Powertrain Seminar

Operating Strategy for a P4 hybrid
Group 01

The Team

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Basic Operating Strategy

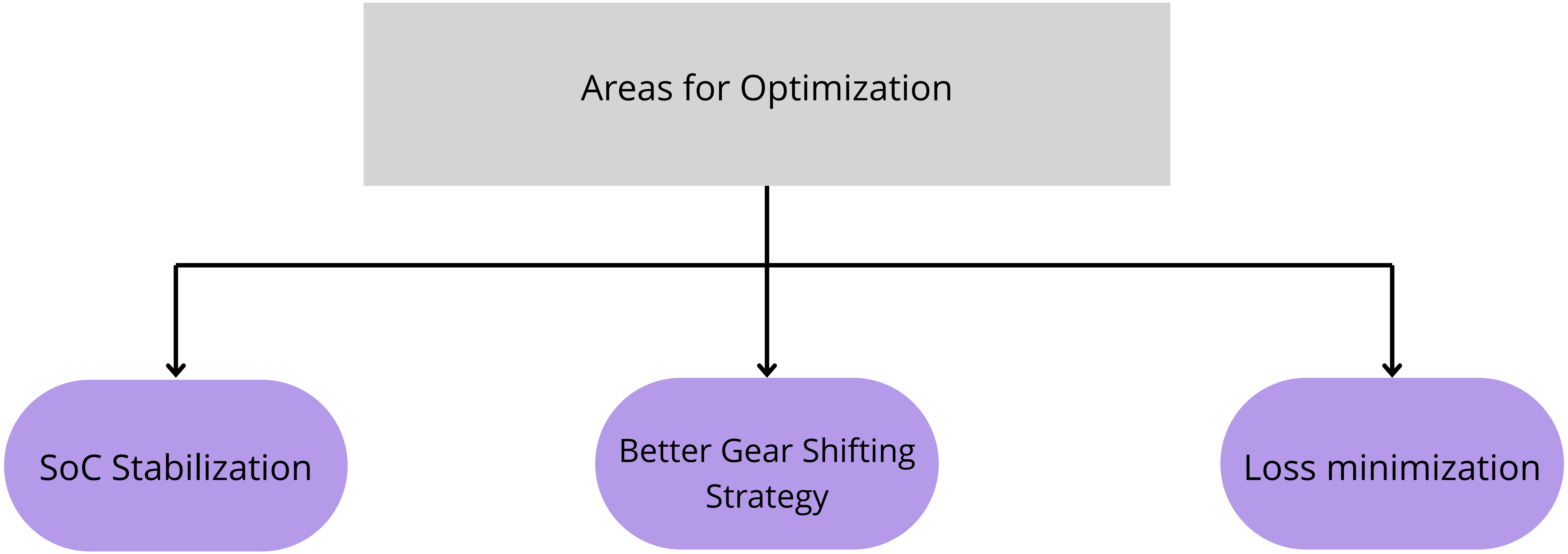
Torque priority: First Ice-torque; Remaining torque goes to the E-Drive, and the remaining torque goes to the friction brakes

The torque of each axle is limited to the maximum torque that can be transferred via the tires to the road (e.g., Body_tqAbsMaxAxFr).

The basic operating strategy switches Off the Ice at low torques, then drives fully electric with the separation clutch open.

The E-Drive does not provide torque to hold the vehicle at a slope; mechanical brakes are used.

The balancing of the state of charge (facSoc) is not yet realised in this basic version.


Areas for Optimization
SoC Stabilization
Better Gear Shifting Strategy
Loss minimization

SoC Stabilisation

Understand how the functionality works

Model study, breakdown of key influencing factors

Perform simulation over drive cycles

Run WLTC cycles with different facslopes (-1/0/1)

Identify critical regions

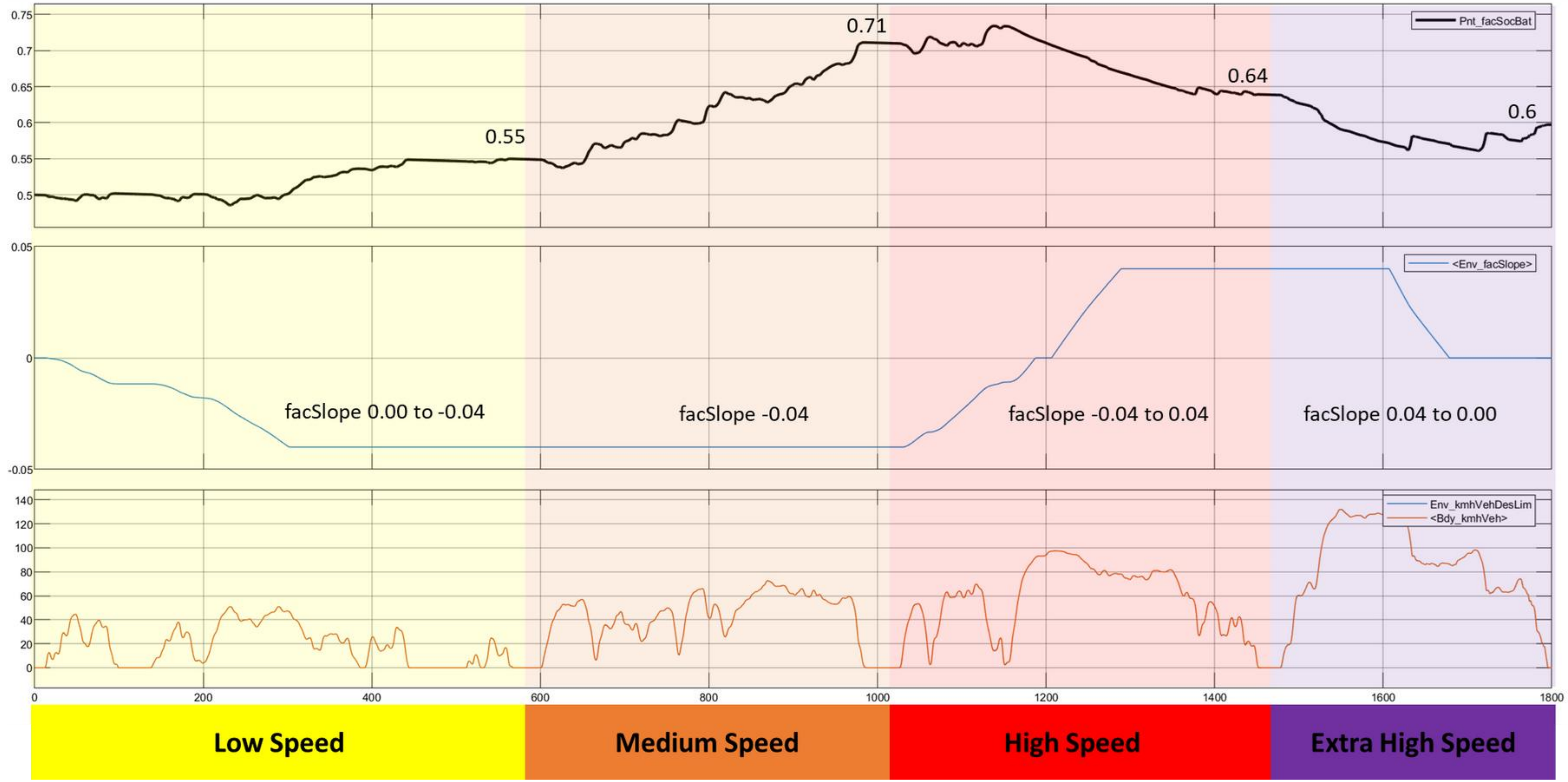
Very low/high SoC regions to be identified

