MODELOVANJE I SIMULACIJA ELEKTRIČNIH VOZILA

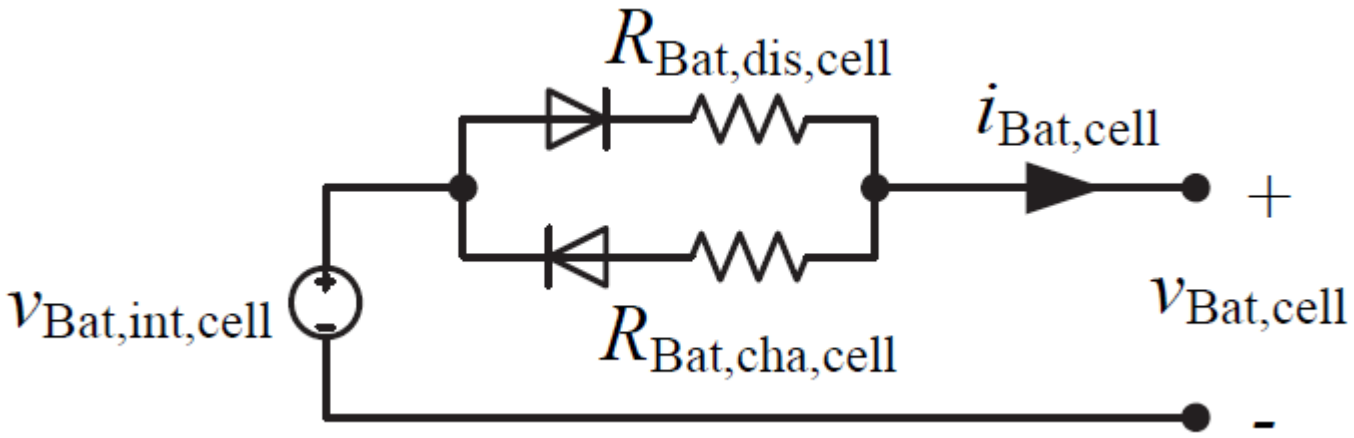
Drugi dio

Prof. dr Srđan Lale

Univerzitet u Istočnom Sarajevu, Elektrotehnički fakultet

Modelovanje vozila – električni model baterije

- Električni model baterije se sastoji od unutrašnjeg izvora napona i dva unutrašnja otpornika, koja se koriste za punjenje i pražnjenje. Dvije diode su idealne i imaju samo simboličko značenje, tj. da bi se obezbjedio prelaz između otpornosti za punjenje i otpornosti za pražnjenje. Struje pražnjenja se tretiraju kao pozitivne struje, a struje punjenja su tada negativne.



Šematski prikaz električnog ekvivalentnog kola baterijske ćelije

Modelovanje vozila - električni model baterije

$$v_{\mathrm{Bat,cell}} = \begin{cases} v_{\mathrm{Bat,int,cell}} - R_{\mathrm{Bat,cell,dis}} i_{\mathrm{Bat,cell}} & , i_{\mathrm{Bat,cell}} \geq 0 \\ v_{\mathrm{Bat,int,cell}} - R_{\mathrm{Bat,cell,cha}} i_{\mathrm{Bat,cell}} & , i_{\mathrm{Bat,cell}} < 0, \end{cases} \tag{23}$$

where
- $v_{\mathrm{Bat,cell}}$ [V] Battery cell voltage
- $v_{\mathrm{Bat,int,cell}}$ [V] Internal battery cell voltage
- $i_{\mathrm{Bat,cell}}$ [A] Battery cell current
- $R_{\mathrm{Bat,cell,dis}}$ [Ω] Inner battery cell resistance during discharge mode
- $R_{\mathrm{Bat,cell,cha}}$ [Ω] Inner battery cell resistance during charge mode

$$\begin{aligned} R_{\mathrm{Bat,cell,dis}} = {} & a_{10} DoD_{\mathrm{Bat}}^{10} + a_9 DoD_{\mathrm{Bat}}^{9} + a_8 DoD_{\mathrm{Bat}}^{8} + a_7 DoD_{\mathrm{Bat}}^{7} + a_6 DoD_{\mathrm{Bat}}^{6} \\ & + a_5 DoD_{\mathrm{Bat}}^{5} + a_4 DoD_{\mathrm{Bat}}^{4} + a_3 DoD_{\mathrm{Bat}}^{3} + a_2 DoD_{\mathrm{Bat}}^{2} + a_1 DoD_{\mathrm{Bat}} + a_0 \end{aligned} \tag{24}$$

Modelovanje vozila – električni model baterije

$$v_{\text{Bat,int,cell}} = b_{10}DoD_{\text{Bat}}^{10} + b_9 DoD_{\text{Bat}}^{9} + b_8 DoD_{\text{Bat}}^{8} + b_7 DoD_{\text{Bat}}^{7} + b_6 DoD_{\text{Bat}}^{6} + b_5 DoD_{\text{Bat}}^{5} + b_4 DoD_{\text{Bat}}^{4} + b_3 DoD_{\text{Bat}}^{3} + b_2 DoD_{\text{Bat}}^{2} + b_1 DoD_{\text{Bat}} + b_0 \quad (25)$$

$$R_{\text{Bat,cell,cha}} = c_{10}DoD_{\text{Bat}}^{10} + c_9 DoD_{\text{Bat}}^{9} + c_8 DoD_{\text{Bat}}^{8} + c_7 DoD_{\text{Bat}}^{7} + c_6 DoD_{\text{Bat}}^{6} + c_5 DoD_{\text{Bat}}^{5} + c_4 DoD_{\text{Bat}}^{4} + c_3 DoD_{\text{Bat}}^{3} + c_2 DoD_{\text{Bat}}^{2} + c_1 DoD_{\text{Bat}} + c_0 \quad (26)$$

where a_{10} = -634.0, a_9 = 2942.1, a_8 = -5790.6, a_7 = 6297.4, a_6 = -4132.1, a_5 = 1677.7
a_4 = -416.4, a_3 = 60.5, a_2 = -4.8, a_1 = 0.2, a_0 = 0.0
b_{10} = -8848, b_9 = 40727, b_8 = -79586, b_7 = 86018, b_6 = -56135, b_5 = -5565
b_4 = 784, b_3 = -25, b_2 = 55, b_1 = 0, b_0 = 4
c_{10} = 2056, c_9 = -9176, c_8 = 17147, c_7 = -17330, c_6 = 10168, c_5 = -3415
c_4 = 578, c_3 = 25, c_2 = 3, c_1 = 0, c_0 = 0

