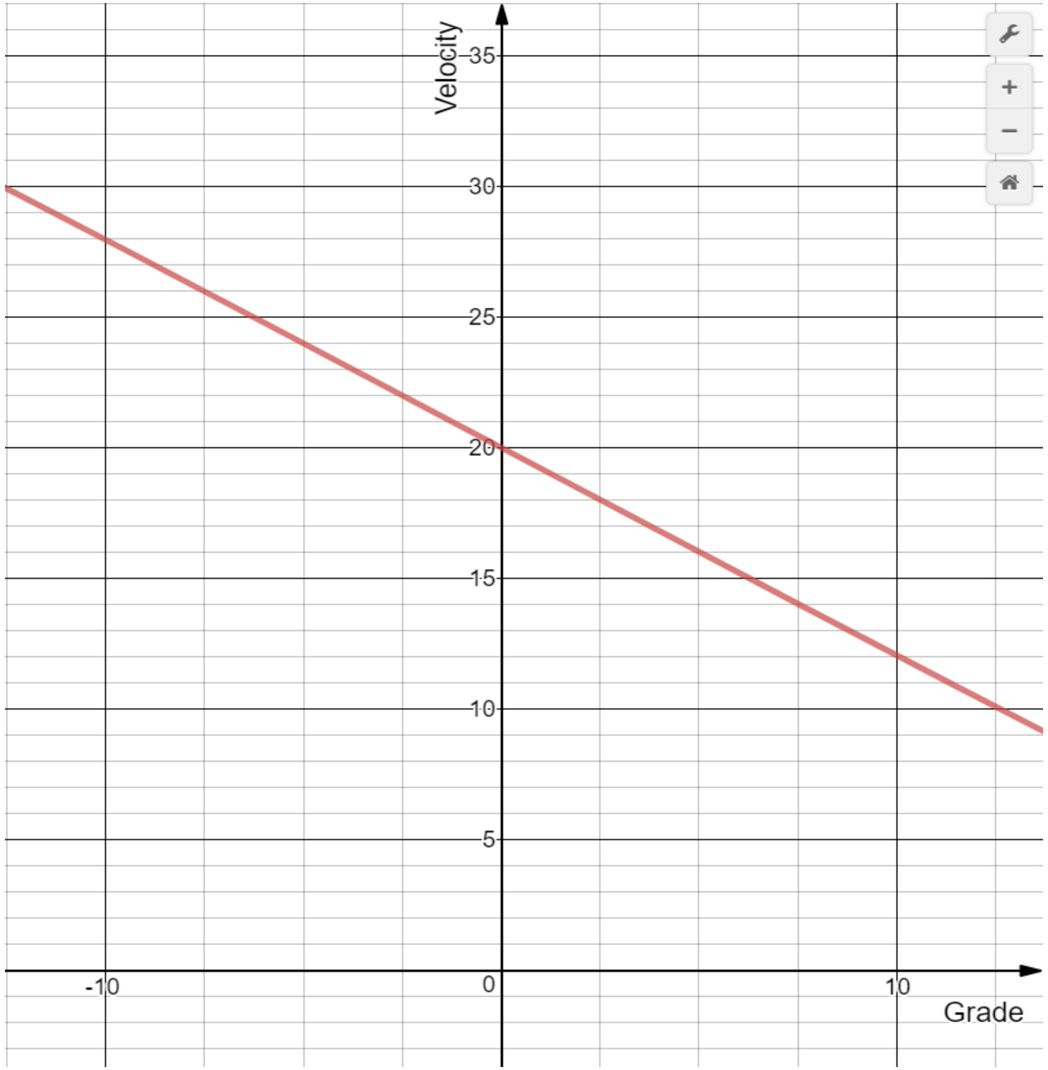


Fig.4 : relation between velocity(km/h) and grade(%)

Calculation of time and acceleration

- Equations
  - $v = u + at$ [1]
  - $v^2 = u^2 + 2ad$ [1]
  - $t(s_i) = \frac{d}{average\ speed}$
  - $a(s_i) = \frac{v-u}{t(s_i)} * \frac{1000}{3600*3600} \frac{m}{s^2}$