Improve/Implement new functionality

Develop new function to maintain SoC in desired range (0,4 - 0,6)

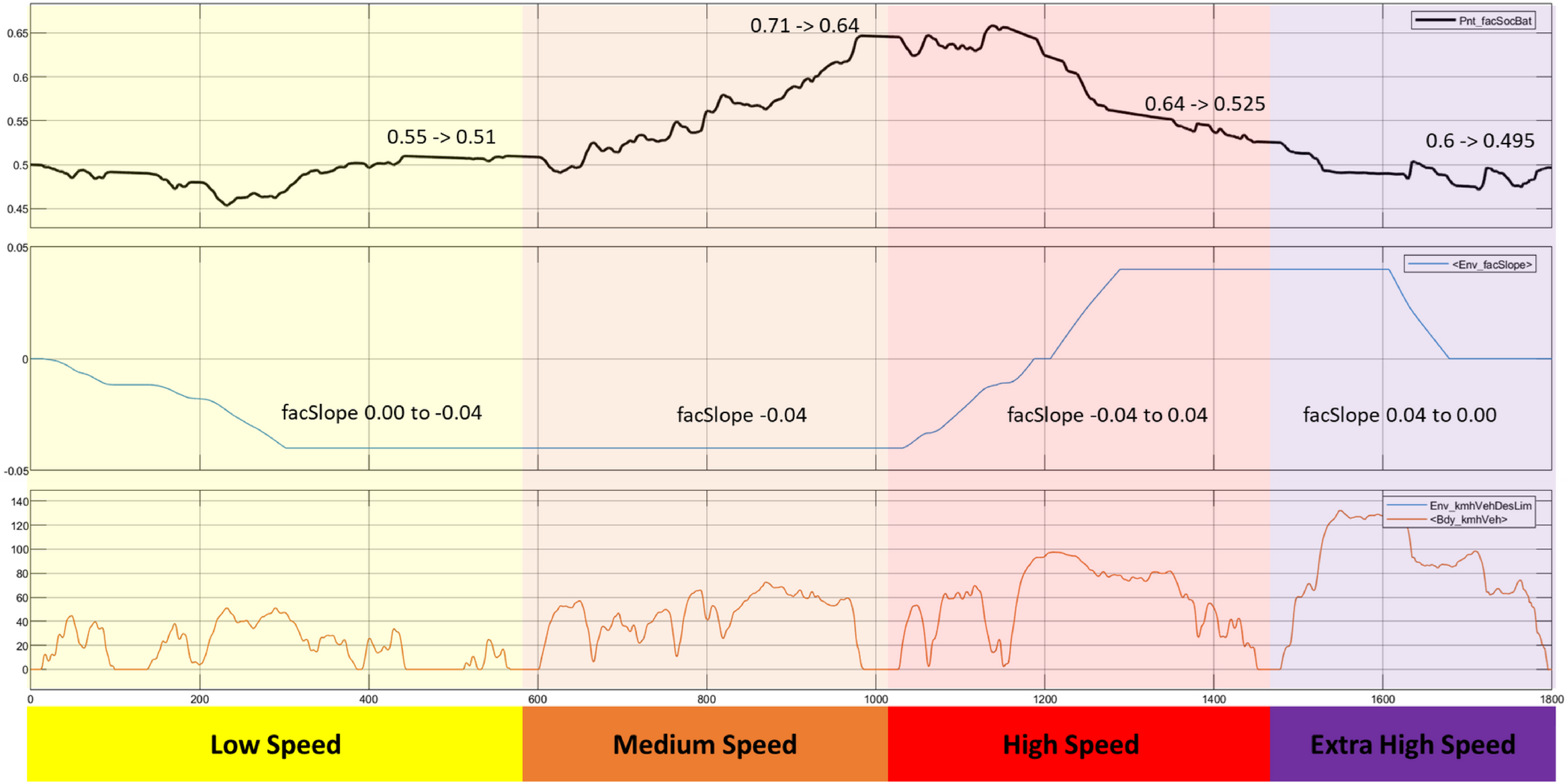
Soc-Balance by varying Switch On Torque of Ice

facActivateSlope = -1;   tqThreshold Ice On = 35 - 25



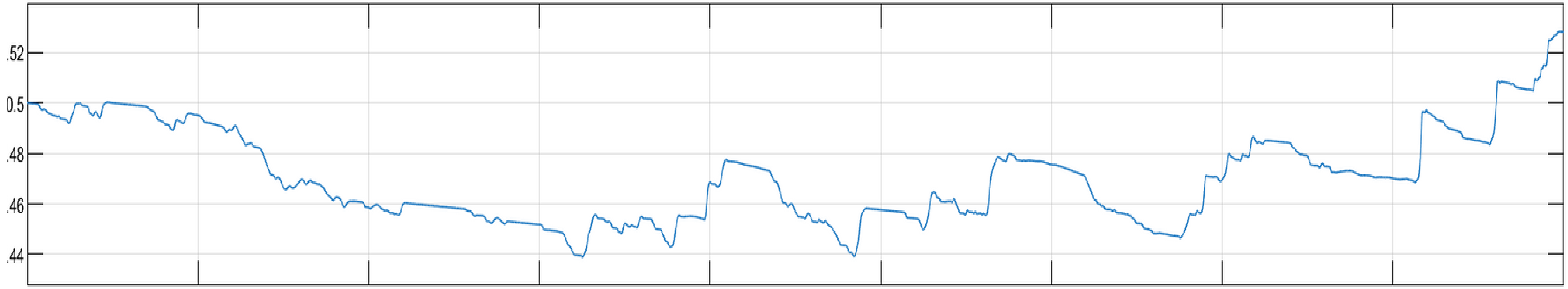
Soc-Balance by varying Switch On Torque of Ice