Modelovanje vozila – kapacitivni model baterije

- Unutrašnji izvor napona i otpornost punjenja i pražnjenja zavise od dubine pražnjenja. Stanje napunjenosti i dubina pražnjenja zavise od integrala struje koja se crpi ili isporučuje bateriji, tj.:

$$DoD_{\mathrm{Bat}} = DoD_{\mathrm{Bat,ini}} + \int \frac{i_{\mathrm{Bat,eq,cell}}}{Q_{\mathrm{Bat,1,cell}}} dt \tag{27}$$

$$SoC_{\mathrm{Bat}} = 1 - DoD_{\mathrm{Bat}} \tag{28}$$

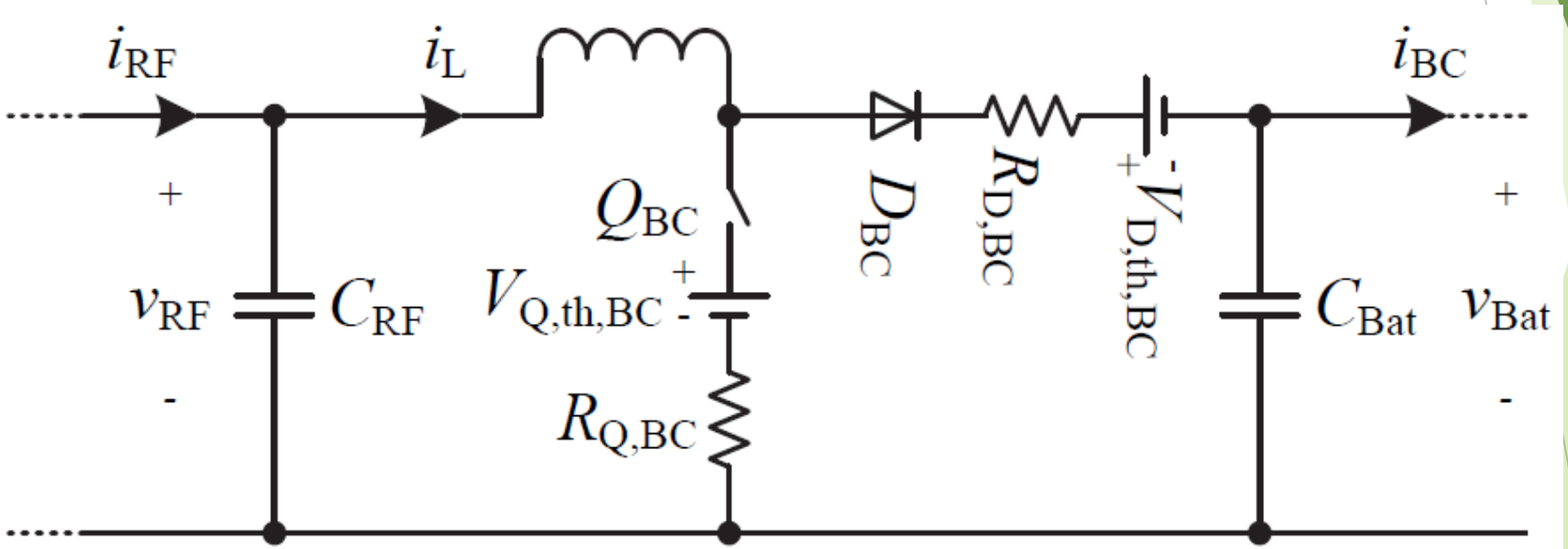
where DoD_{Bat} [−] Depth-of-discharge
$DoD_{\mathrm{Bat,ini}}$ [−] Initial depth-of-discharge
SoC_{Bat} [−] Battery state-of-charge
$i_{\mathrm{Bat,eq,cell}}$ [A] Equivalent battery cell current

$$i_{\mathrm{Bat,eq,cell}} = \begin{cases} I_{\mathrm{Bat,1,cell}} \left(\frac{i_{\mathrm{Bat,cell}}}{I_{\mathrm{Bat,1,cell}}} \right)^k , & i_{\mathrm{Bat,cell}} \geq 0 \\ \eta_{\mathrm{Bat,cha}} i_{\mathrm{Bat,cell}} , & i_{\mathrm{Bat,cell}} < 0 \end{cases} \tag{29}$$

$$k = \begin{cases} 1 , & i_{\mathrm{Bat,cell}} \leq I_{\mathrm{Bat,1,cell}} \\ 1.125 , & i_{\mathrm{Bat,cell}} > I_{\mathrm{Bat,1,cell}}, \end{cases} \tag{30}$$

where k [−] Peukert number
$\eta_{\mathrm{Bat,cha}} = 0.95$ [−] Charging efficiency

Modelovanje vozila – DC/DC podizač napona



Šema električnog kola podizača napona

Modelovanje vozila – DC/DC podizač napona

- Jednačine snage podizača napona su date sa:

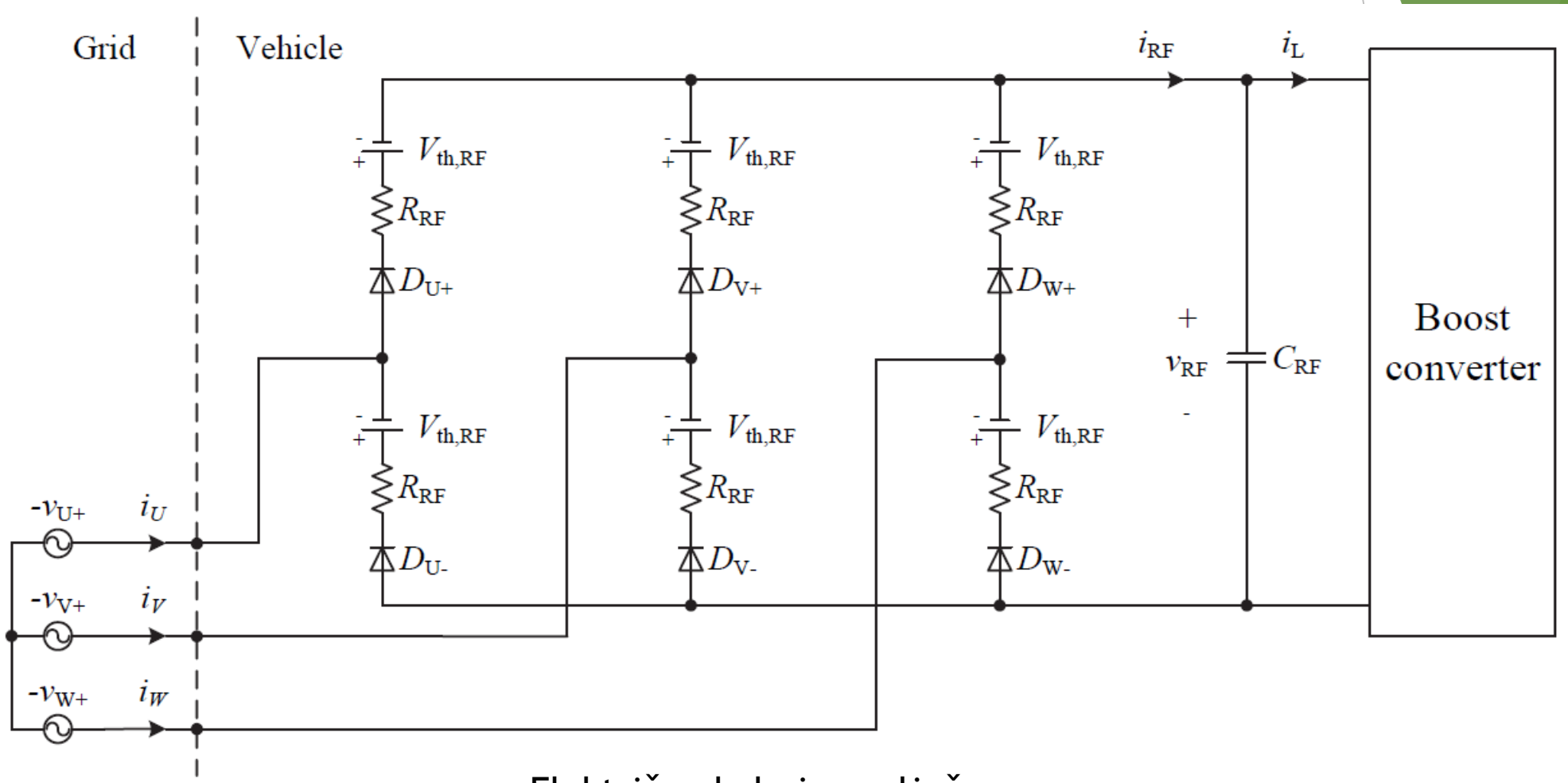
$$P_{RF} = V_{RF} i_{RF} = P_{BC} + P_{Loss,BC} \quad (31)$$

