AUE 817 Final Project Presentation

Clemson University CU-ICAR

Sizing and Controlling of a Parallel Hybrid SUV Powertrain

Team 3:

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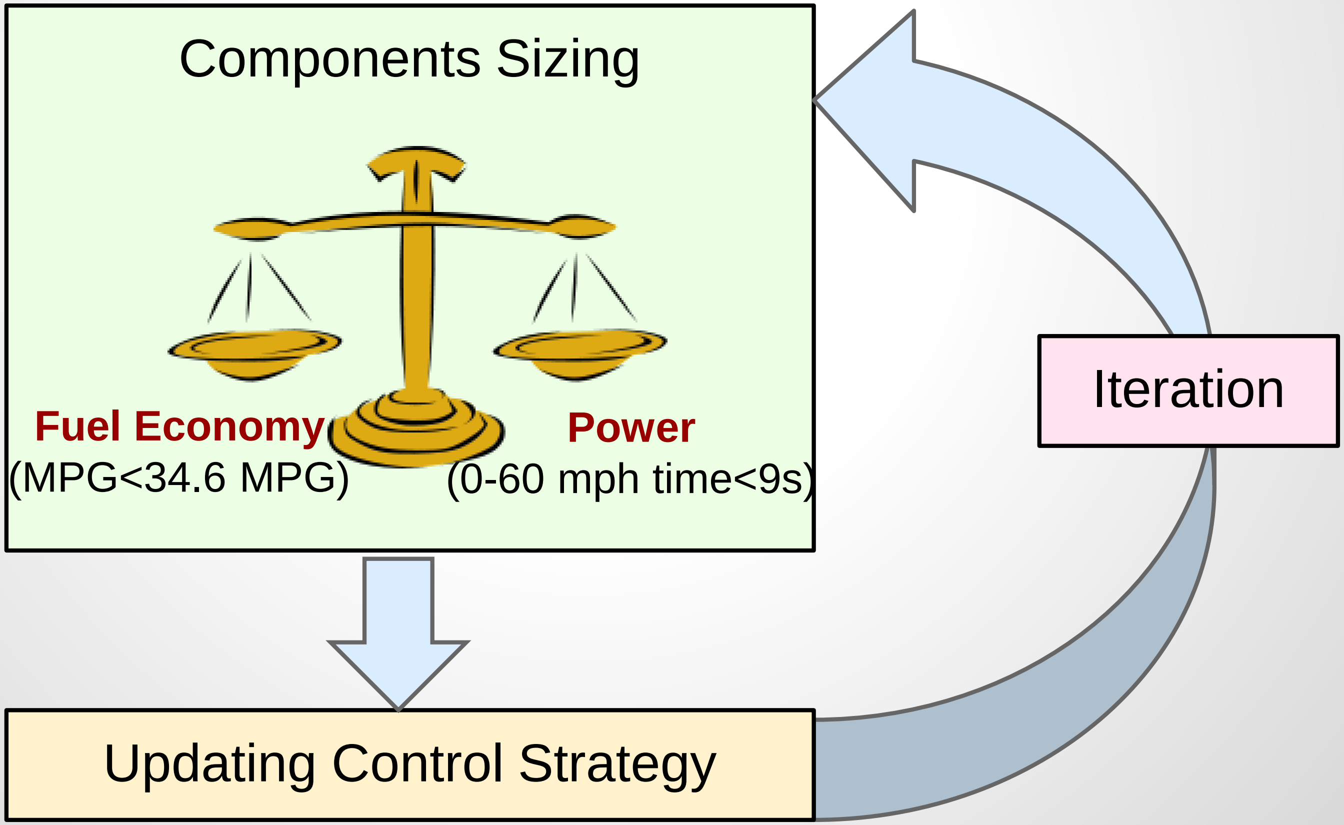
Project Overview

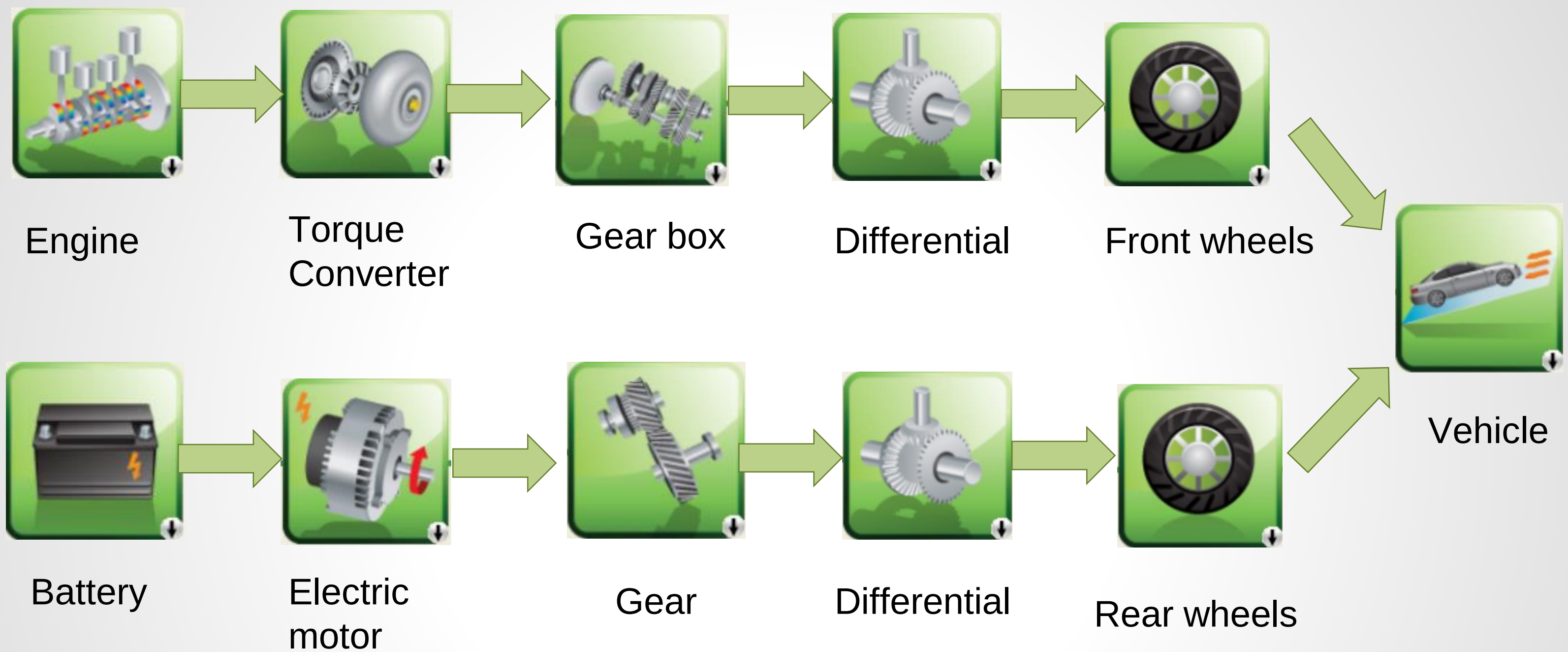
Process Flow

- Components sizing need to consider the competing requirements of fuel economy and power. Bigger engine means higher power and lower efficiency.

- Iteration is needed due to the change of one component will affect other components and total weight.