facActivateSlope = -1;   tqThreshold Ice On = 60 - 50

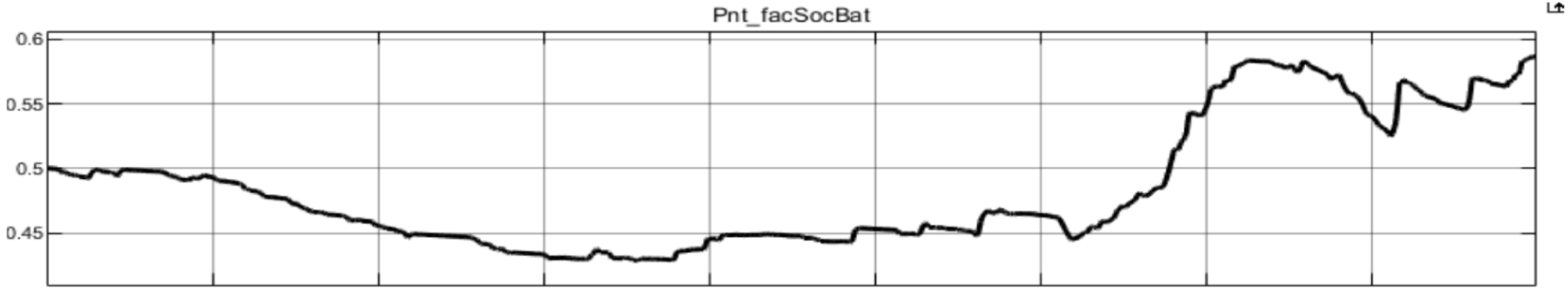


Soc–Balance by varying Switch On Torque of Ice

facActivateSlope = 0 ; tqThreshold Ice On = 35-25



facActivateSlope = +1 ; tqThreshold Ice On = 35-25



Soc-Balance by varying Switch On Torque of Ice

After implementing our operating strategy, the tqthreshold ICE ON values changed to:

- facActivateSlope = -1 , tqThreshold Ice On = 70 - 65
- facActivateSlope = 0 ; tqThreshold Ice On = 35 - 25
- facActivateSlope = +1 ; tqThreshold Ice On = 45 - 40