Where,

v – Final Velocity at s_{i+1} in km/h

u – Initial Velocity at s_i in km/h

a – Acceleration in m/s^2

d – Segment distance in km

t(s$_i$) – Time taken in hours for segment s_i

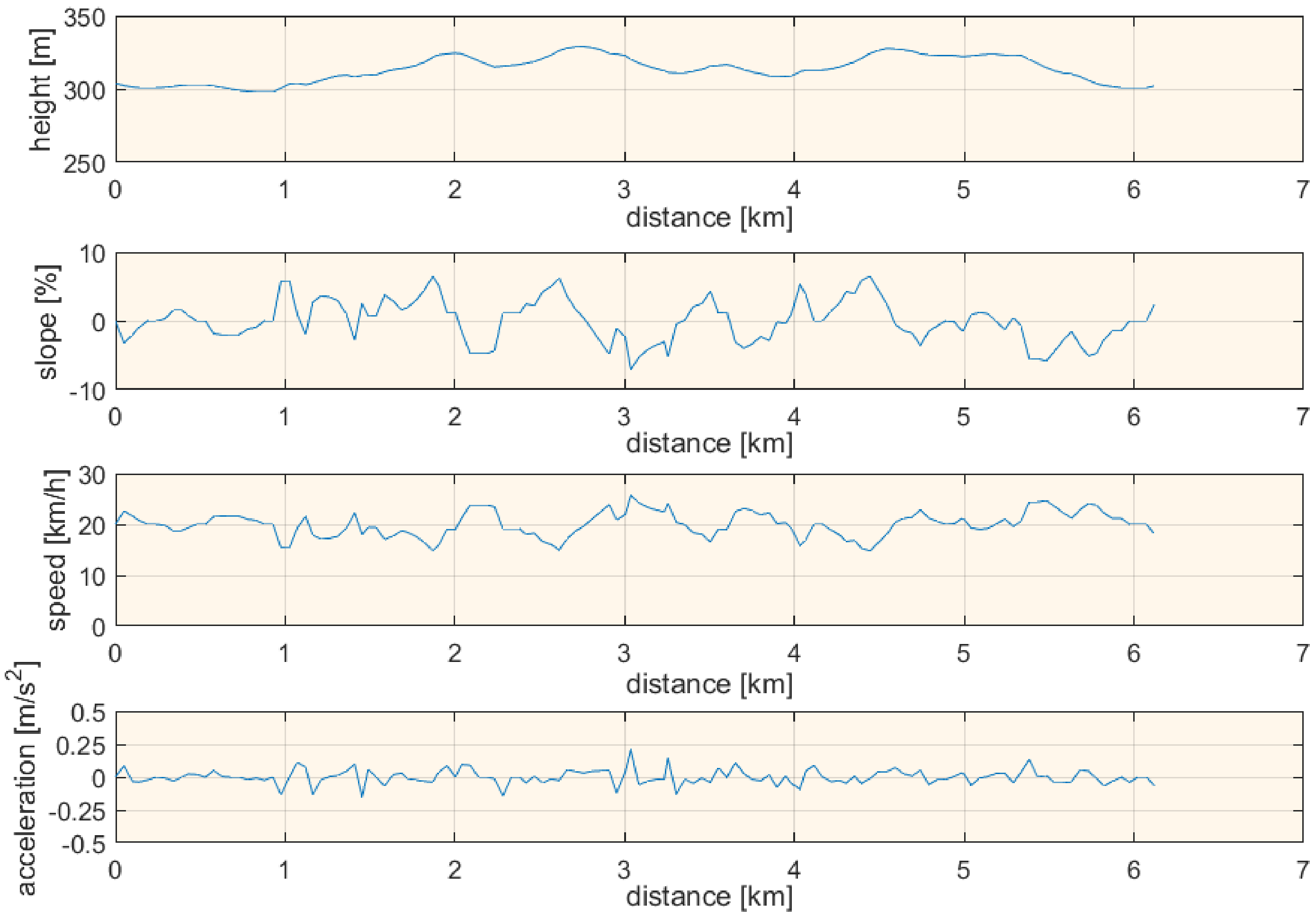


Fig.5 : Elevation, slope, speed and acceleration graphs

Calculation of Power

- Power required for the Pedelec to drive the track is calculated.

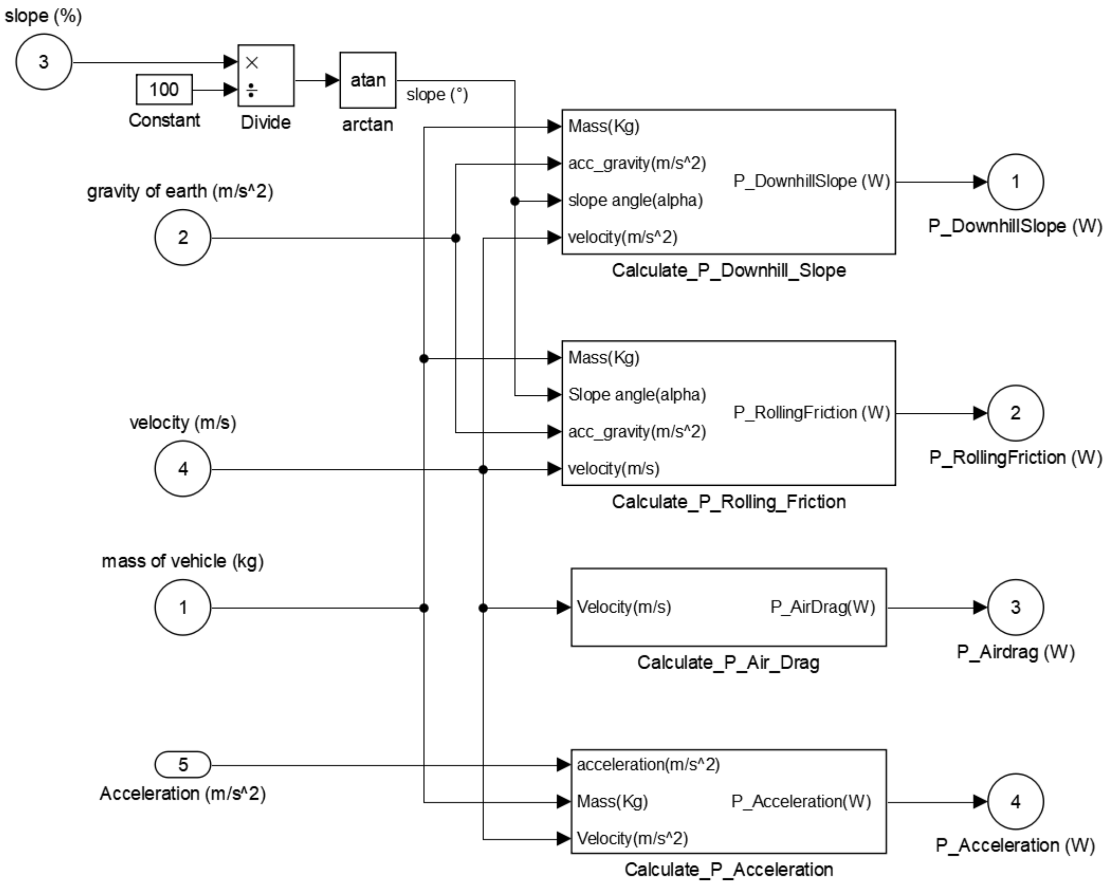


Fig.6 : Power calculation subsystem – Simulink model

$$P_{Downhill\ Slope}\ (s_i) = \sin(\alpha_i)\,.\,g\,.\,(m_{Pedelec} + m_{Driver})\,.\,v_i$$ [2]

$$P_{Rolling\ Friction}\ (s_i) = c_r.\cos(\alpha_i)\,.\,g\,.\,(m_{Pedelec} + m_{Driver}).v_i$$ [2]

$$P_{Air\ Drag}\ (s_i) = \frac{\rho.c_W.A.v_i^2}{2}\,.\,v_i$$ [2]

$$P_{Acceleration}(s_i) = a_i.(m_{Pedelec} + m_{Driver}).v_i$$ [2]

$$P_{Pedelec}(s_i) = P_{Acceleration}(s_i) + P_{Rolling\ Friction}\ (s_i) + P_{Downhill\ Slope}\ (s_i) + P_{Air\ Drag}\ (s_i)$$ [2]

Distribution of Power

1. Support power = 0W, when driver does not provide minimum power or when battery is empty.
2. Support subsystem does current limiting and redistributes excess power to the driver.
3. Maximum continuous shaft power is 250W.