Project Overview Vehicle Configuration



Note: Engine and electric motor are connected by road

Vehicle parameters:
Frontal area A = 2.48 m^2
Curb weight = 1300 kg, GVWR = 1750 kg
Rolling resistance coefficient = 0.008
Aerodynamic drag coefficient Cd = 0.32
Tire size: 255/55R18, dynamic rolling radius = 357mm
Rotating inertia: 1.4 kgm2 (per wheel)

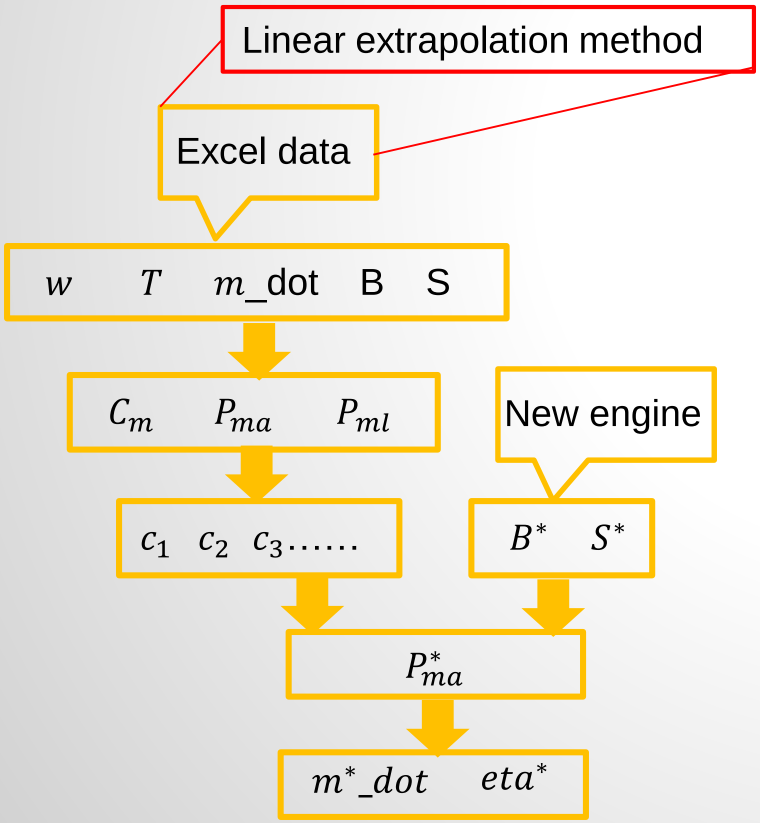
Transmission:
4 speed Automatic Transmission:
Gear ratio: 2.847, 1.552, 1.000, 0.700
Differential ration: 4.13
Shift points under normal driving loads
1→2 1,500 RPM
2→ 3 2,000 RPM
3→ 4 2,500 RPM