Concept

Split the drive cycle into 3 regions based on slope

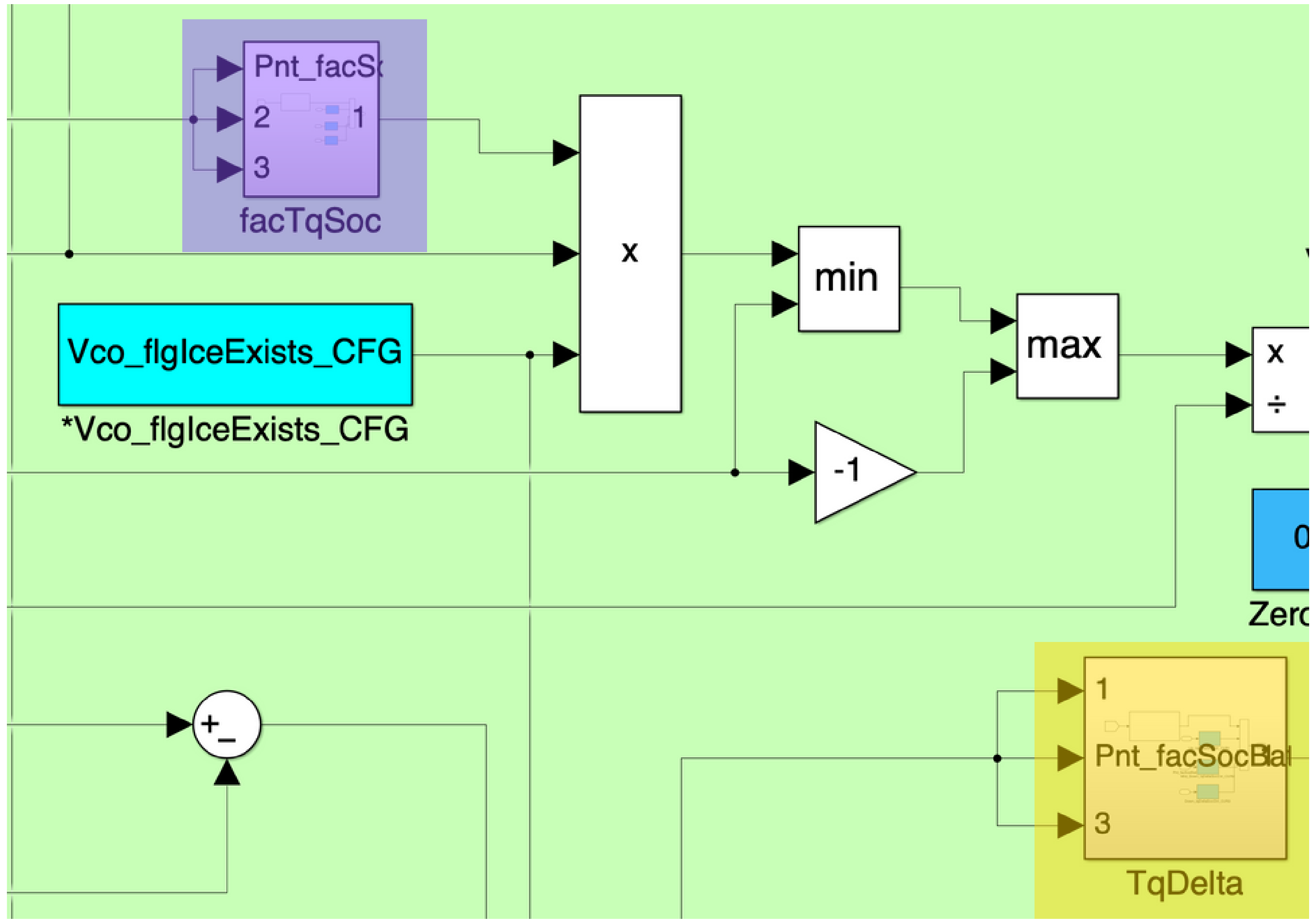
Positive Upward slope region >= 0%

Mildly Downhill region
0% <= slope <= -2%

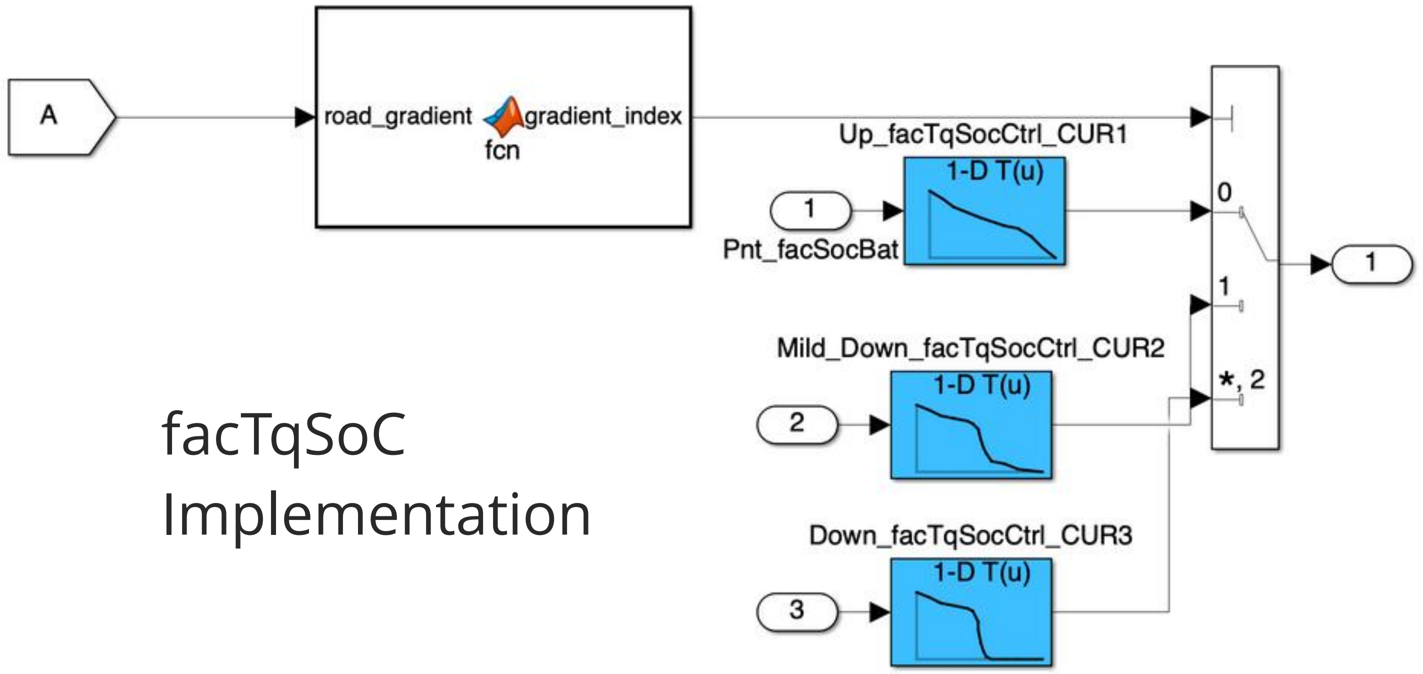
Downhill region
-2% <= slope <= -4%

- Develop specific 1D lookup tables for each case for each of the factors (3 facTqSoC + 3 tqDeltaSocCtrl maps)
- Function receives road gradient as input; gives factors as output
- Switch to the corresponding table based on the region being driven
- Goal: control SoC usage between 40% and 60%