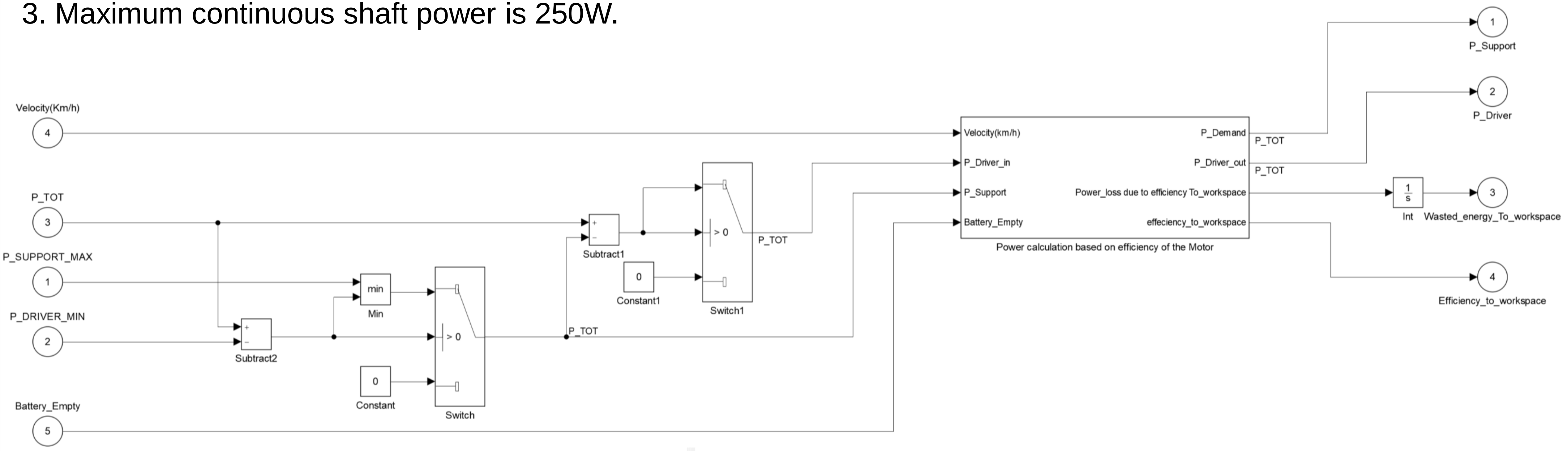


Fig.7 : Support subsystem – Simulink model

Calculation of Motor Efficiency

Functions:

1. $\eta(v) = \begin{cases} 0.85 & , v > 22\ km/h \\ 0.40 & , v = 0\quad km/h \\ \frac{0.45}{22} * v + 0.40, & v = others \end{cases}$

2. $P_{demand}(t) = \dfrac{P_{support}(t)}{\eta(v(t))}$

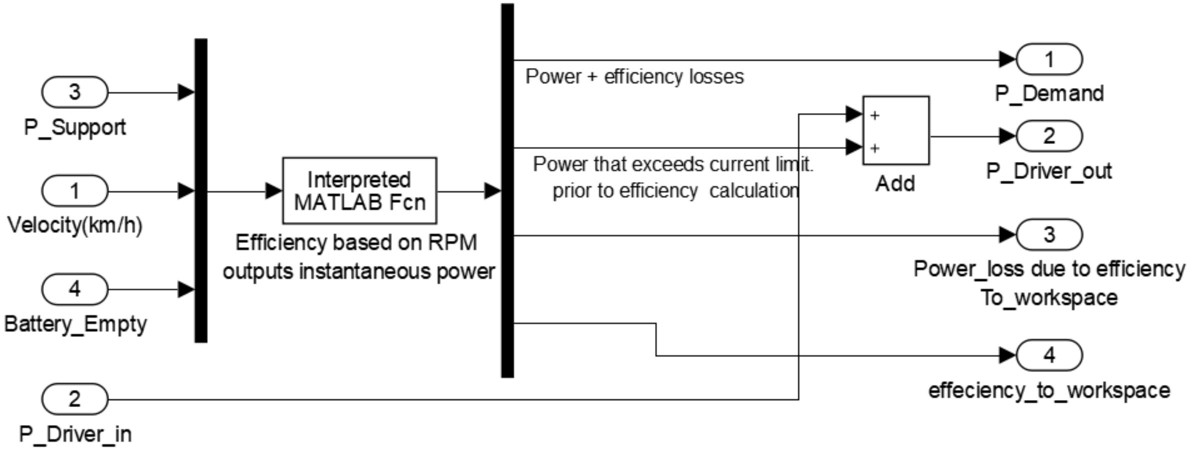


Fig.8.1 : Power calculation based on efficiency of motor – Simulink model subsystem