$$P_{BC} = V_{Bat} i_{BC} \quad (32)$$

$$P_{Loss,BC} = R_{BC} i_{RF}^2 + V_{th,BC} i_{RF}, \quad (33)$$

where
P_{RF} [W] Input power of boost converter
P_{BC} [W] Output power of boost converter
$P_{Loss,BC}$ [W] Power loss of boost converter
V_{RF} [V] Input voltage of boost converter
$V_{th,BC}$ [V] Threshold voltage of switch and diode
R_{BC} [Ω] Resistance of switch and diode
i_{RF} [A] Input current of boost converter
i_{BC} [A] Output current of boost converter

Modelovanje vozila – ispravljač



Električno kolo ispravljača

Modelovanje vozila - ispravljač

$$i_{RF} = I_{Grid}\sqrt{\frac{3}{2}} \tag{34}$$

$$V_{RF} = \frac{3\sqrt{2}}{\pi}V_{LL} - 2R_{RF}i_{RF} - 2V_{th,RF} \tag{35}$$

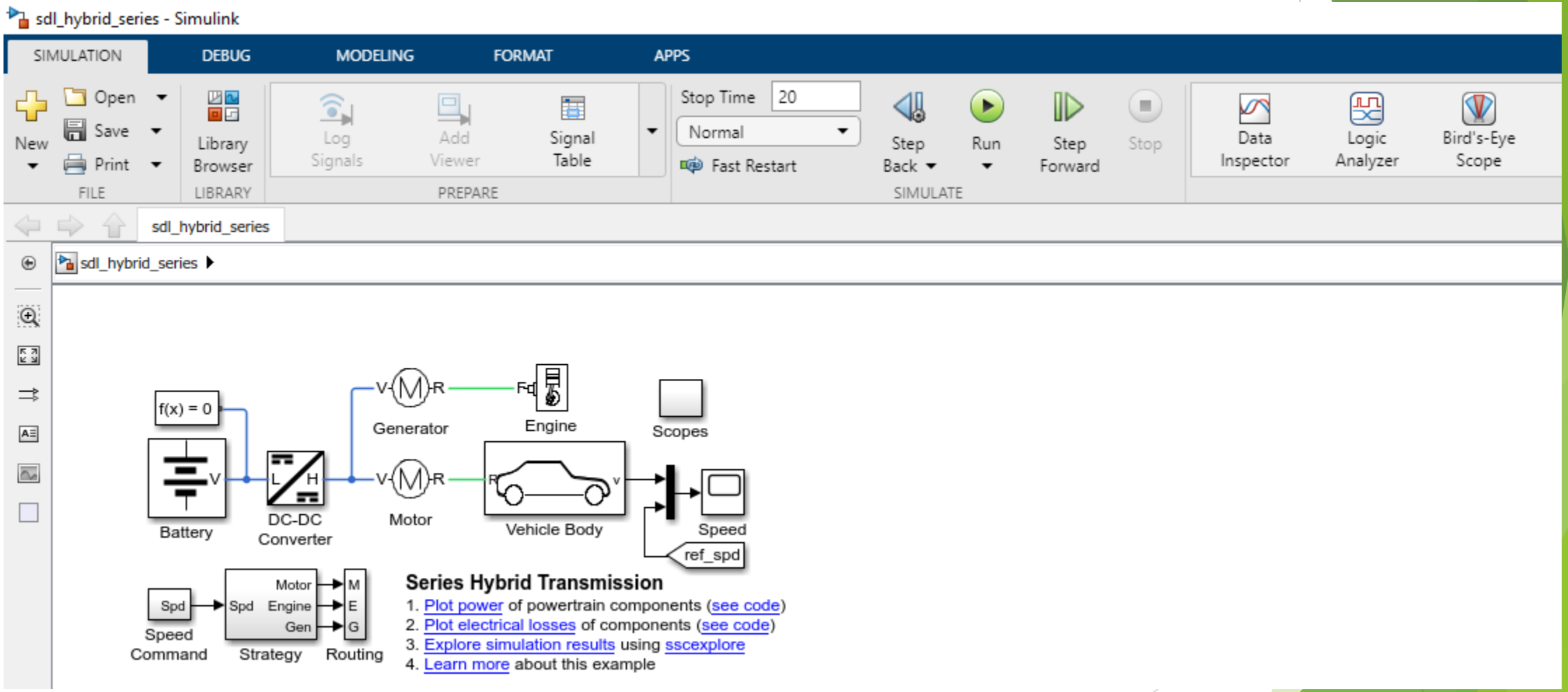
$$P_{RF} = V_{RF}i_{RF} = P_{Grid} - P_{RF,loss} \tag{36}$$