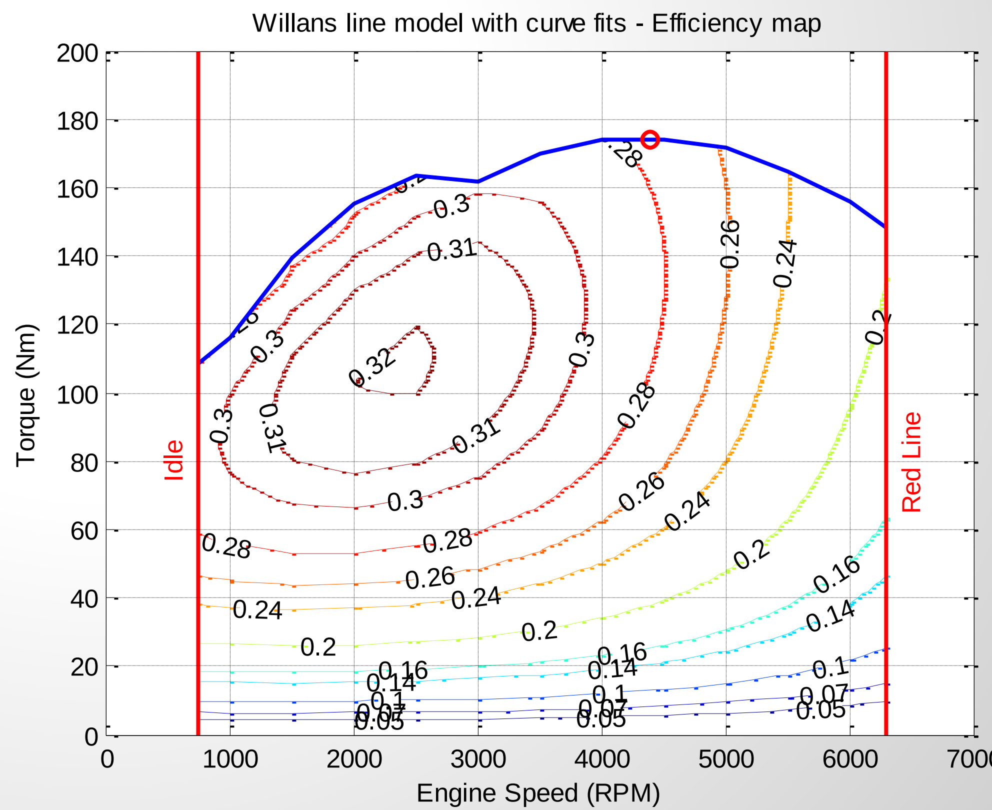
Powertrain Sizing Engine

$$P_{me} = eP_{ma} - P_{ml}$$

$$e = (c_1 + c_2 C_m + c_3 C_m^2) - (c_4 + c_5 C_m) P_{ma}$$

$$P_{ml} = c_6 + c_7 C_m^2$$

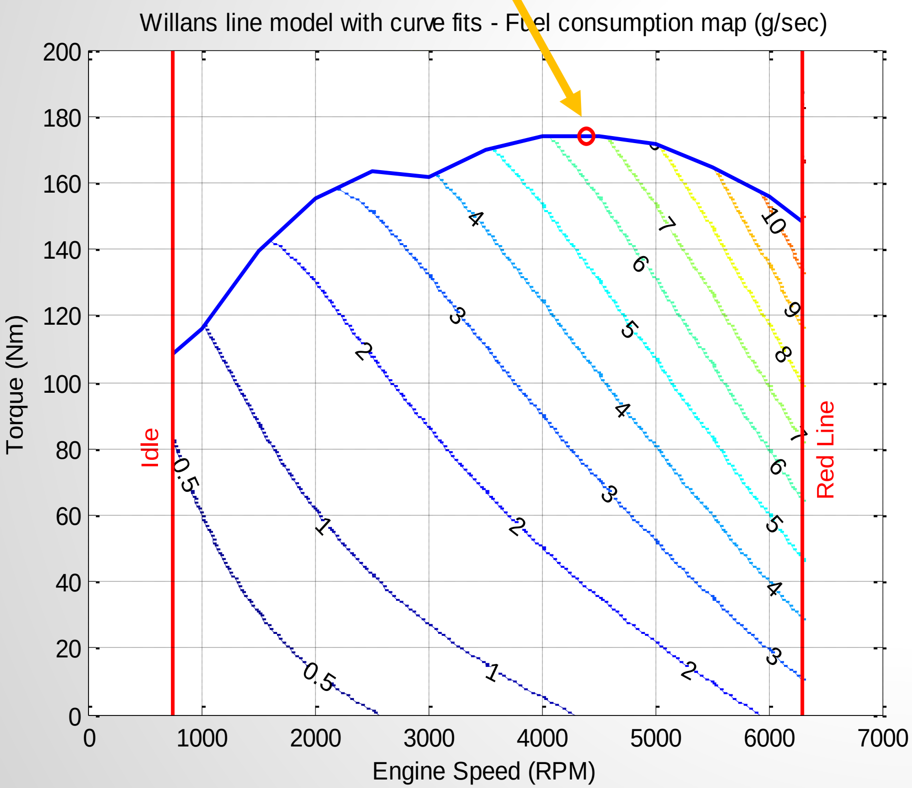


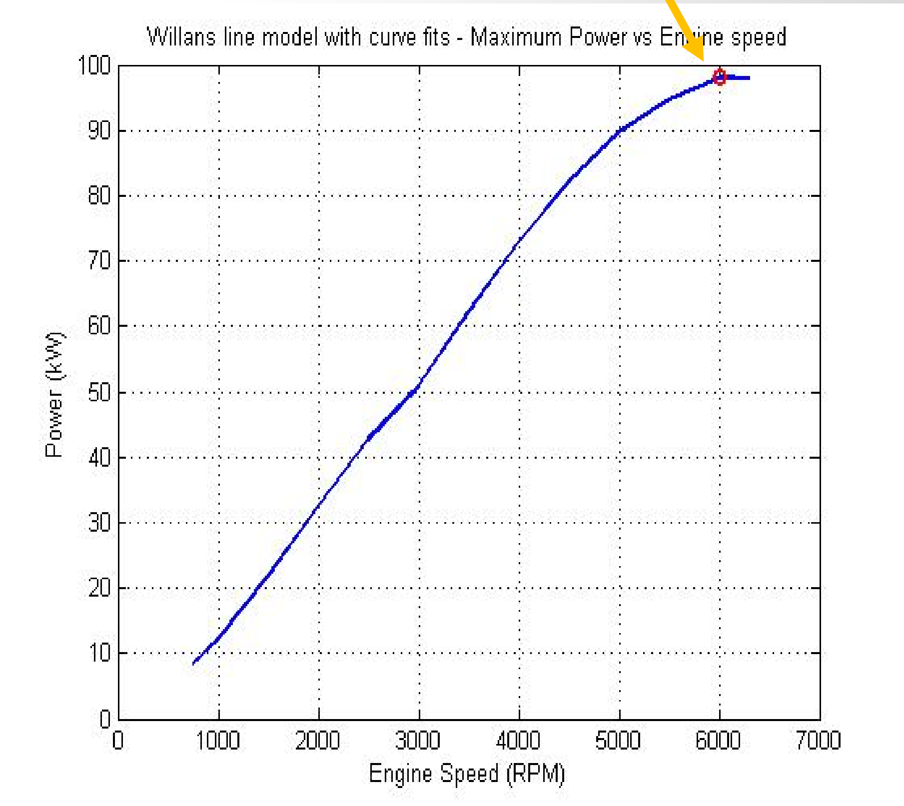


Powertrain Sizing Engine

Maximum torque:
174 Nm @4400 RPM

Maximum Power:
98 kW @6000 RPM





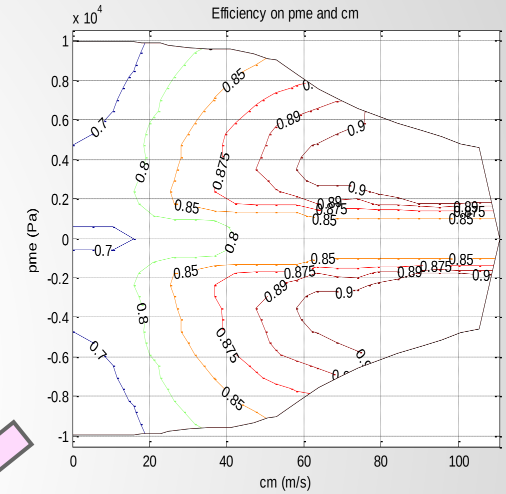
Powertrain Sizing Motor

1. Willan's line model: Convert initials motor efficiency map from *Torque* and *RPM* to *pme* (mean effective pressure) and *cm* (mean piston speed).

$$c_m = r\omega, \qquad p_{me} = \frac{T_e}{2\pi r^2 l}$$

$$P = T_e \omega = 2\pi\, r\, l\, c_m\, p_{me}$$

1.Convert Initial map to *pme* and *cn*



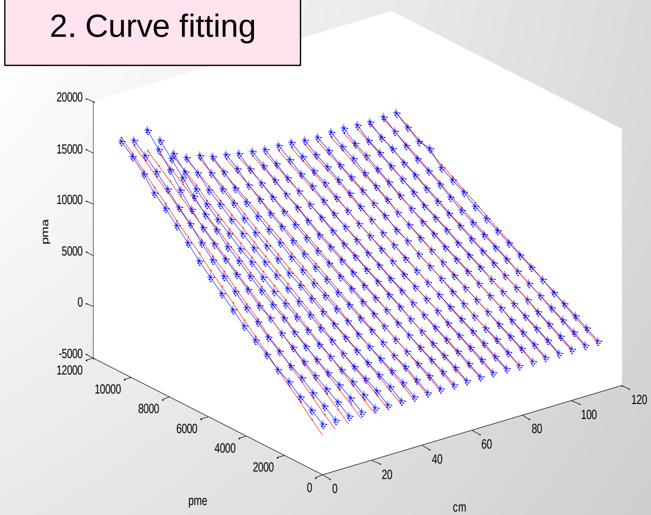
2. Curve fitting (Least square method): parameterize *e* and *ploss* with polynomial functions of cm.