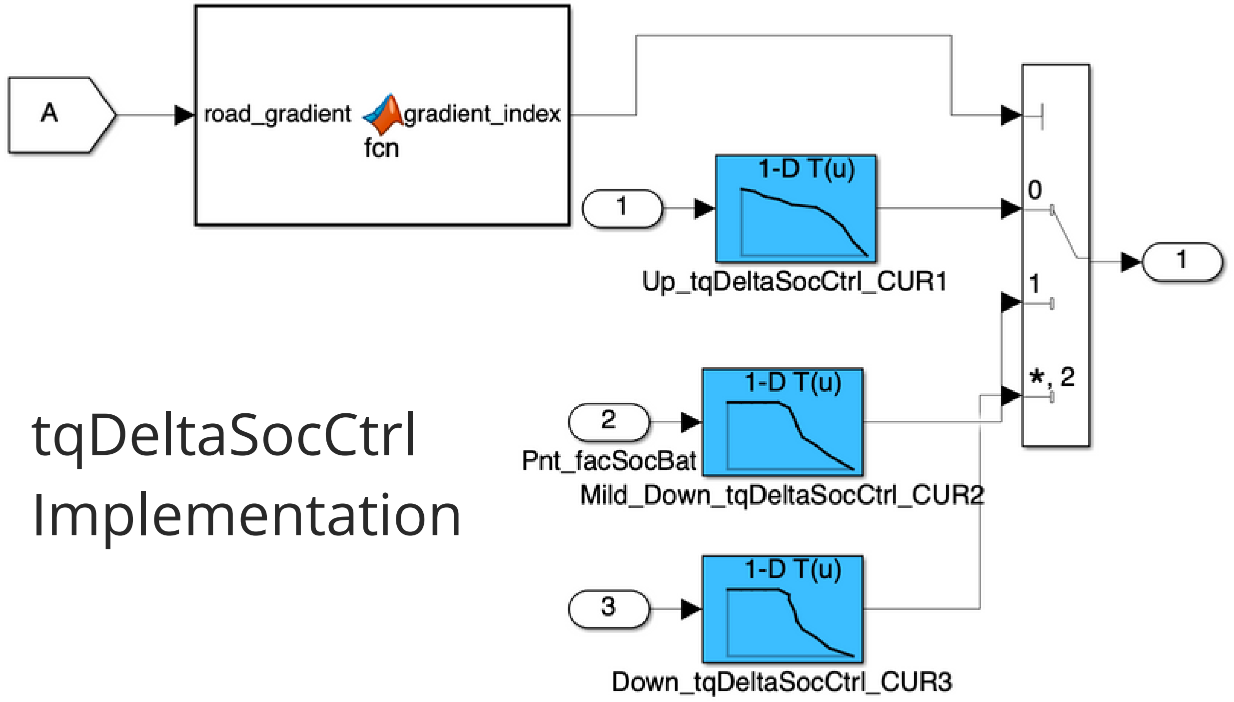
Model Implementation



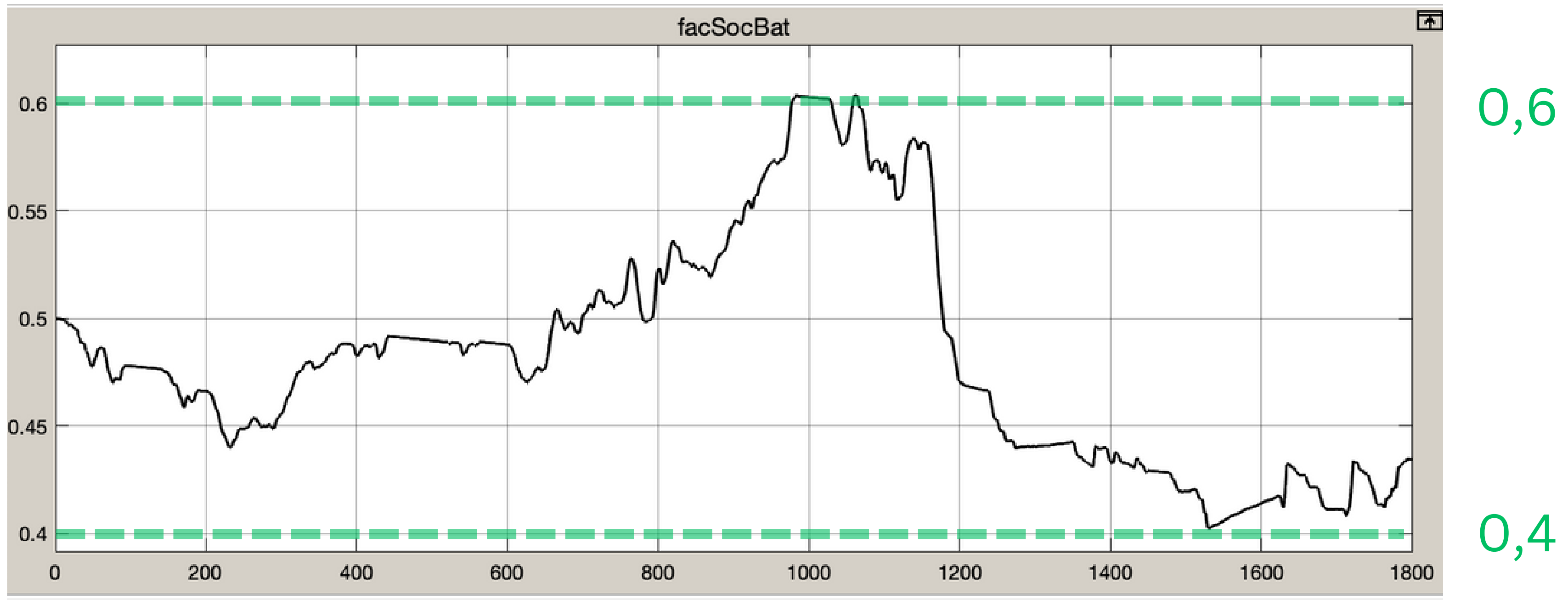
facTqSoC Implementation



tqDeltaSocCtrl Implementation



Results



SoC Behaviour for WLTC Downhill cycle (-1)

BAB185	Original Soc range	Optimised Soc range
1	0.6379 - 0.4576	0.533 - 0.445
0	0.6258 - 0.4549	0.5235 - 0.4345
-1	0.5601 - 0.4301	0.5079 - 0.4124

Cross Country	Original Soc range	Optimised Soc range
1	0.7283 - 0.4802	0.6052 - 0.4667
0	0.5721 - 0.4745	0.5117 - 0.4174
-1	0.5444 - 0.3841	0.5016 - 0.3525

1.Desired target range achievable across all drive cycles

2.Good improvement in fuel consumption values without any compromise in power demand

3.New performance =Baseline for further optimisation

Gear Optimization Strategy

Understand & Evaluate existing Gbx Strategy

Inputs, Shifting Rules, basic effects, performance

Explore other methods for shifting

RPM-based strategies

Develop new strategy

Change from velocity - based to torque and rpm - based strategy

Validate and Test against Legacy

Check for improved, smoother performance and lower fuel consumption

Torque from Power

- Area of sweet spot from be-map has been considered.
- Power is obtained through Torque * ω
- Through power-map, we can identify which powers can be achieved by running the ICE in the sweet spot.
- Values from ~10kW to ~62kW.

Sweet Spot of the ICE
be ~ 260-270 g/kWh

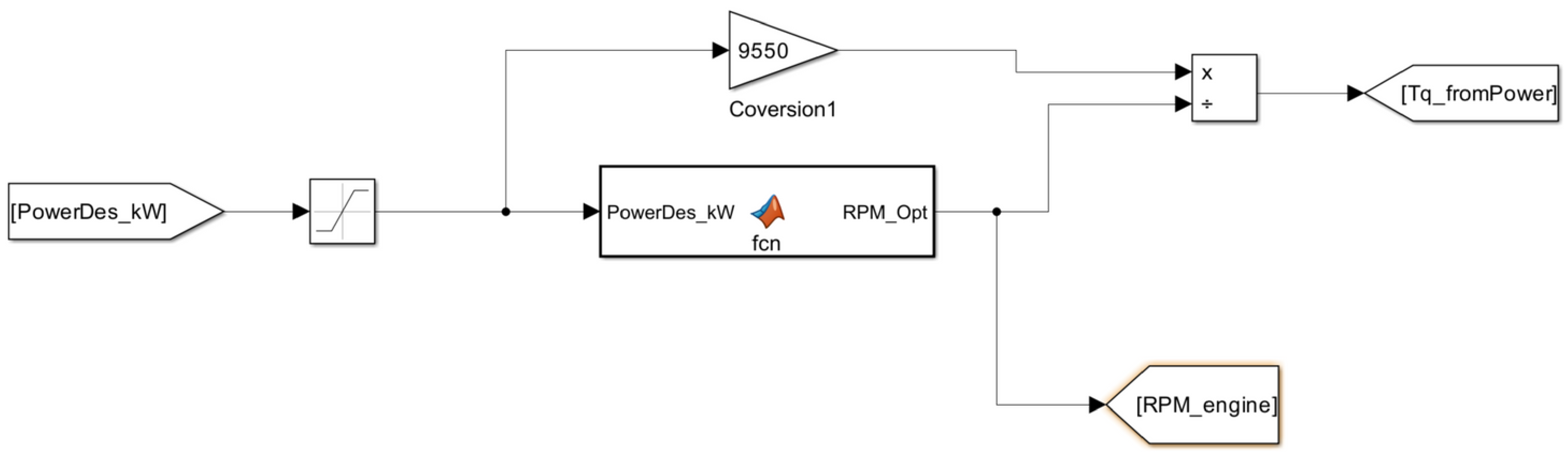
Sweetest Spot of the ICE
be < 250 g/kWh

Power	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500
	52.35988	78.53982	104.7198	130.8997	157.0796	183.2596	209.4395	235.6194	261.7994	287.9793	314.1593	340.3392	366.5191
10	524	785	1047	1309	1571	1833	2094	2356	2618	2880	3142	3403	3665
20	1047	1571	2094	2618	3142	3665	4189	4712	5236	5760	6283	6807	7330
30	1571	2356	3142	3927	4712	5498	6283	7069	7854	8639	9425	10210	10996
40	2094	3142	4189	5236	6283	7330	8378	9425	10472	11519	12566	13614	14661
50	2618	3927	5236	6545	7854	9163	10472	11781	13090	14399	15708	17017	18326
60	3142	4712	6283	7854	9425	10996	12566	14137	15708	17279	18850	20420	21991
70	3665	5498	7330	9163	10996	12828	14661	16493	18326	20159	21991	23824	25656
80	4189	6283	8378	10472	12566	14661	16755	18850	20944	23038	25133	27227	29322
90	4712	7069	9425	11781	14137	16493	18850	21206	23562	25918	28274	30631	32987
100	5236	7854	10472	13090	15708	18326	20944	23562	26180	28798	31416	34034	36652
110	5760	8639	11519	14399	17279	20159	23038	25918	28798	31678	34558	37437	40317
120	6283	9425	12566	15708	18850	21991	25133	28274	31416	34558	37699	40841	43982
130	6807	10210	13614	17017	20420	23824	27227	30631	34034	37437	40841	44244	47647
140	7330	10996	14661	18326	21991	25656	29322	32987	36652	40317	43982	47647	51313
150	7854	11781	15708	19635	23562	27489	31416	35343	39270	43197	47124	51051	54978
160	8378	12566	16755	20944	25133	29322	33510	37699	41888	46077	50265	54454	58643
170	8901	13352	17802	22253	26704	31154	35605	40055	44506	48956	53407	57858	62308
180	9425	14137	18850	23562	28274	32987	37699	42412	47124	51836	56549	61261	65973
190	9948	14923	19897	24871	29845	34819	39794	44768	49742	54716	59690	64664	69639
200	10472	15708	20944	26180	31416	36652	41888	47124	52360	57596	62832	68068	73304
210	10996	16493	21991	27489	32987	38485	43982	49480	54978	60476	65973	71471	76969
220	11519	17279	23038	28798	34558	40317	46077	51836	57596	63355	69115	74875	80634
230	12043	18064	24086	30107	36128	42150	48171	54192	60214	66235	72257	78278	84299
240	12566	18850	25133	31416	37699	43982	50265	56549	62832	69115	75398	81681	87965
250	13090	19635	26180	32725	39270	45815	52360	58905	65450	71995	78540	85085	91630