$$P_{Grid} = \frac{3\sqrt{2}}{\pi}V_{LL}I_{RF} \tag{37}$$

$$P_{RF,loss} = 2R_{RF}i_{RF}^2 + 2V_{th,RF}i_{RF}, \tag{38}$$

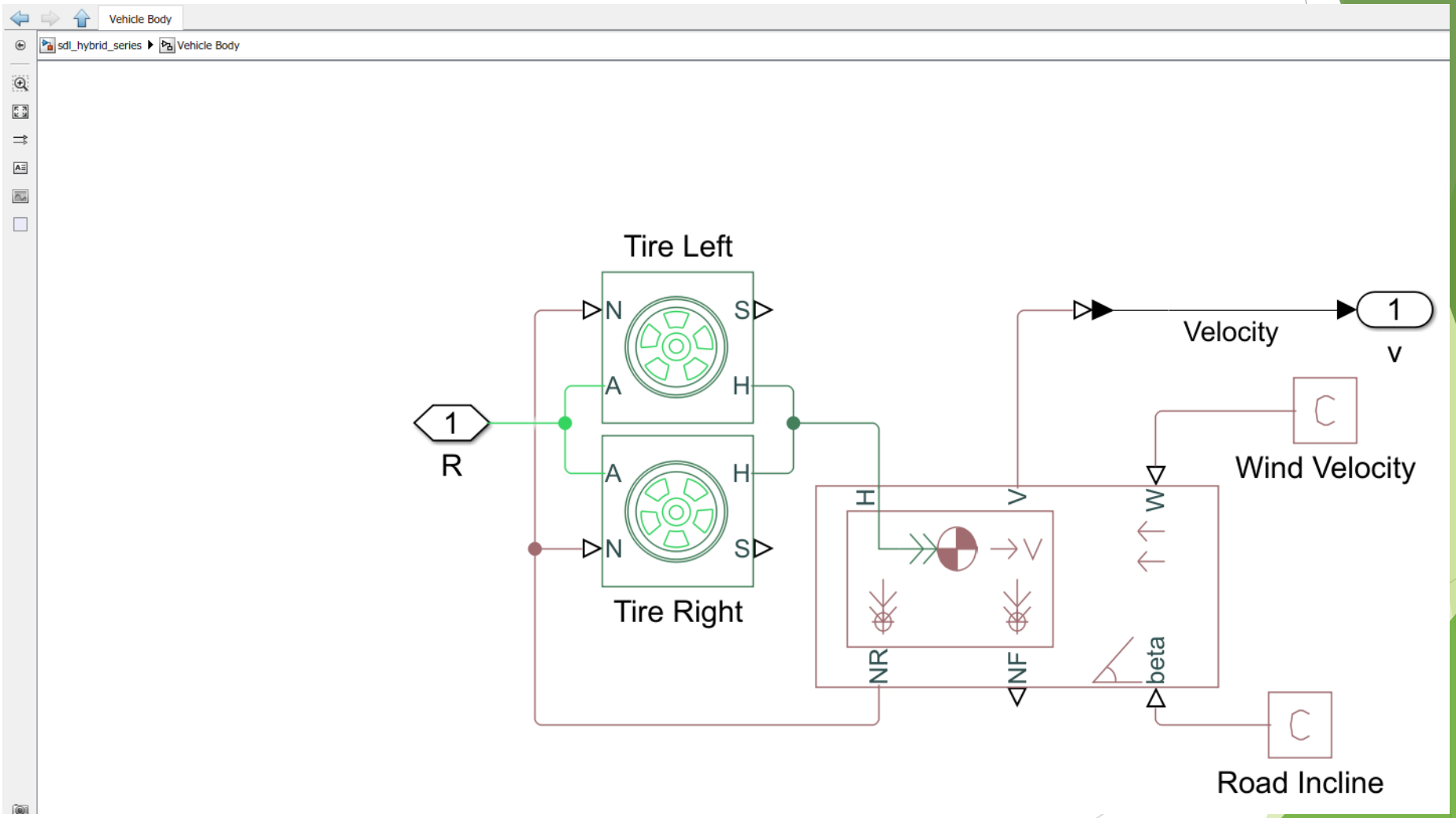
where
I_{Grid} [A] Grid RMS-current
P_{Grid} [W] Power of three phase grid
$P_{loss,RF}$ [W] Total loss of the rectifier
R_{RF} [Ω] Resistance of switch and diode
$V_{th,RF}$ [V] Threshold voltage of switch and diode

Simulacija električnih vozila



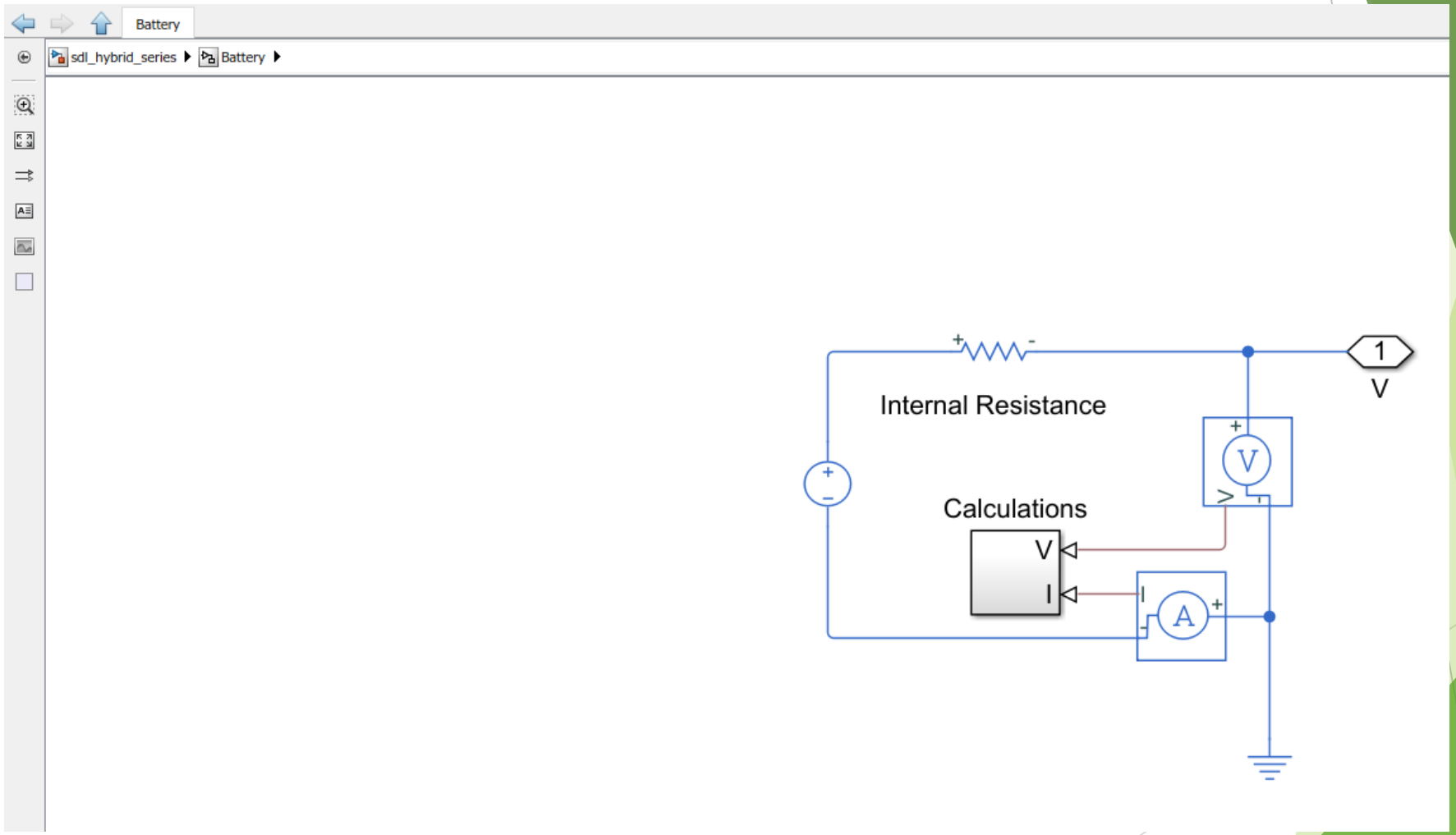
Serijska hibridna transmisija – Matlab/Simulink demo