$$e = \alpha_0 + \alpha_1 c_m + \alpha_2 c_m^2 \qquad \alpha_0 = 0.554;\ \alpha_1 = 0.00806, \alpha_2 = -4.84\text{e}{-05}$$

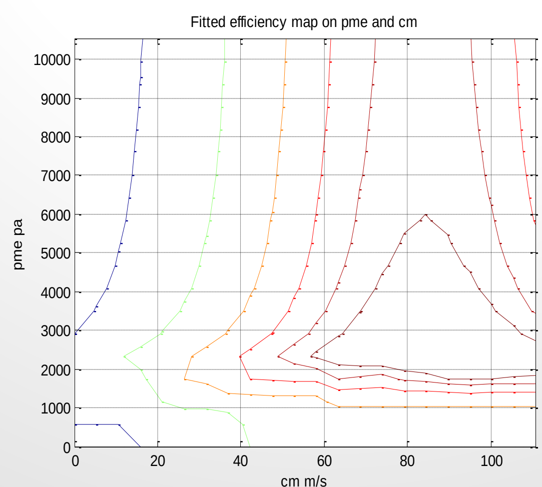
$$p_{loss} = \beta_0 + \beta_1 c_m + \beta_2 c_m^2 \qquad \beta_0 = -605.6;\ \ \beta_1 = 13.3;\ \ \beta_2 = -0.08218$$

3. Sizing: Convert dimensionless model back to dimensional model to acquire the efficiency map of a machine of new size

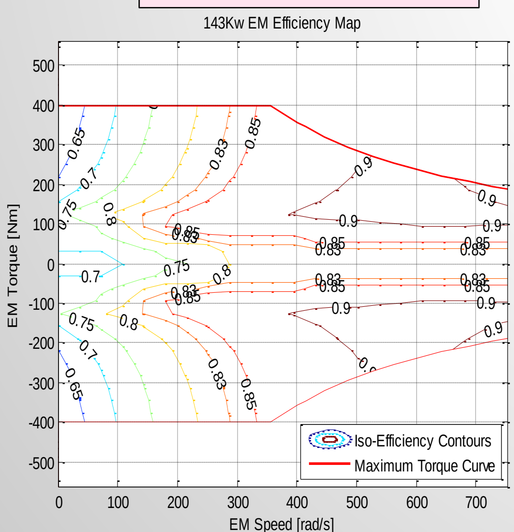
2. Curve fitting



Dimensionless model



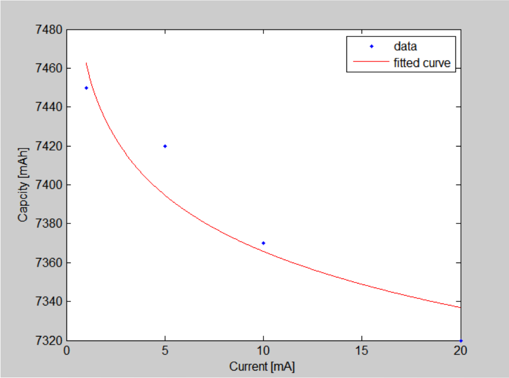
3.Dimensional model



Powertrain Sizing

Battery Pack

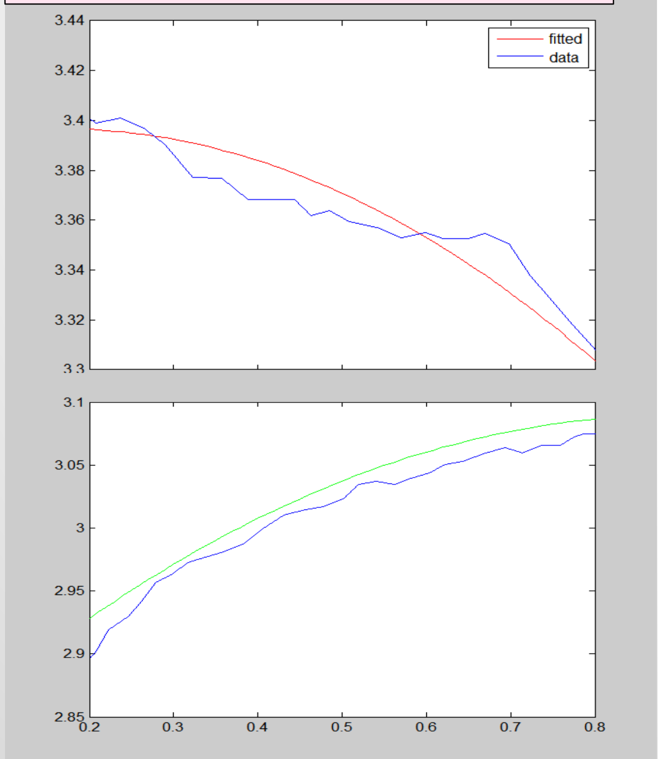
Peukert Equation Fitting



Picking points using Plot Digitizer

As is done in HW4, peukert effect is taken into consideration, and the least square fitting method is implemented when building up the battery model. Validation is executed, and the results show the fitting is acceptable.