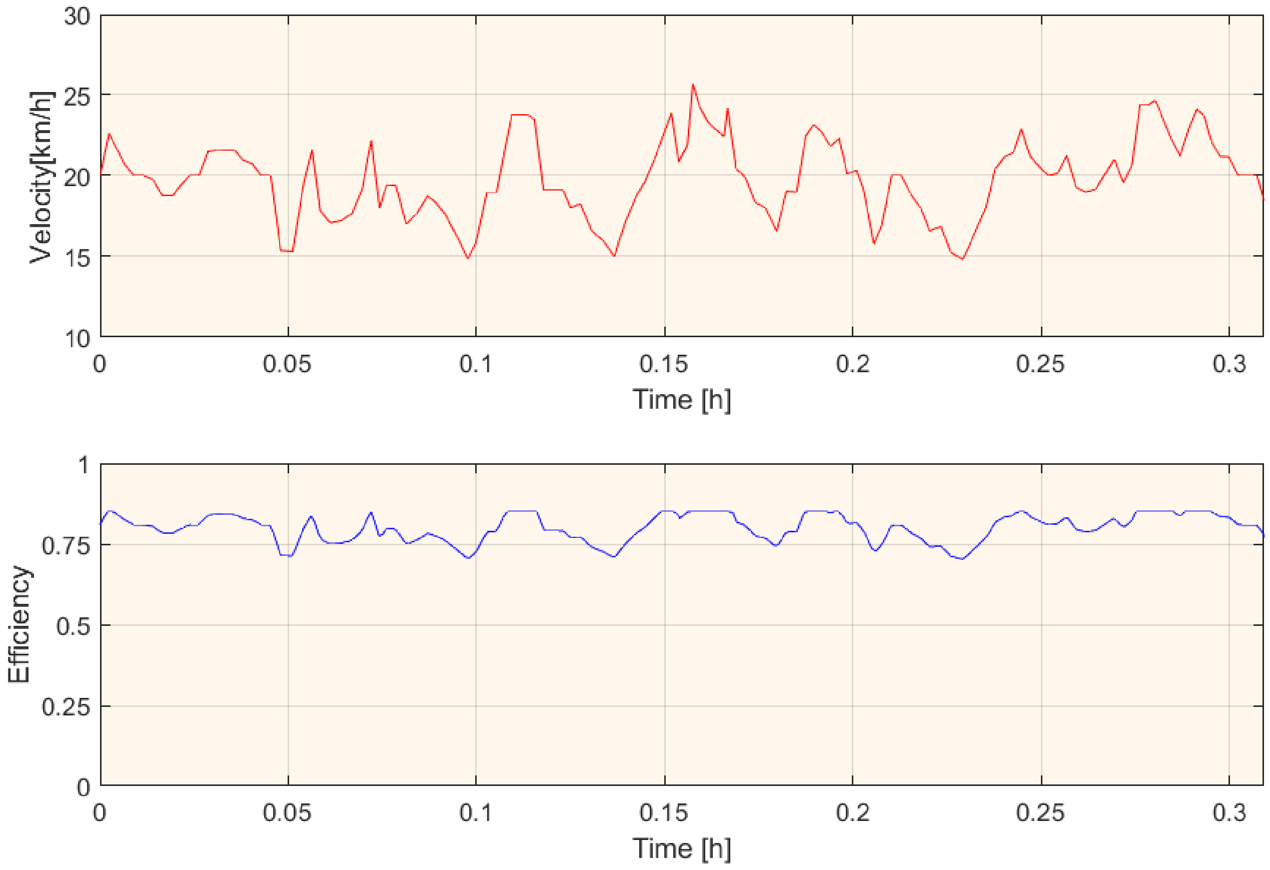


Fig.8.2 : Efficiency calculated based on velocity of the e-bike

Gradual shutoff of motor support

- By statutory rule, if velocity > 25 km/h, motor should be shutoff. Full power to be given by driver[3].
- This shutoff is linear from 22km/h, expressed by the following function.

$$power\_\max(v) = \begin{cases} 0W & , v > 25\ km/h \\ 250W & , v < 22\ km/h \\ \left(\frac{250}{25-22}\right) * (25 - v), others \end{cases}$$

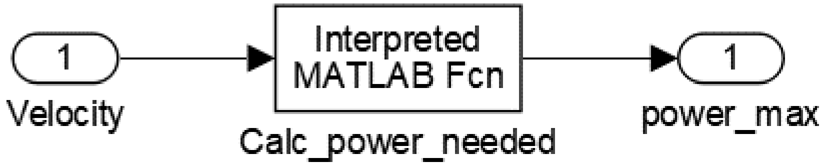


Fig.9.1 : Simulink block to calculate max power with the help of a script.