Simulacija električnih vozila



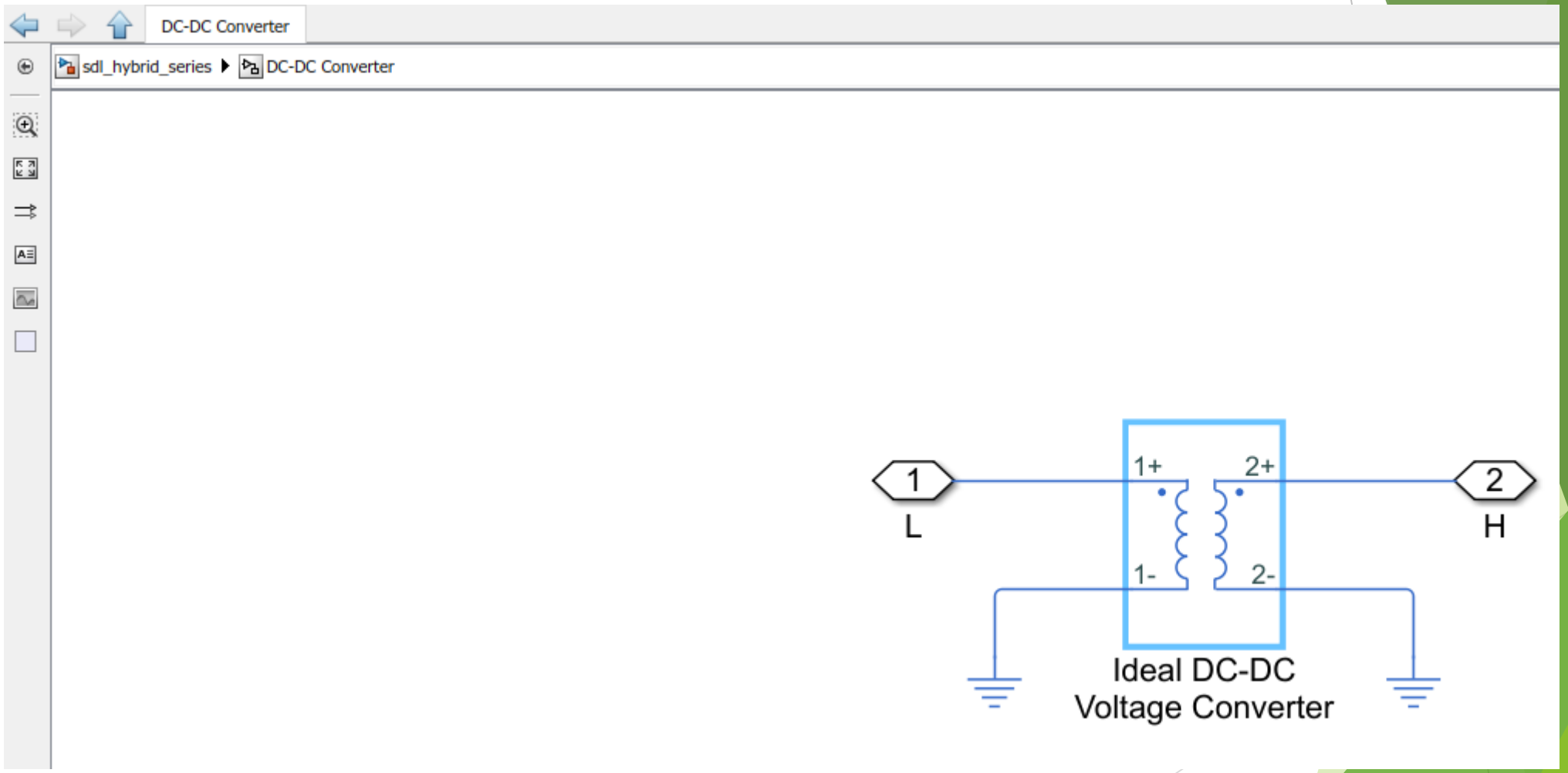
Serijska hibridna transmisija – Matlab/Simulink demo (podsistem karoserije vozila)

Simulacija električnih vozila



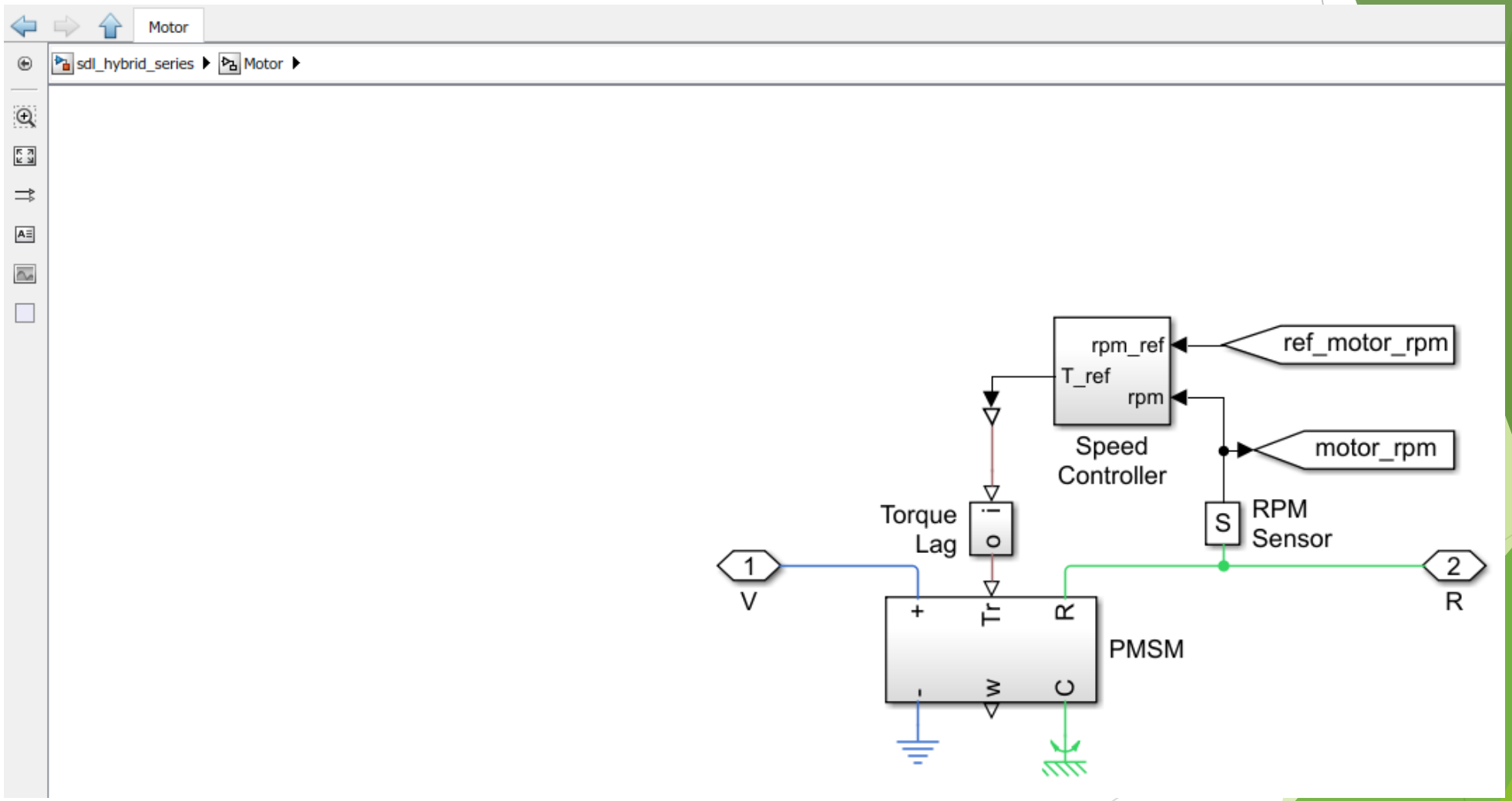
Serijska hibridna transmisija – Matlab/Simulink demo (podsistem baterije)