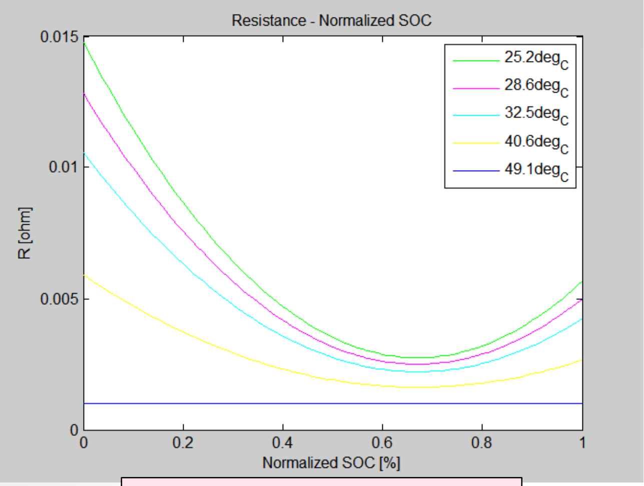
Validation for both discharge & charge



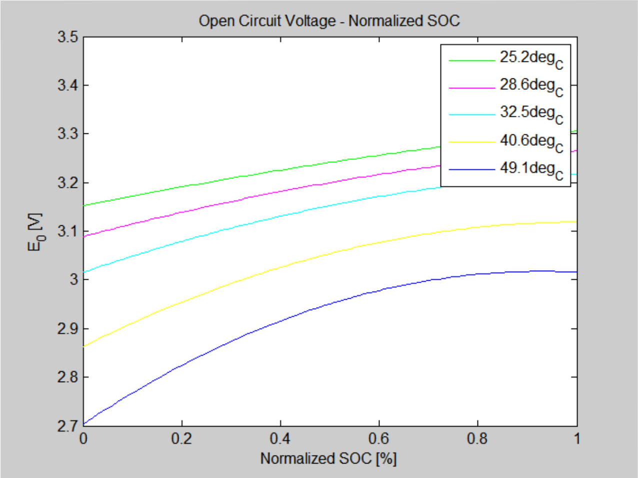
Powertrain Sizing

Battery Pack

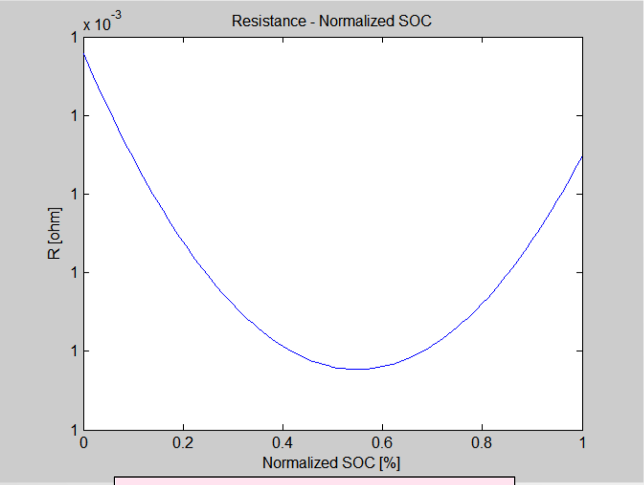
Results



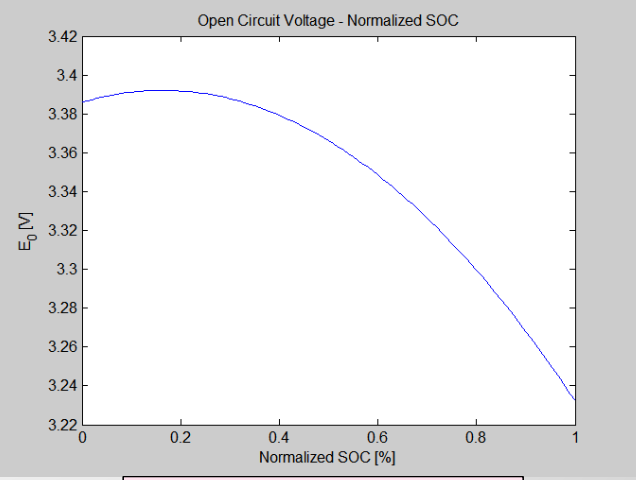
R_vs_SOC_disch



V_oc_vs_SOC_disch



R_vs_SOC_ch



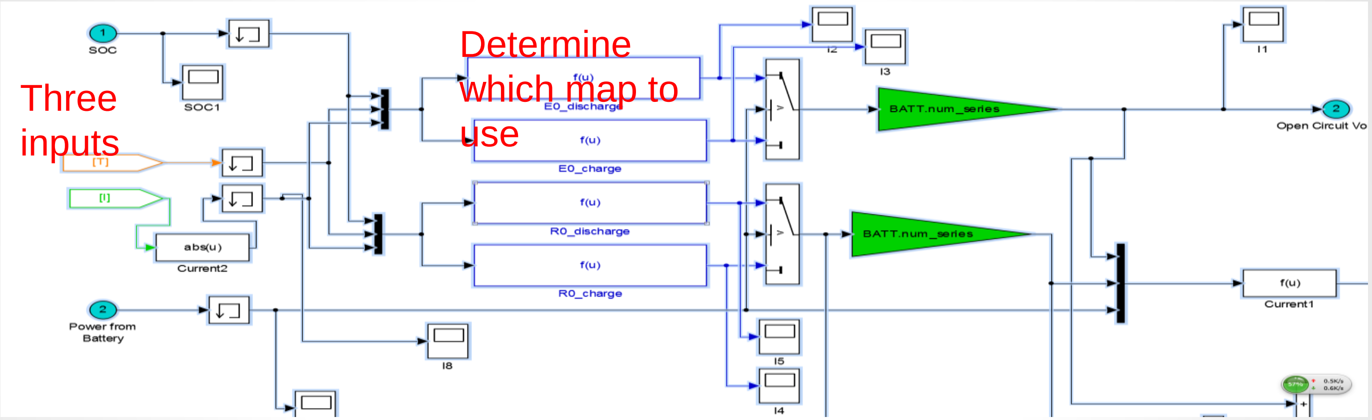
V_oc_vs_SOC_ch

Powertrain Sizing

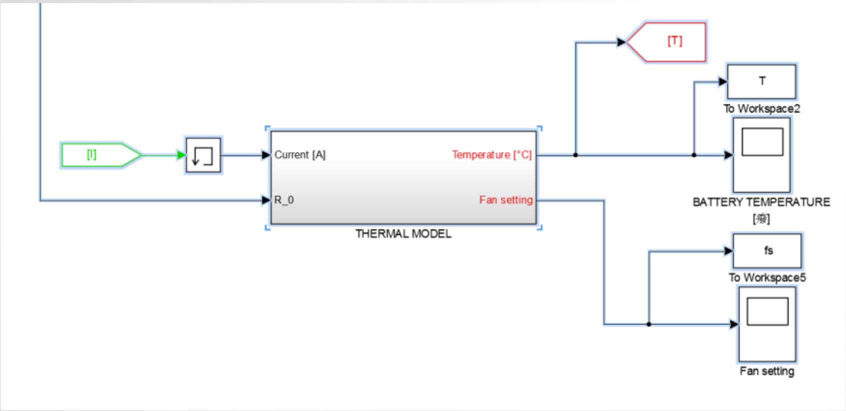
Battery Pack

Thermal Model Description

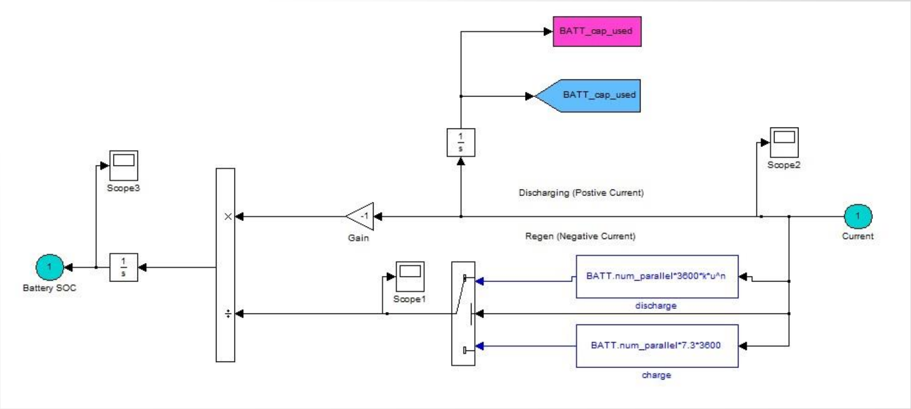
E=fcn(SOC, T, I)



Thermal Model added



Subsystem: Obtain SOC



Powertrain Sizing

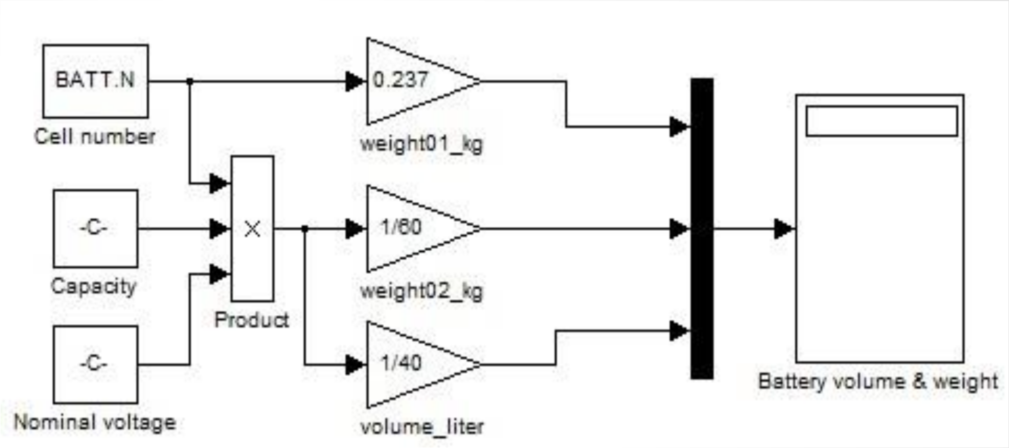
Battery&Fuel tank Pack

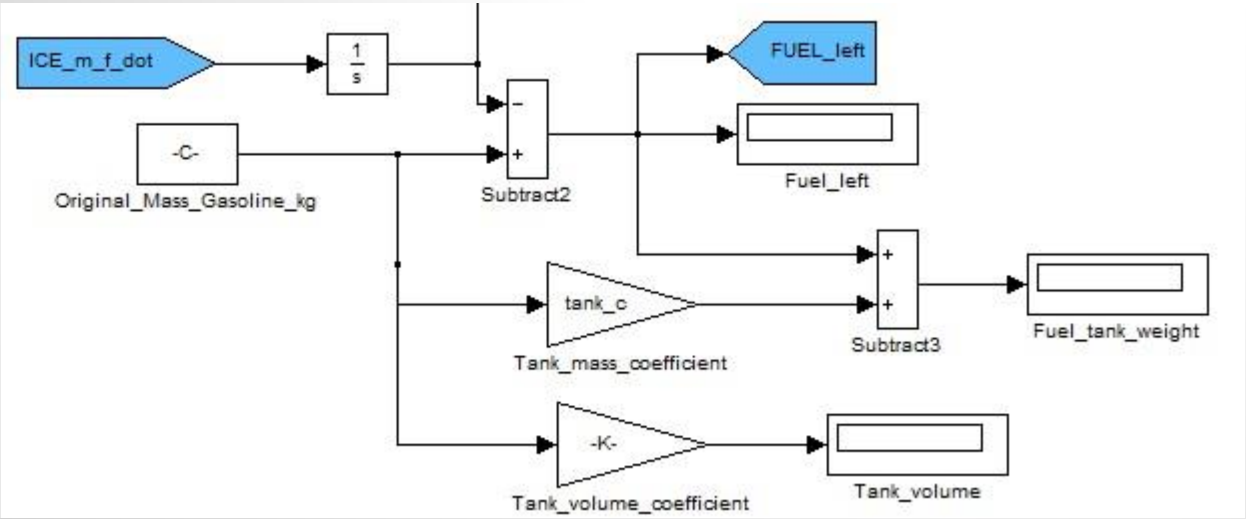
Battery sizing

Volume: 144 Litrers

Mass: 105 kg

Cell: 247





Fuel tank sizing

Volume: 8.5 gallon with 350 miles

UDDS&HWFET combined cycle

Control Strategy ECMS

Equivalent Consumption Minimization Strategy (ECMS):

Minimize instantaneous fuel consumption instead of global

$$min\left[\int \dot{m}_f\,(t)dt\right] \rightarrow \int min\left[\dot{m}_f(t)\right]dt$$

Steps:

1. Calculate motor speed at a given engine speed by gear ratio.

2. Discretization: Split torque between engine an motor

$$T_{ice} = \text{linspace}(0, T_{max}, n)$$
$$T_{em} = T_{request} - T_{ice}$$

3. Calculation Equivalent fuel consumption of electrical motor

$$m_{equ\ em} = f_{penalty} * \left(\frac{gamma}{s_{chag}} + \frac{1 - gamma}{s_{dischg}}\right) * \frac{em_{trq} * ice_w}{QHLV}$$

$$gamma = \frac{1+sign(em_{trq})}{2}; \qquad f_{penalty} = (1 - x_{soc}{}^3/2) * weight$$