Torque from Power

Tq_fromPwr Calculated with Matlab fcn-block:

- If PwrDes lies between 10 & 25 kW: rpm_opt = 1250 rpms
- If PwrDes between 25 & 50 kW: rpm_opt = 2250 rpms
- If PwrDes between 50 & 62 kW: rpm_opt = 3000 rpms
- Else: rpm_opt = 2000 rpms (the ICE runs in the sweet spot for most torque values at 2000 rpm)



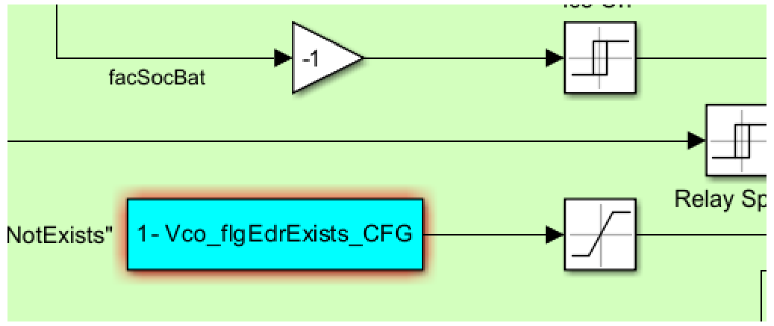
Desired Torque from ICE

Torque provided by the ICE is decided as follows:

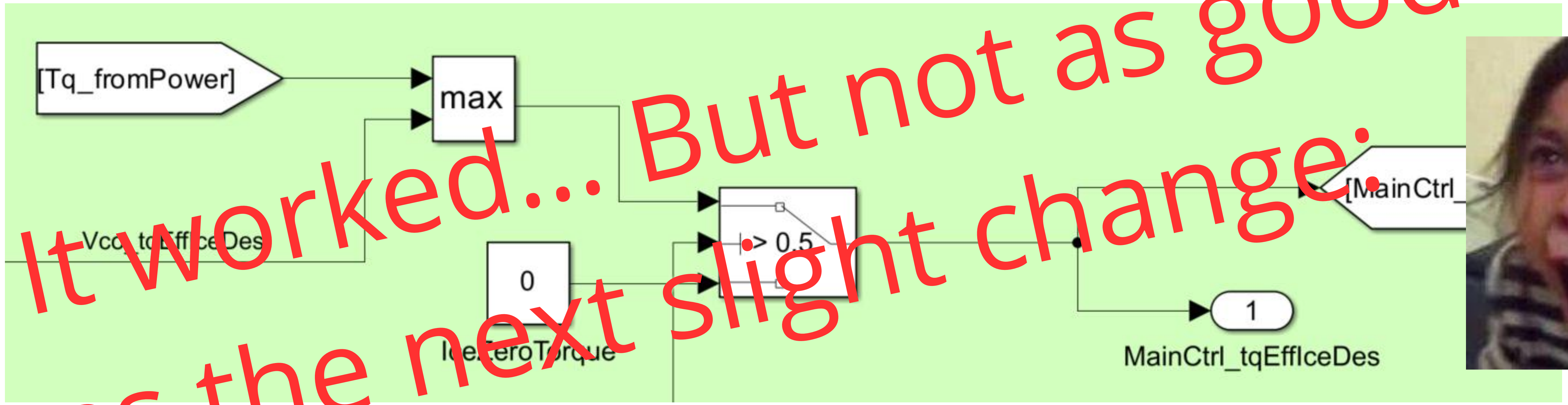
- Torque based on Power Demand or Torque based on SOC value - decided by the **Max** block.

If ICE is ON ⟶ ICE has Torque
If ICE is OFF ⟶ ICE does not receive Torque

Decides ICE On/Off



ICE ON or OFF depends on facSocBat, Bdy_kmhVeh, torque demand based on velocity profiles and slopes.



It worked… But not as good as the next slight change:

Desired Torque from ICE

The modifications:

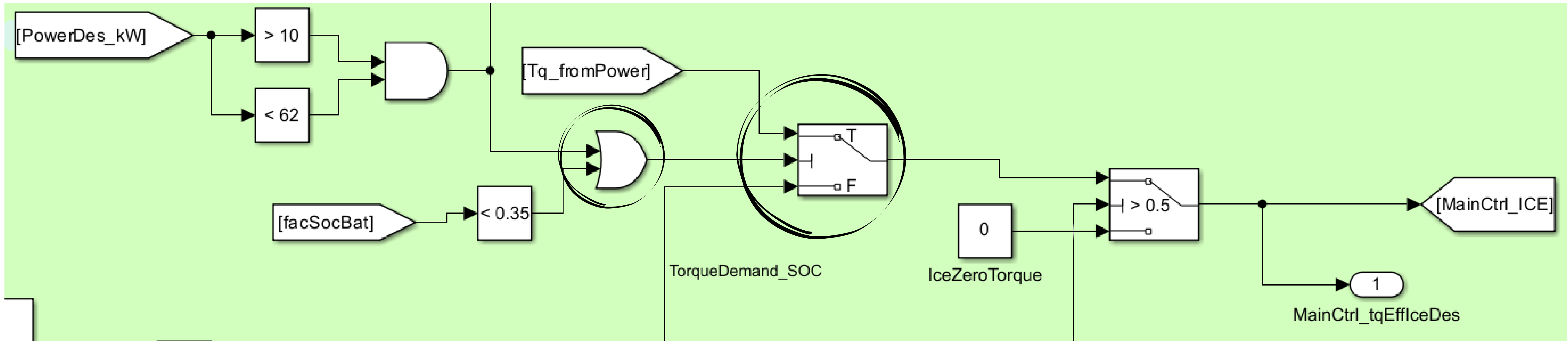
Max block ⟶ Switch Block

The switch checks if SoC is low OR if the powerDes is between 10kW & 62kW

Then it provides a sweet spot torque

Else, it uses the SoC demand Torque

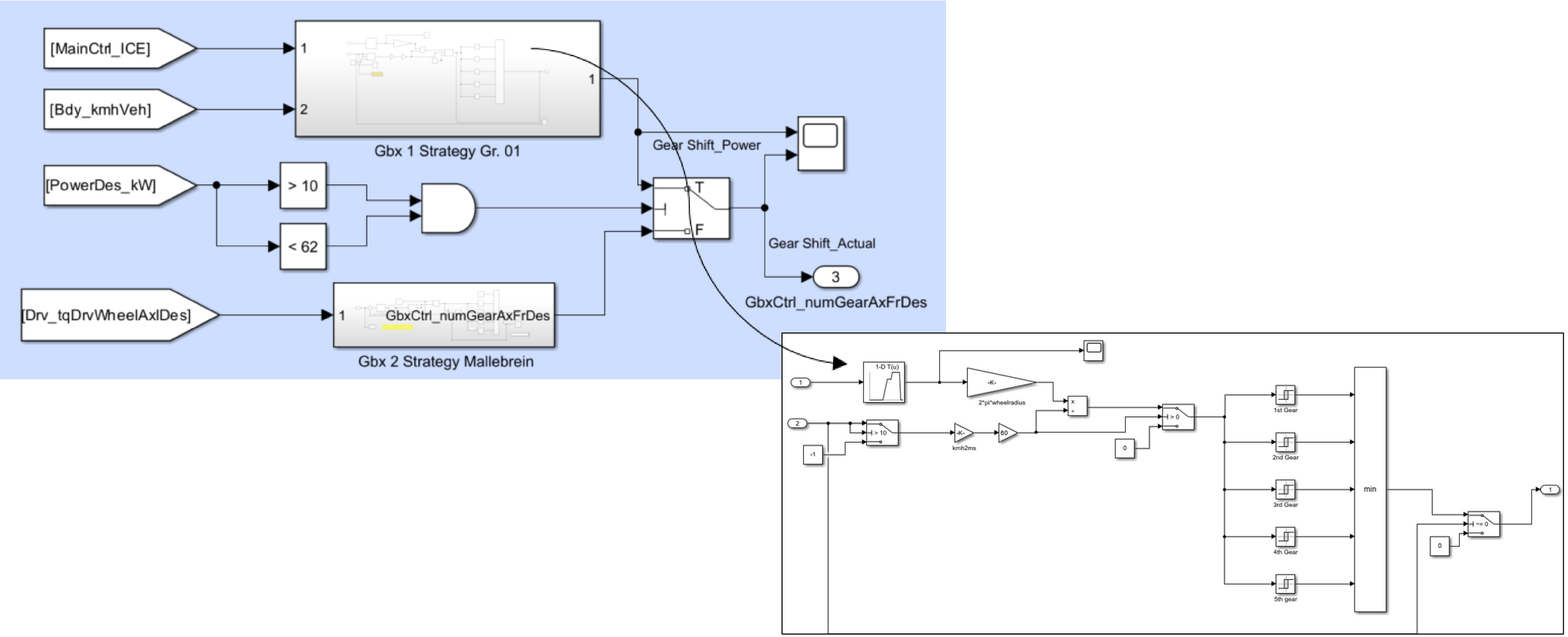
This change has reported small improvements to all drive Cycles, except for the NEDC cycle, where it consumes more fuel.



Gear Shifting

Combination of Two gear selection strategies used:

1. Based on gear ratio (be-map rpm based) which forces ICE to operate in the sweet spot.
2. Based on Bdy_kmhVeh (torque and speed based) -the original strategy - used only in case of extreme power demands



Gear Shifting

Look-up Table: Torque to RPM. From the torque, it extracts the RPMs to maintain the ICE in the sweet spot of be-map.

[2000;2000;2000;2750;2750;3000;3000;2000;2000]

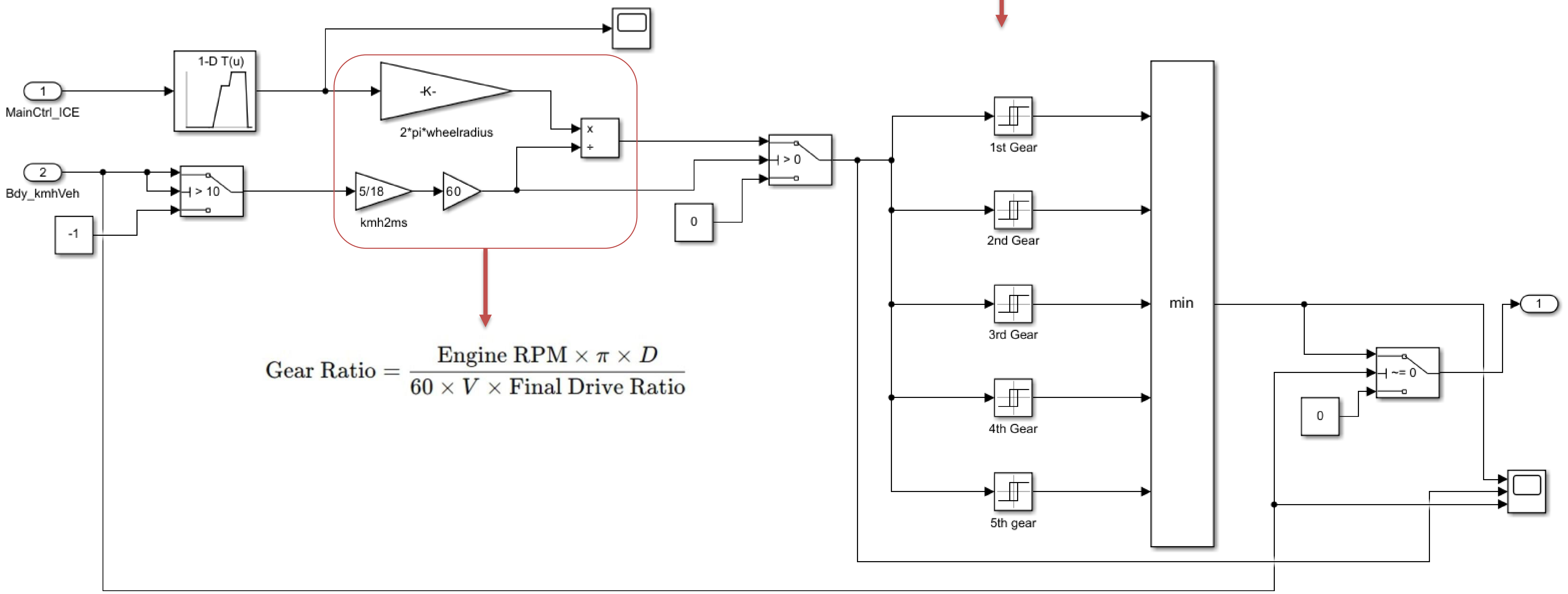
[50;120;130;160;180;190;230;240;250]

From Look-up table from GbxModel, it is known what is the Gear ratio for every selected gear.