Simulacija električnih vozila



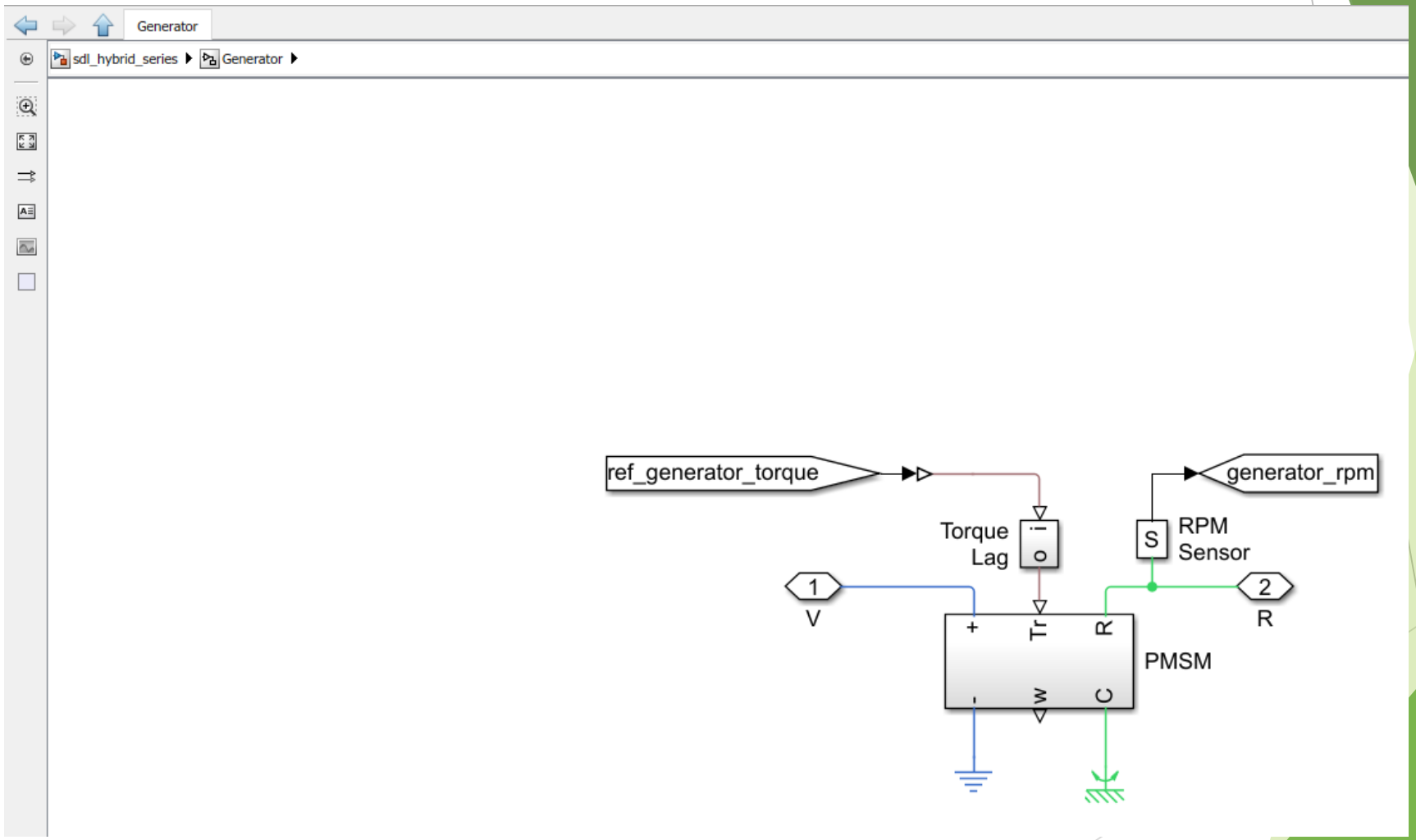
Serijska hibridna transmisija – Matlab/Simulink demo (podsistem DC-DC pretvarača)

Simulacija električnih vozila



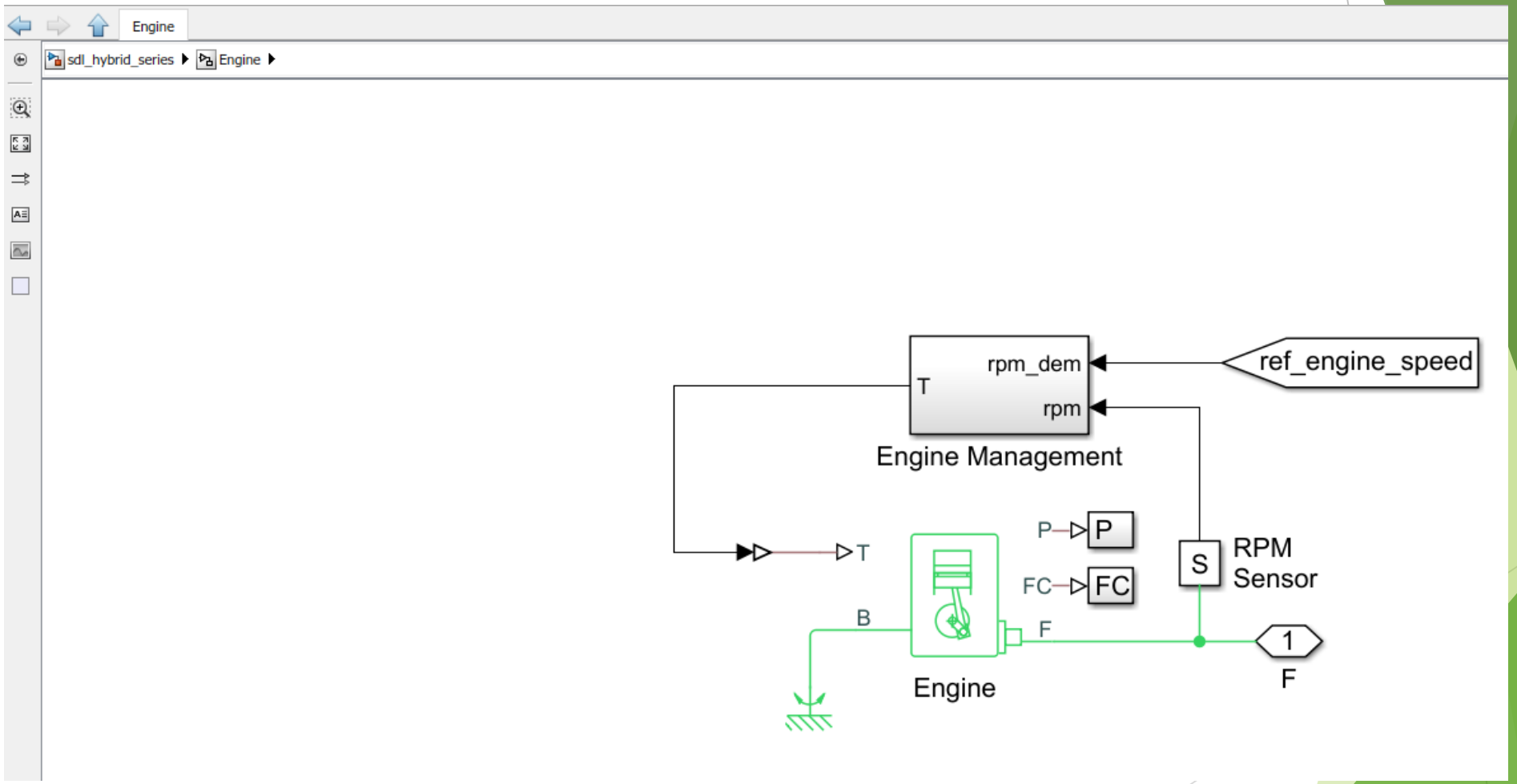
Serijska hibridna transmisija – Matlab/Simulink demo (podsistem motora)