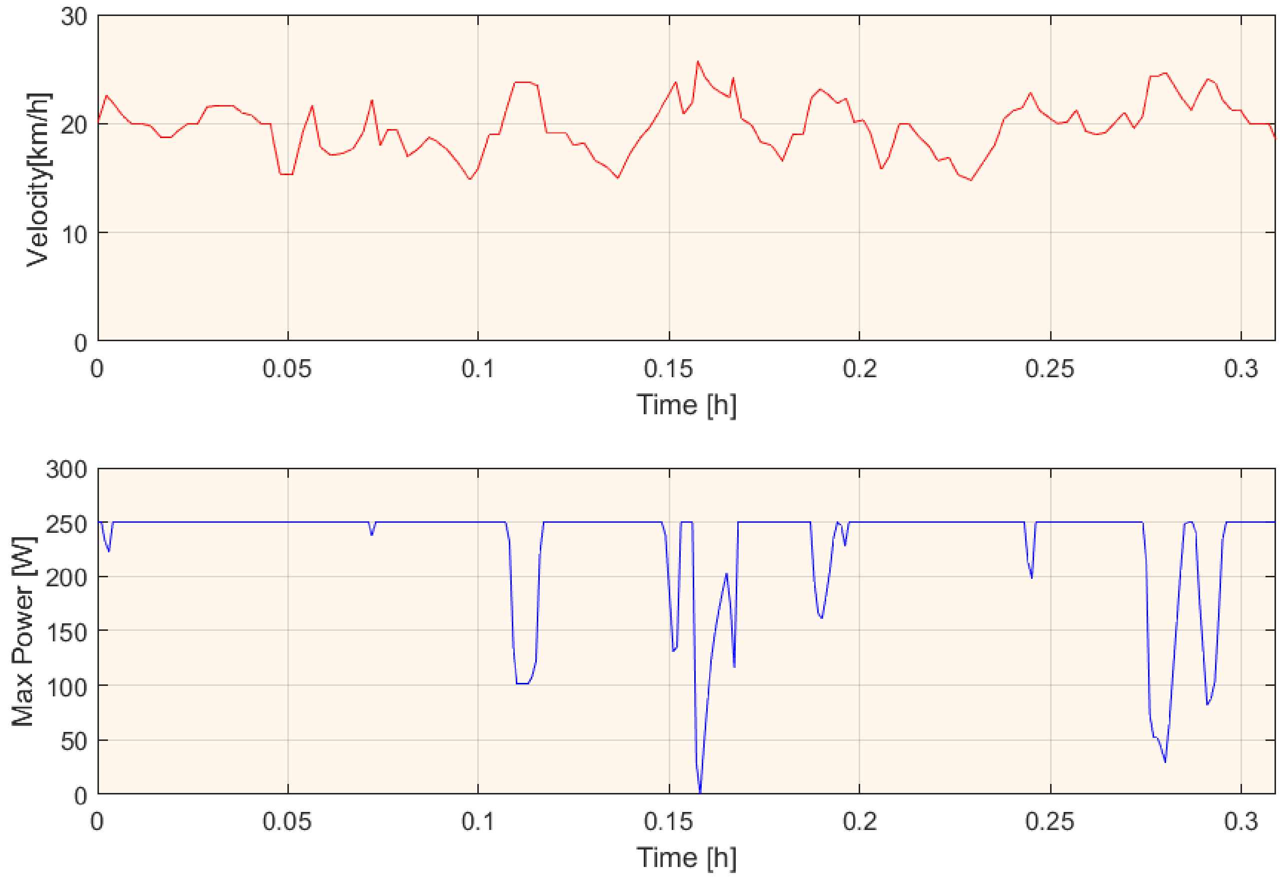


Fig.9.2 : Variation of max power with velocity

Calculation of Energy

- The energy required to drive the complete track is given by below equation

$$W_{Track} = \sum_{i=1}^{n_t - 1} W(s_i) = \sum_{i=1}^{n_t - 1} P(s_i).t_i$$ [2]

- Where,

W_{Track} – Energy required for the entire track

s_i – i^{th} segment

$P(s_i)$ – Power required to drive the segment

t_i –Time required to drive the segment

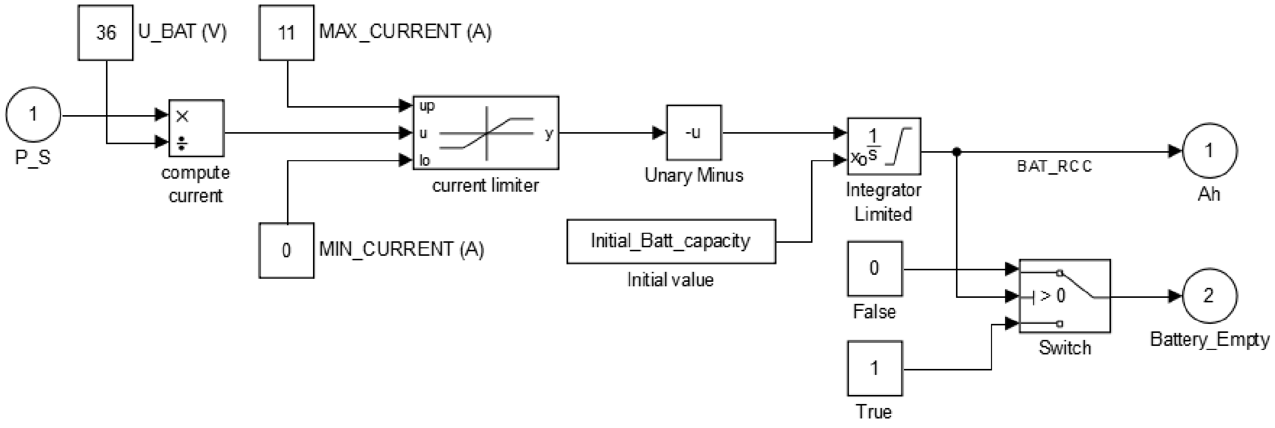


Fig.10.1 :Calculation of reserve capacity – Battery subsystem

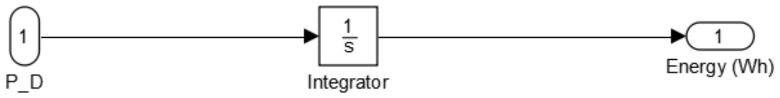


Fig.10.2 :Calculation of energy given by driver

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Results – Conditions are feasible

Figure 500

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Results:

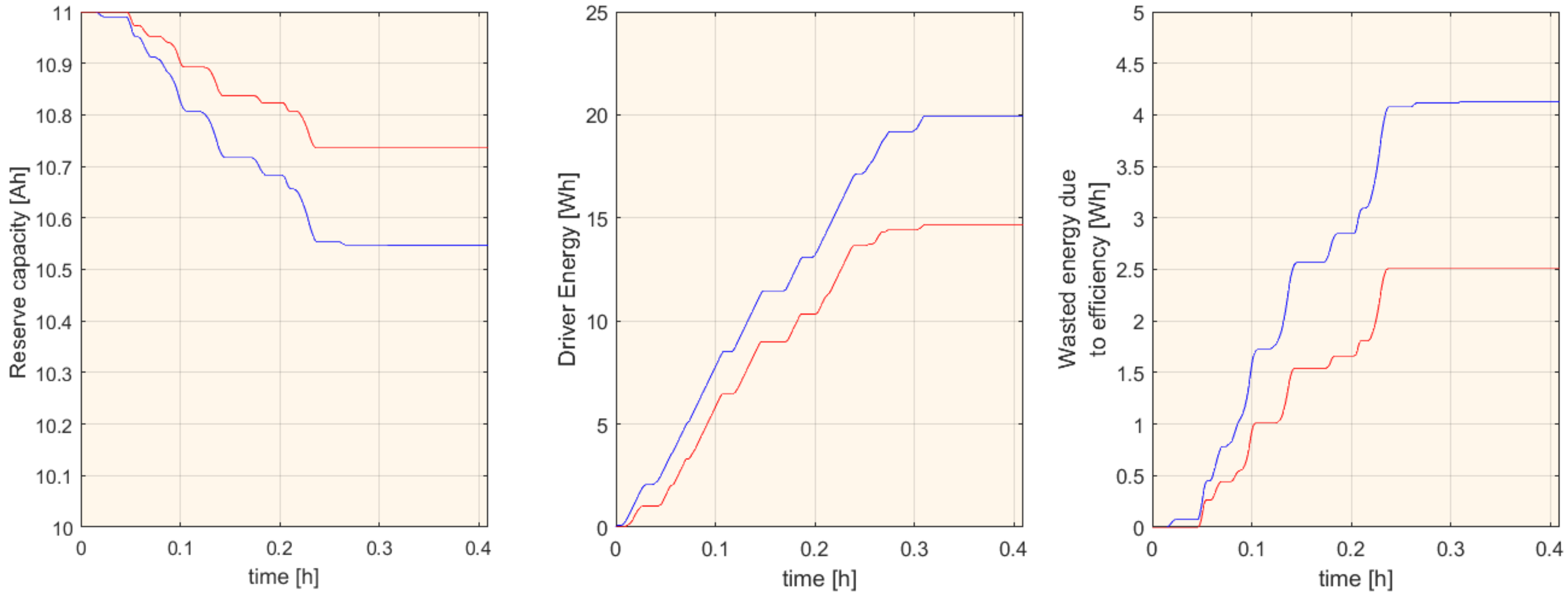
Simulation 1 : Racing Bike

Battery Reserve Capacity : 10.735754 Ah
Energy given by driver : 14.678229 Wh
Energy consumed by the Motor : 9.512871 Wh
Total energy spent : 24.191099 Wh
Total energy wasted : 2.506138 Wh
This system is feasible to run this track!

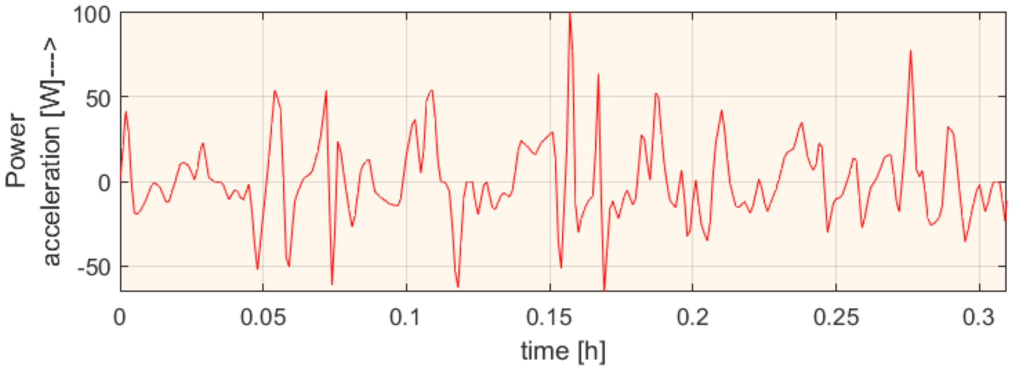
Simulation 2 : Standard Bike

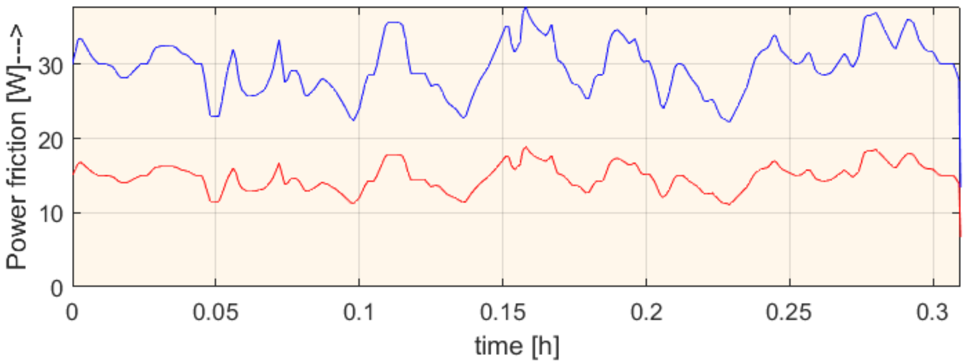
Battery Reserve Capacity : 10.546470 Ah
Energy given by driver : 19.950132 Wh
Energy consumed by the Motor : 16.327071 Wh
Total energy spent : 36.277202 Wh
Total energy wasted : 4.126162 Wh
This system is feasible to run this track!

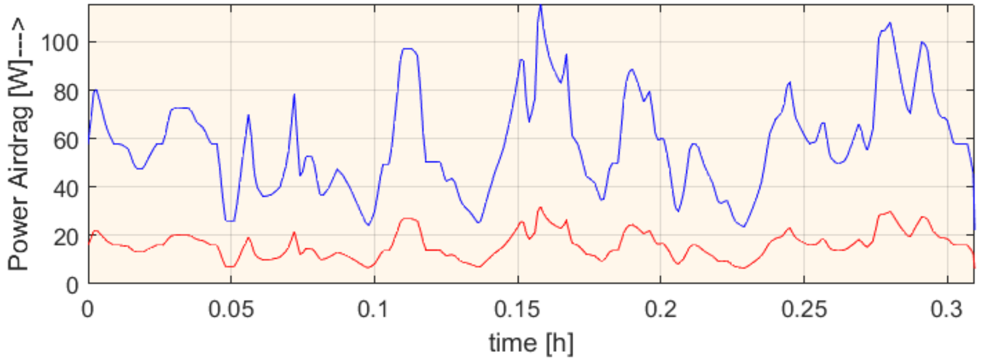
Standard Bike consumed 12.086103 Watthours more than Racing bike