[10 7.1 5 3.6 2.6]

[1 2 3 4 5]

Gear selector: Selects the minimum Gear Ratio, and outputs desGear



$$\text{Gear Ratio} = \frac{\text{Engine RPM} \times \pi \times D}{60 \times V \times \text{Final Drive Ratio}}$$

Loss Minimization

Understand how losses occur

ICE, E-machine and other systems

Incorporate findings in Gear Strategy

Operate at low losses w/o compromising power demand

Results

Default Strategy

Slope	Drive Cycles	mFuel Balance [kg]	beAverage[g/kWh]	mFuel[kg]
1	WLTC	0.7848	271.3	0.8246
0	WLTC	0.79	275.4	0.8013
-1	WLTC	0.78	258.8	0.8201
1	NEDC	0.66	263.2	0.6533
0	NEDC	0.36	276.8	0.3096
-1	NEDC	0.04	279.3	0.0941
1	BAB185	1.39	252.2	1.45
0	BAB185	1.5	253	1.56
-1	BAB185	1.64	257.1	1.682
1	Cross Country	0.69	258	0.7551
0	Cross Country	0.68	264.4	0.6987
-1	Cross Country	0.66	260.1	0.6961

Optimized Strategy

Slope	Drive Cycles	mFuel Balance [kg]	beAverage[g/kWh]	mFuel[kg]
1	WLTC	0.7937	247.14	0.7933
0	WLTC	0.7857	251.87	0.7973
-1	WLTC	0.7816	243.36	0.775
1	NEDC	0.66	247.03	0.7503
0	NEDC	0.369	266.67	0.3933
-1	NEDC	0.039	240.88	0.05013
1	BAB185	1.408	246.71	1.423
0	BAB185	1.5	245.97	1.52
-1	BAB185	1.638	252.55	1.646
1	Cross Country	0.69	241.79	0.7377
0	Cross Country	0.6712	245.39	0.6815
-1	Cross Country	0.6488	242.15	0.6095

The SOC of the battery lies between 0.35 & 0.69 [within the established boundaries]

Identified Loss Drivers

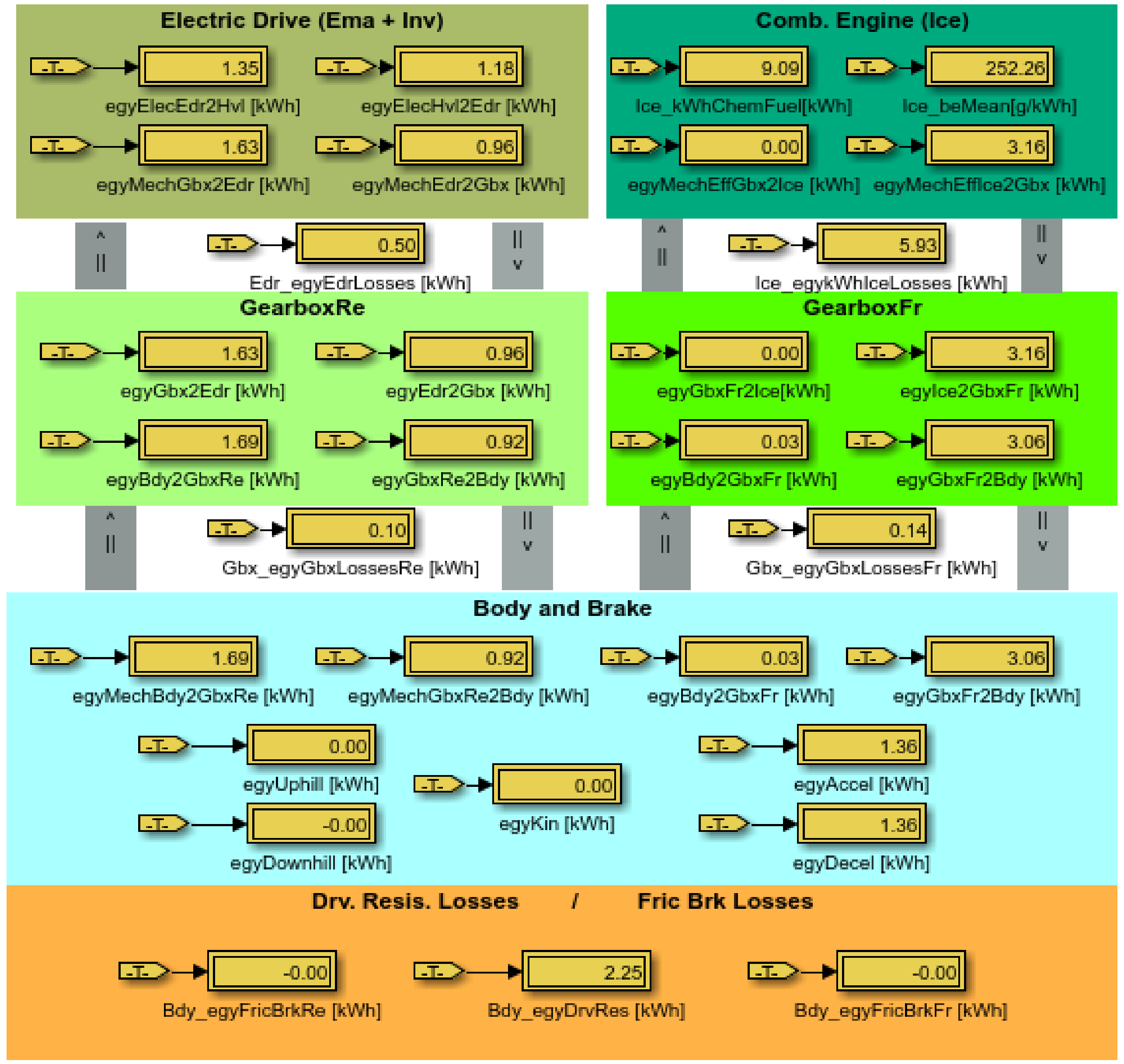
Which losses are the greatest?

Sankey Diagram helps visualize the losses of the whole system:

for all Drive Cycles w/ facSlope= -1/0/+1

Total losses ~6,7kWh:

- ~89% are due to ICE
- ~2.1% are due to Gearbox Fr losses
- ~1.5% are due to Gearbox Re losses
- ~7.5% are due to Electric Drive losses



**Overall egy_loss improvement of ~2% compared to default strategy

Limitations & Areas of improvement

- Implementing automatic threshold adjustment based on road gradient to replace the current manual switching mechanism.
- The model operates near fuel-efficient regions (sweet spots) across most drive cycles; further optimization can be achieved by adapting torque demand more dynamically based on the battery's state of charge (SOC).
- Gear shifting performance is generally smooth, though occasional minor gear hunting is observed, indicating potential for further refinement.

Vielen Dank!