4. Minimize fuel consumption of Engine and Motor combined

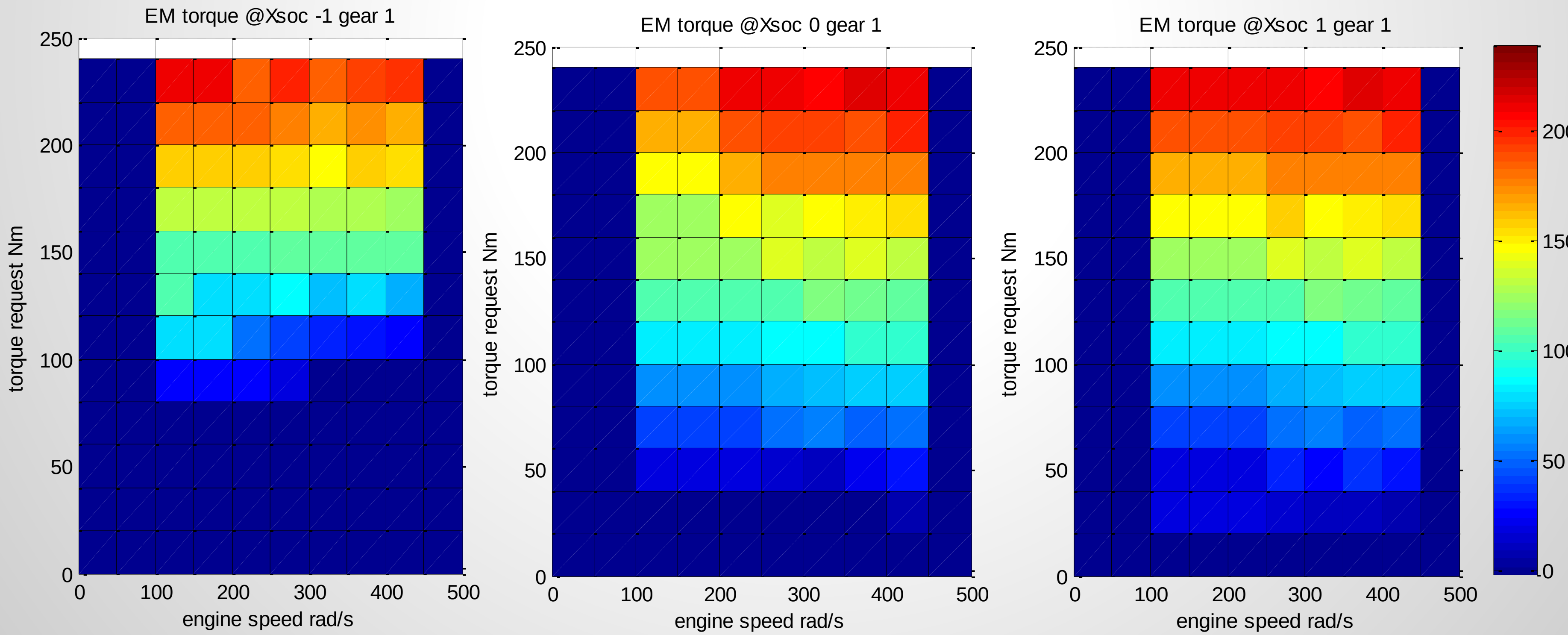
$$\min(m_{ice} + m_{equ\_em})$$

Control Strategy Lookup Table

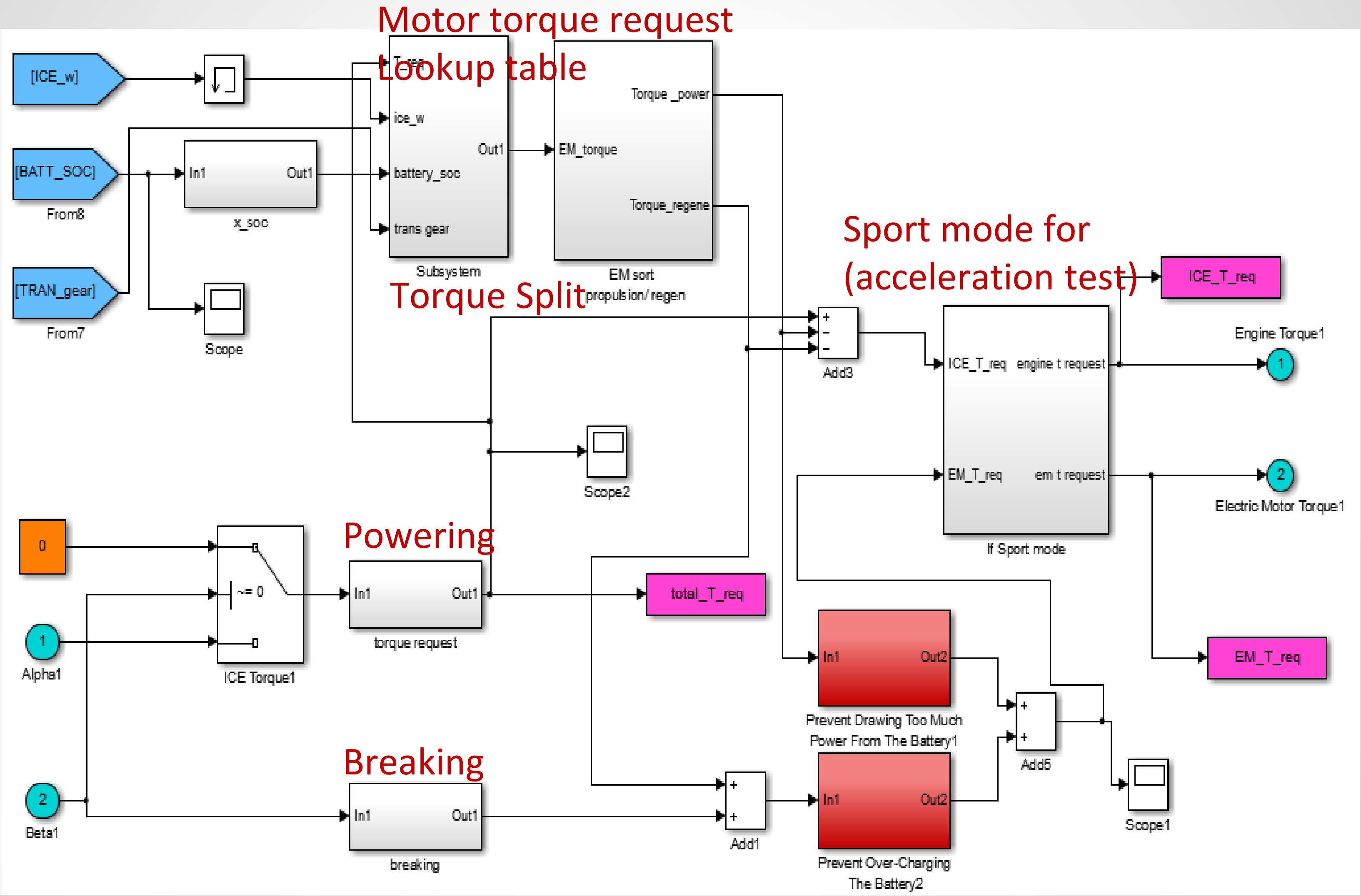
- A 3+1D look up (engine speed, torque request, x_soc + gear) table of motor torque request is pre-computed to reduce online computational cost.

Note: X_SOC is mapping of SOC between [-1, 1]

- As x _soc decreases, less is requested from electrical motor due to the penalty function on low SOC