Simulacija električnih vozila



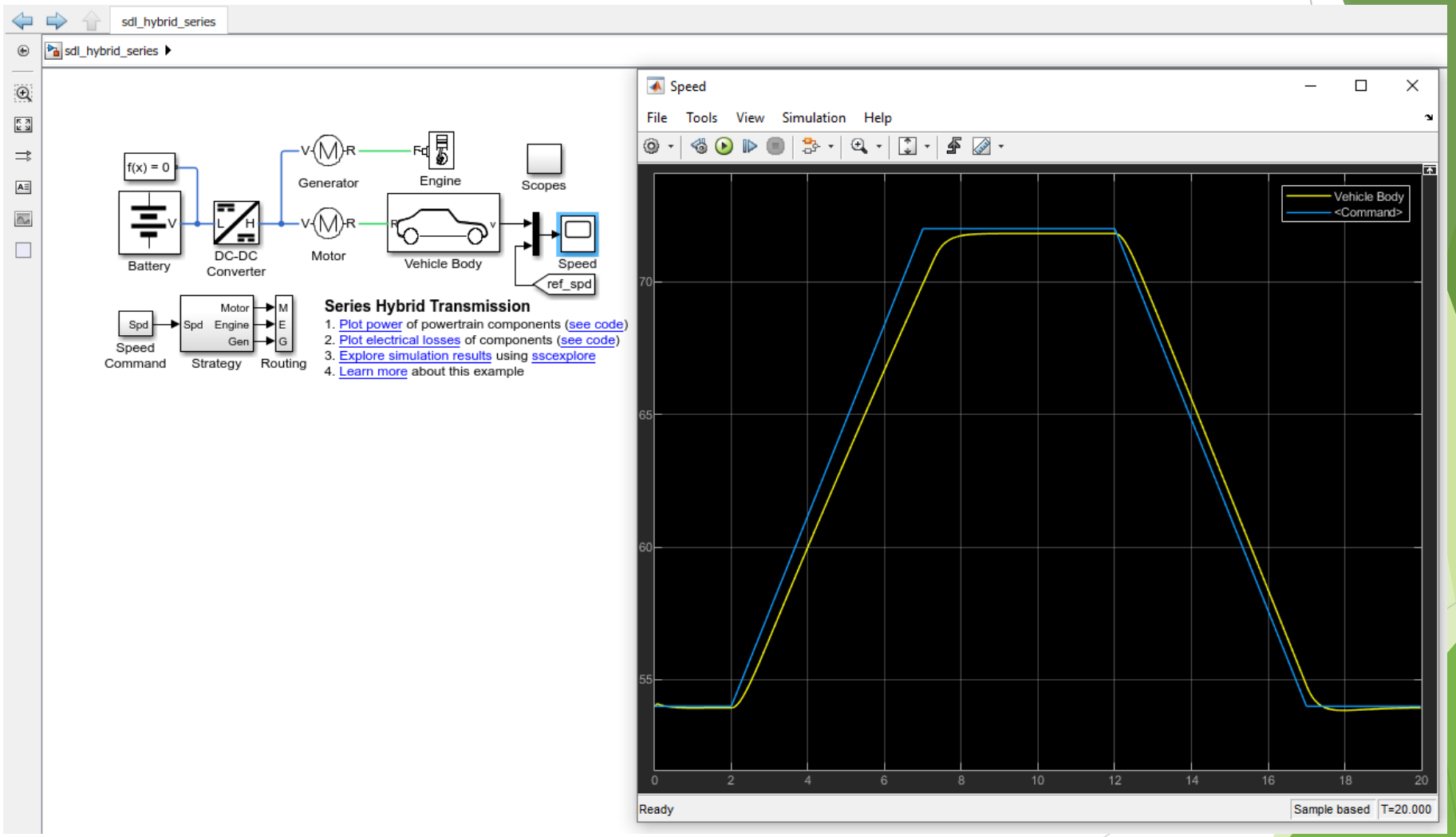
Serijska hibridna transmisija – Matlab/Simulink demo (podsistem generatora)

Simulacija električnih vozila



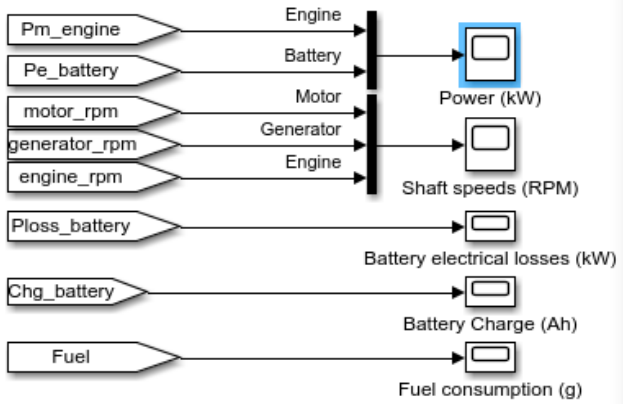
Serijska hibridna transmisija – Matlab/Simulink demo (podsistem pogona)

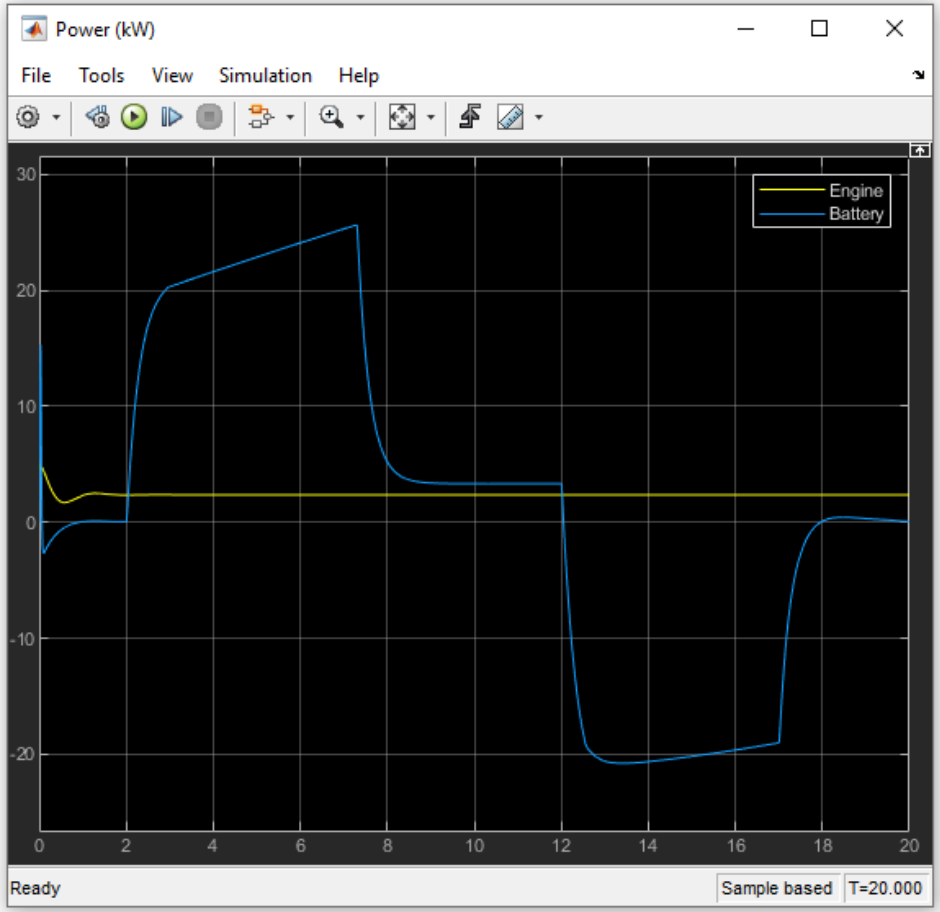
Simulacija električnih vozila



Serijska hibridna transmisija – Matlab/Simulink demo (simulirana brzina vozila)