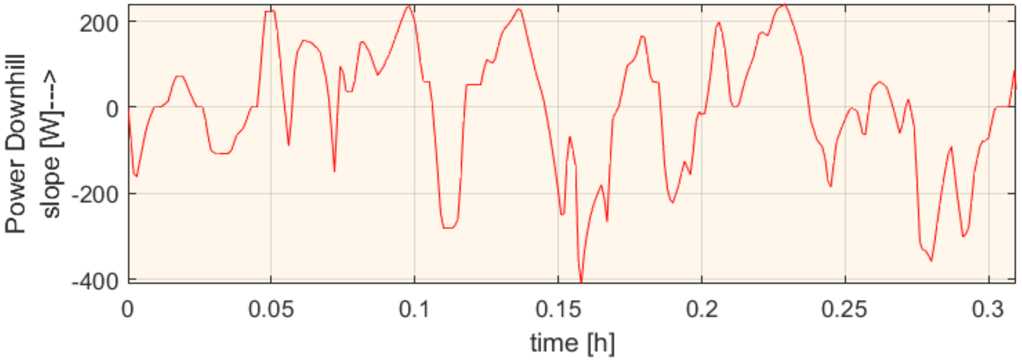


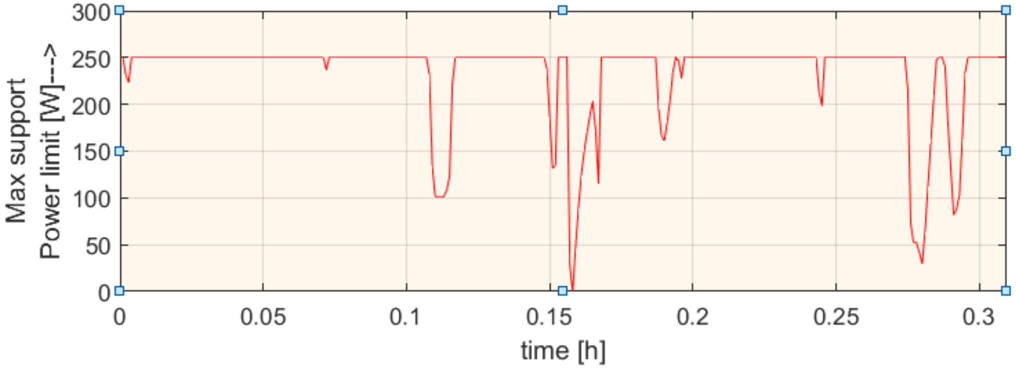
Results – Conditions are feasible

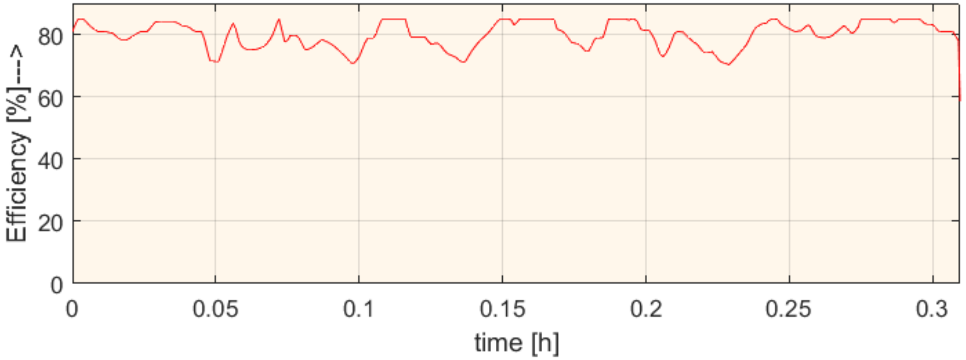












Results – Conditions are infeasible

Figure 500

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Results:

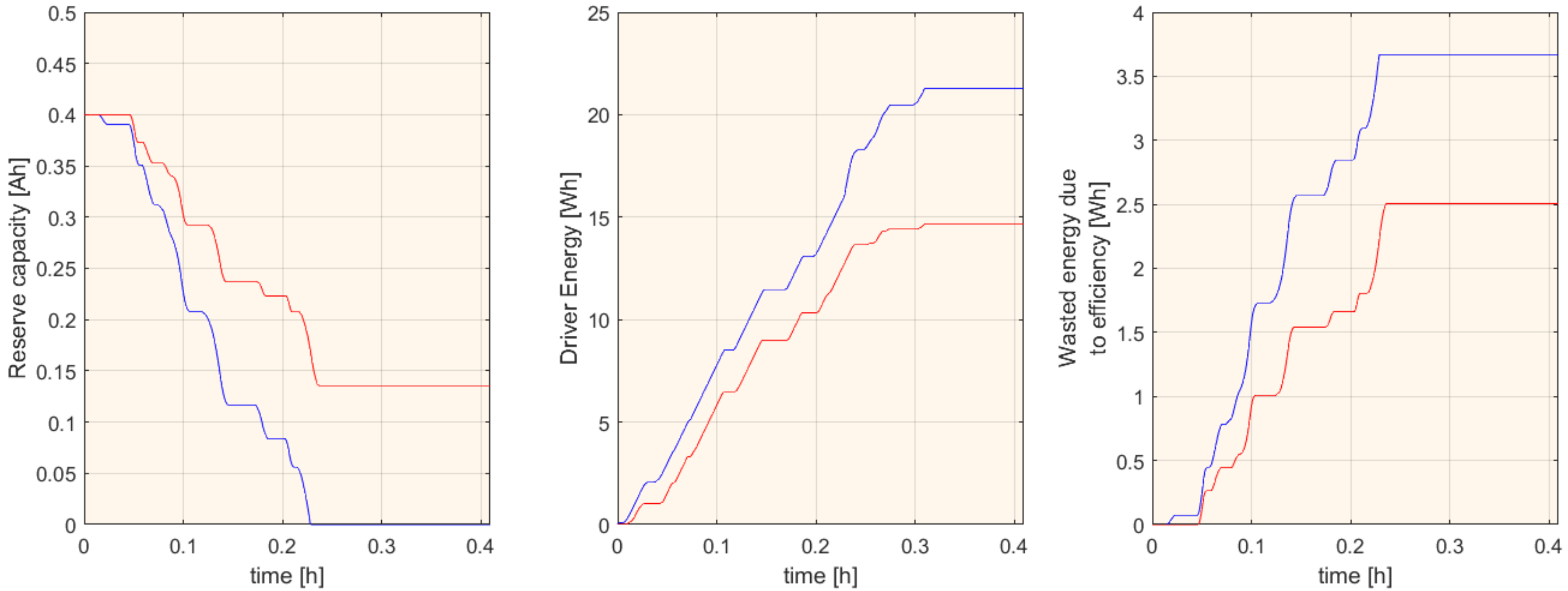
Simulation 1 : Racing Bike

Battery Reserve Capacity : 0.135754 Ah
Energy given by driver : 14.678229 Wh
Energy consumed by the Motor : 9.512871 Wh
Total energy spent : 24.191099 Wh
Total energy wasted : 2.506138 Wh
This system is feasible to run this track!

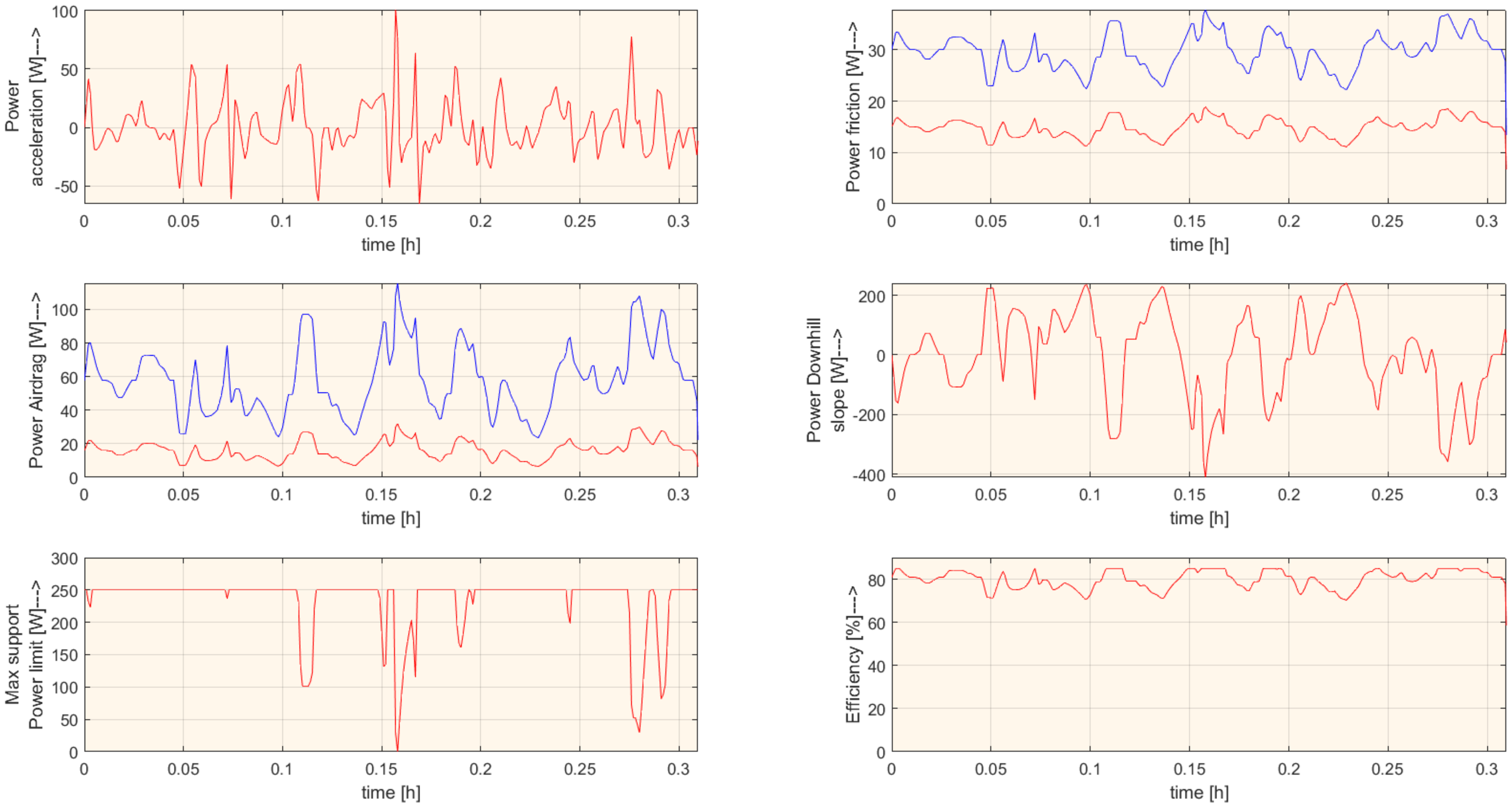
Simulation 2 : Standard Bike

Battery Reserve Capacity : 0.000000 Ah
Energy given by driver : 21.273588 Wh
Energy consumed by the Motor : 14.400000 Wh
Total energy spent : 35.673588 Wh
Total energy wasted : 3.670000 Wh
This system is not feasible to run this track!

Standard Bike consumed 11.482489 Watthours more than Racing bike



Results – Conditions are infeasible



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2. Steffen Weichold (2014): Lab task document - Advanced range estimation of battery electric vehicles, TU Chemnitz.
3. Directive 2002/24/EC of the European Parliament and Council of 18 March 2002 relating to type-approval of two or three-wheel motor vehicles: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32002L0024&from=EN

QUESTIONS?

THANK YOU!