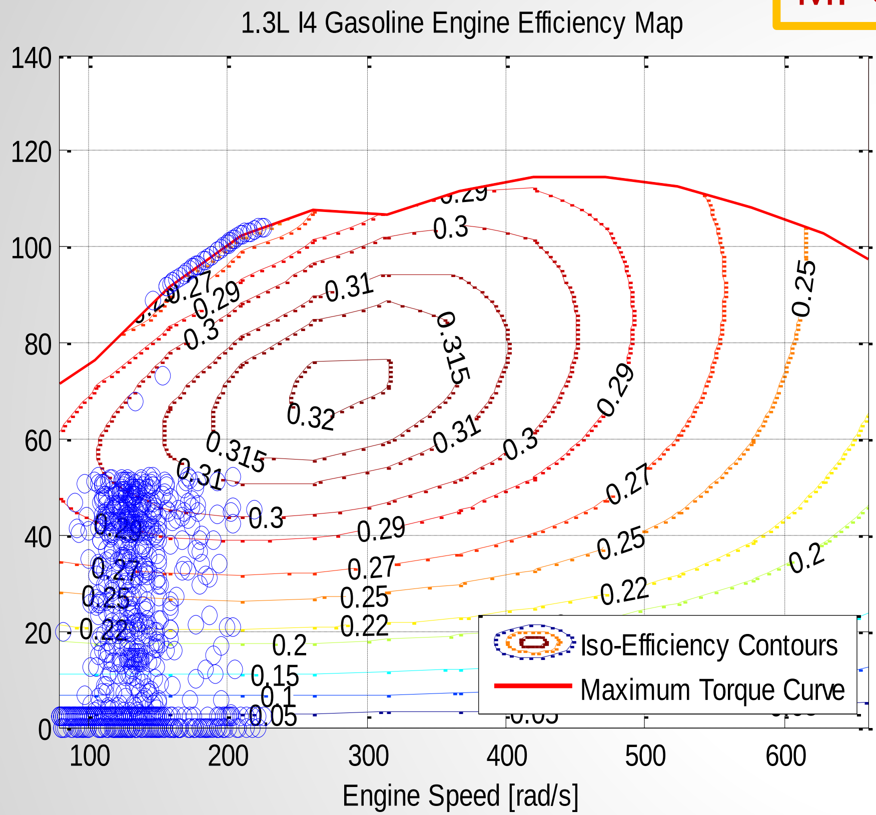
Control Strategy Simulink Implement

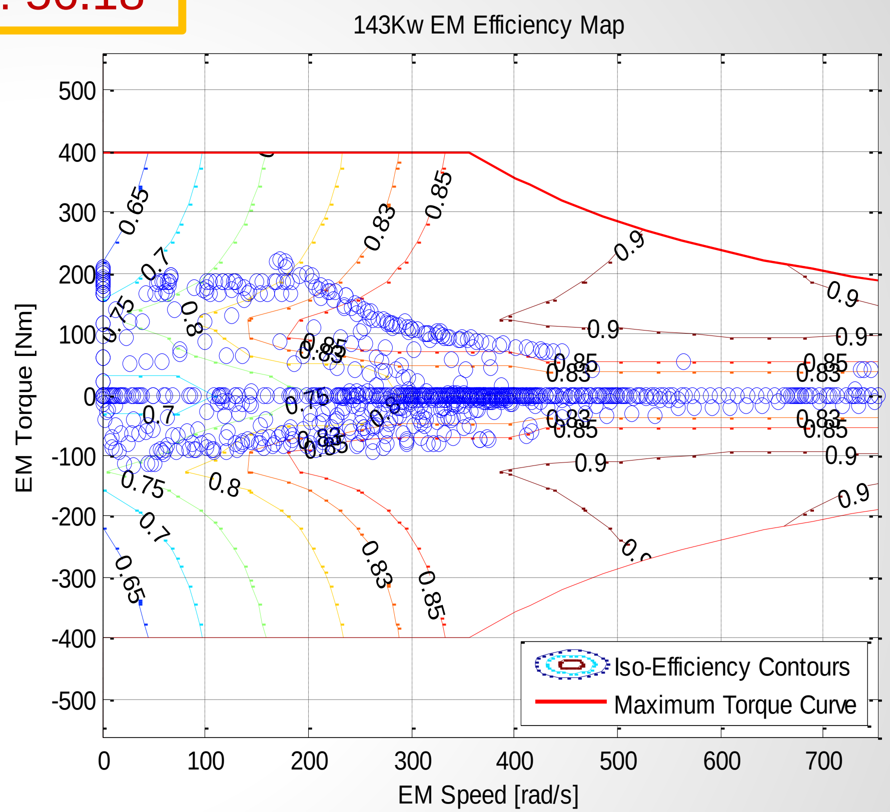


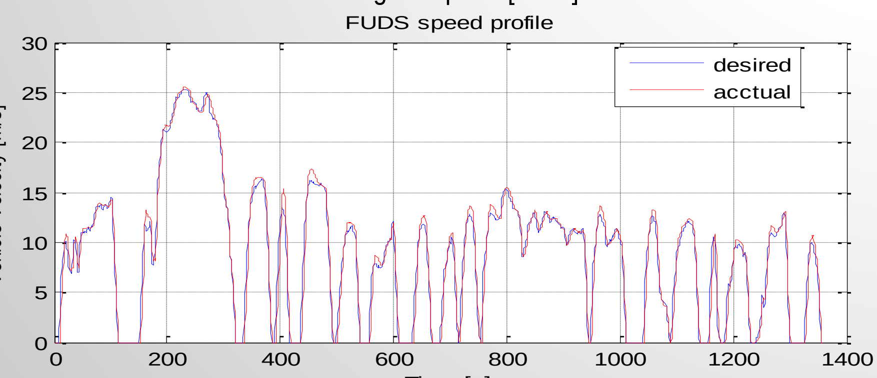
Results

Urban (UDDS) Cycle

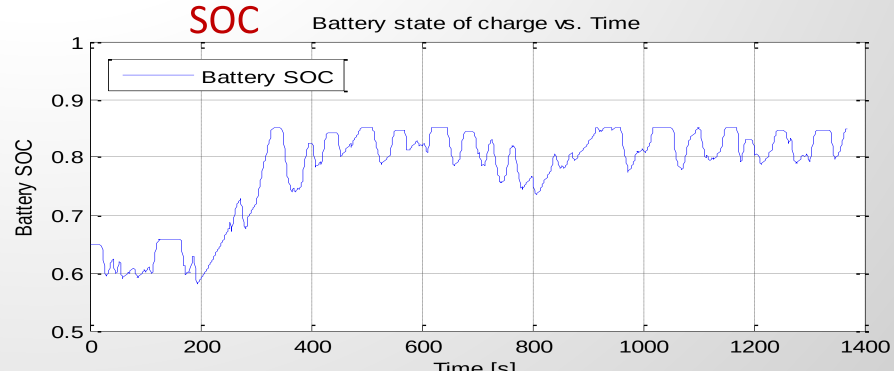
MPG: 56.18







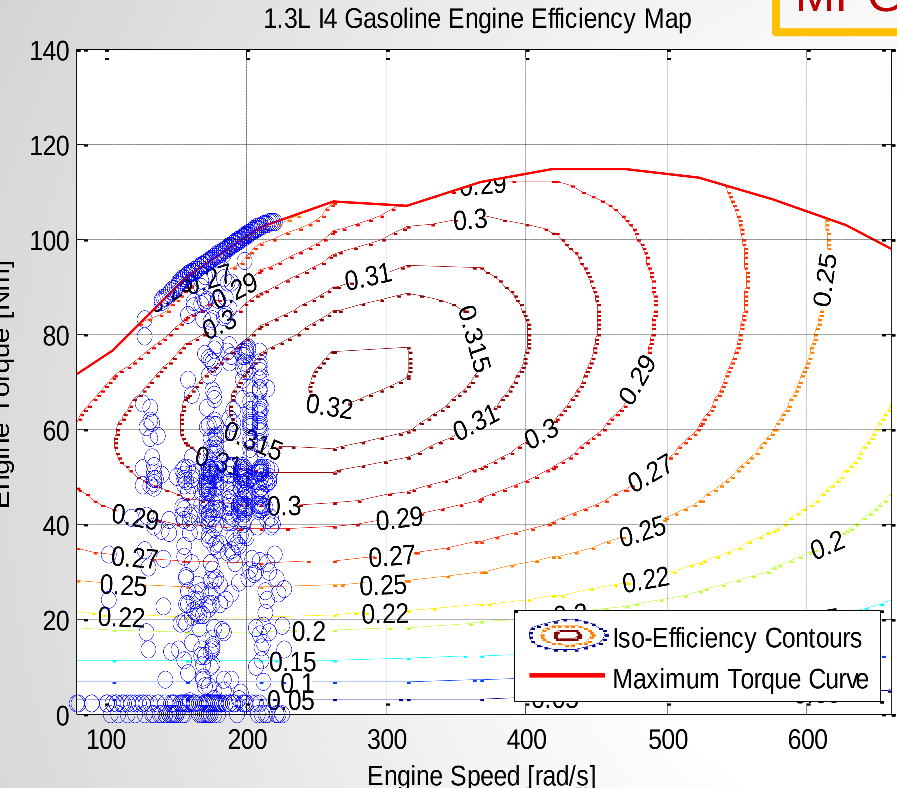