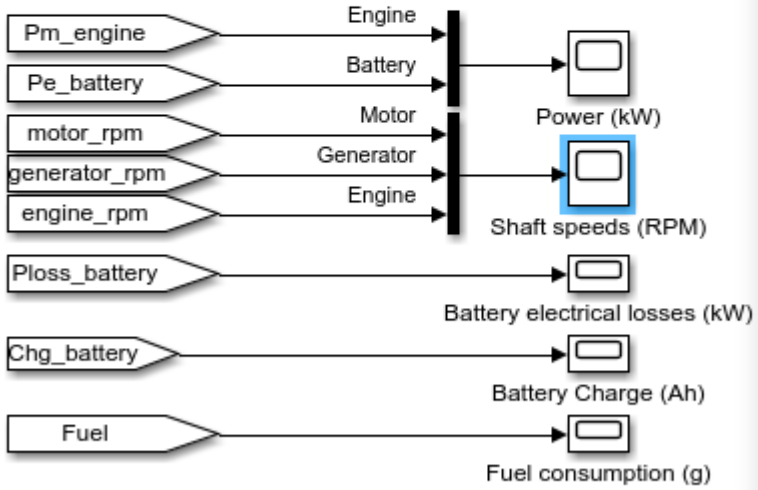
Simulacija električnih vozila

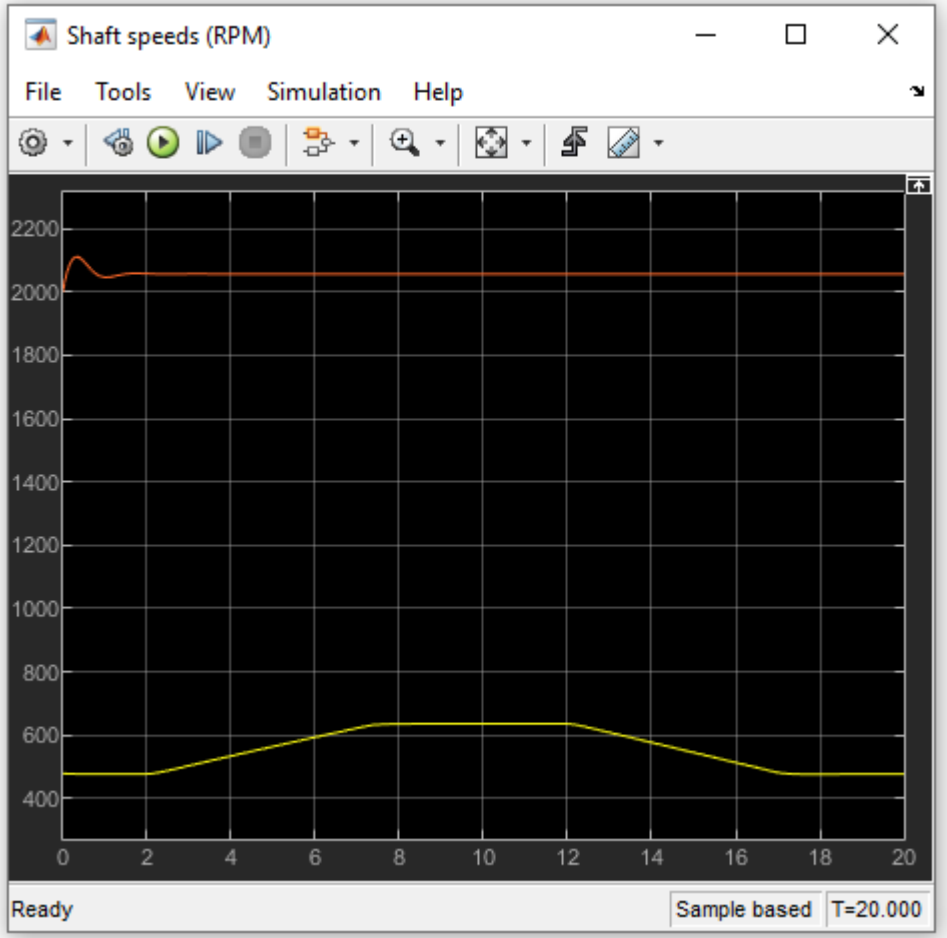




Serijska hibridna transmisija – Matlab/Simulink demo (simulirane snage)

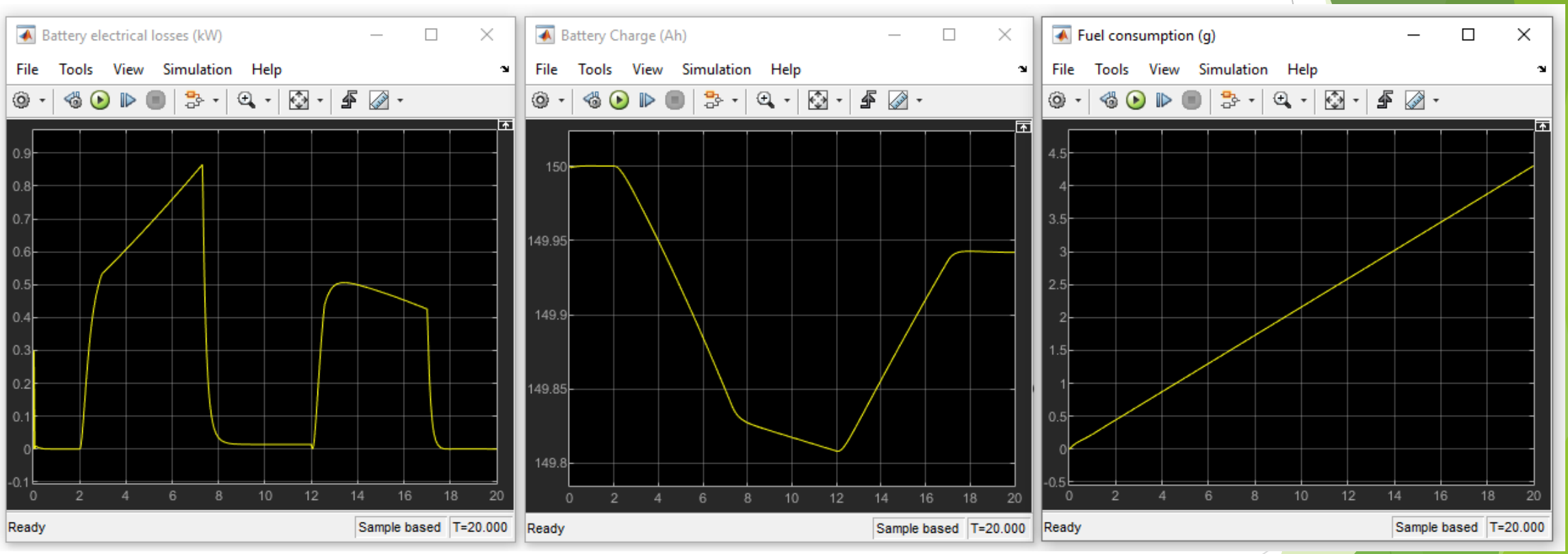
Simulacija električnih vozila





Serijska hibridna transmisija – Matlab/Simulink demo (simulirane brzine)

Simulacija električnih vozila



Serijska hibridna transmisija – Matlab/Simulink demo (simulirani gubici baterije, napunjenost baterije i potrošnja goriva)