SOC

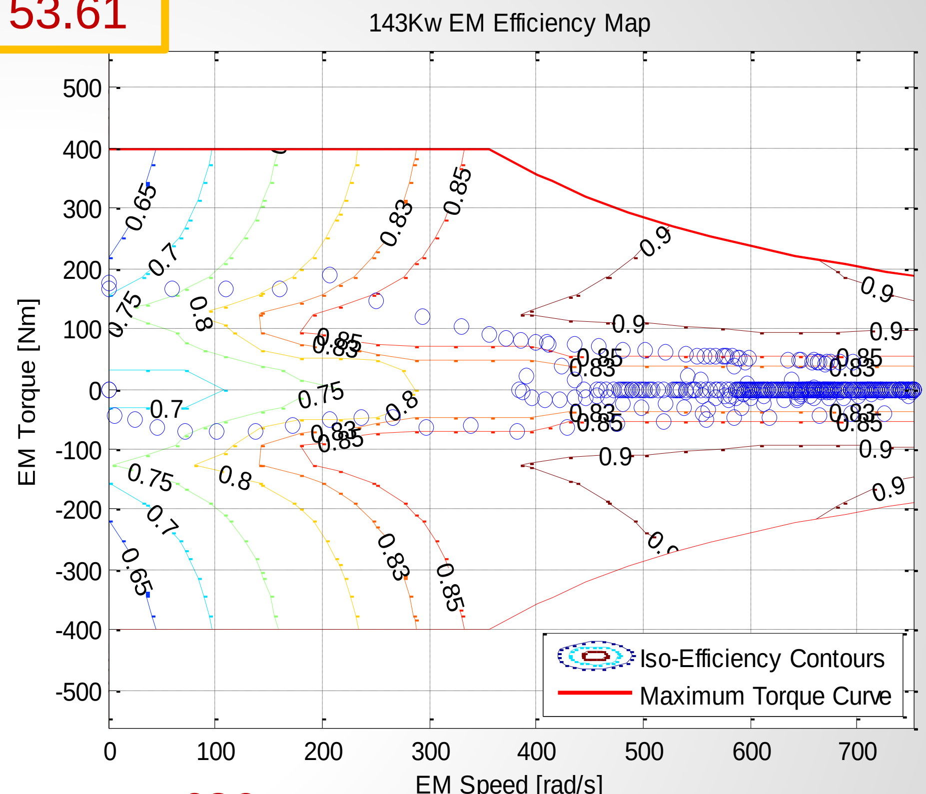


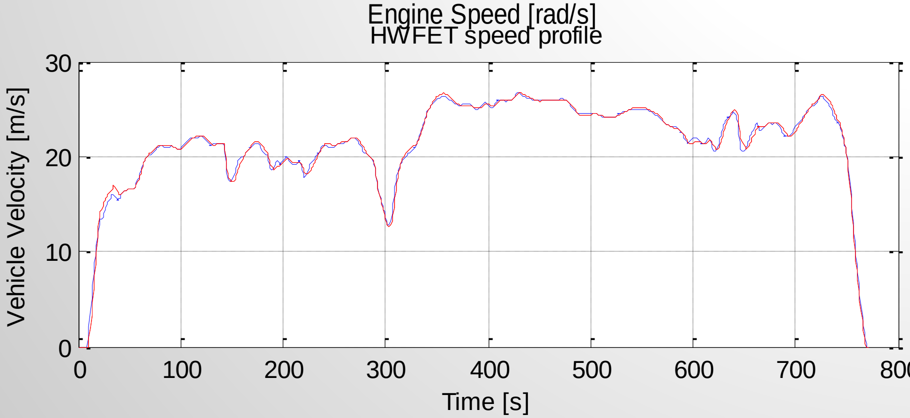
Results

Highway (HWFET) Cycle

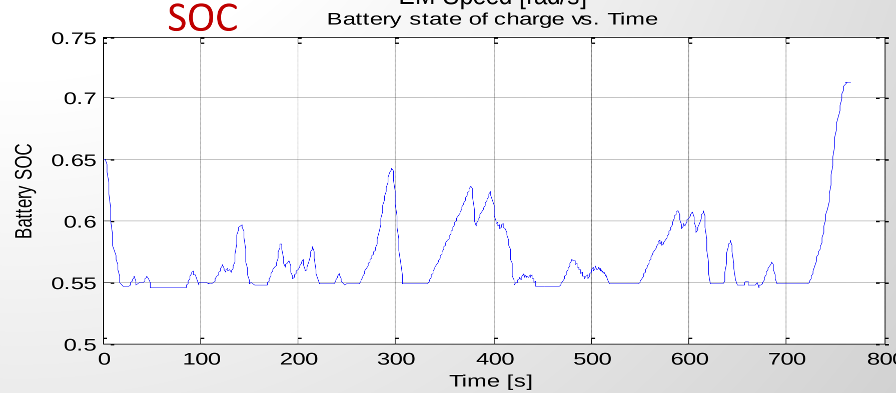
MPG: 53.61





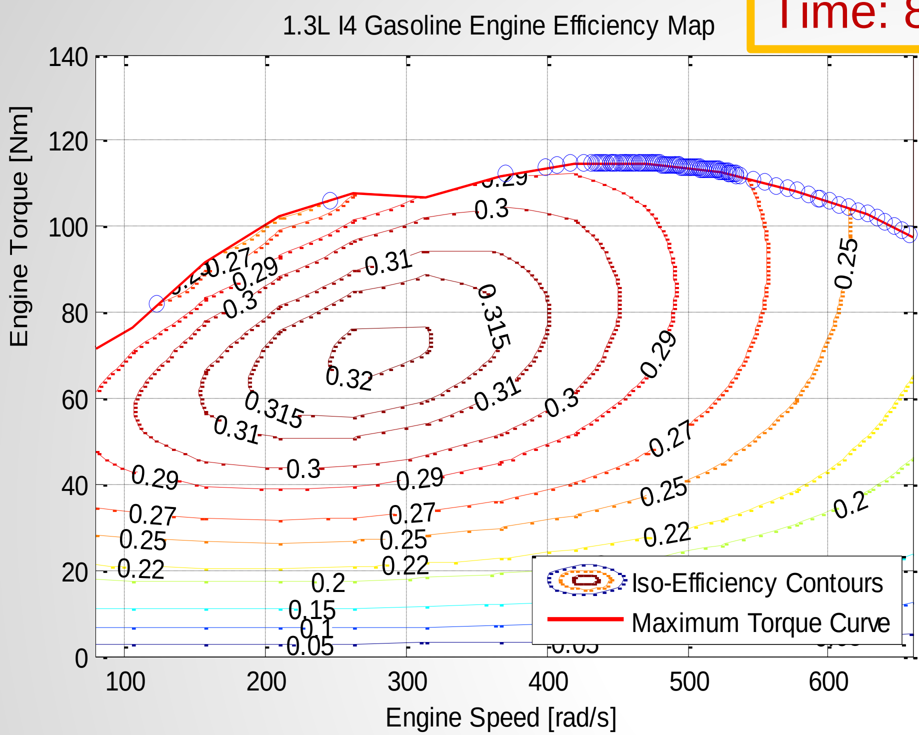


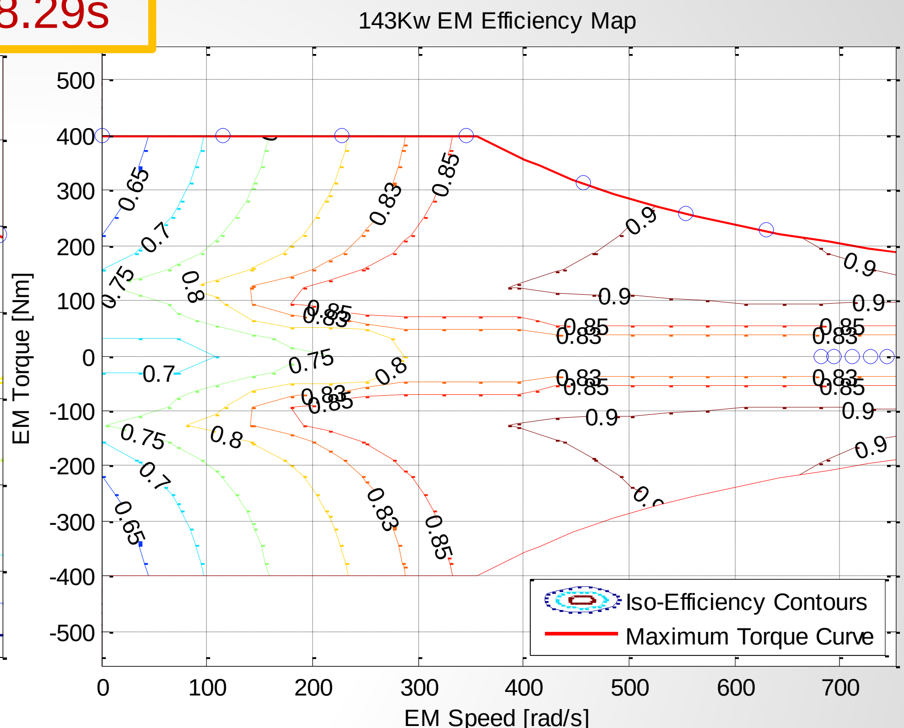
SOC

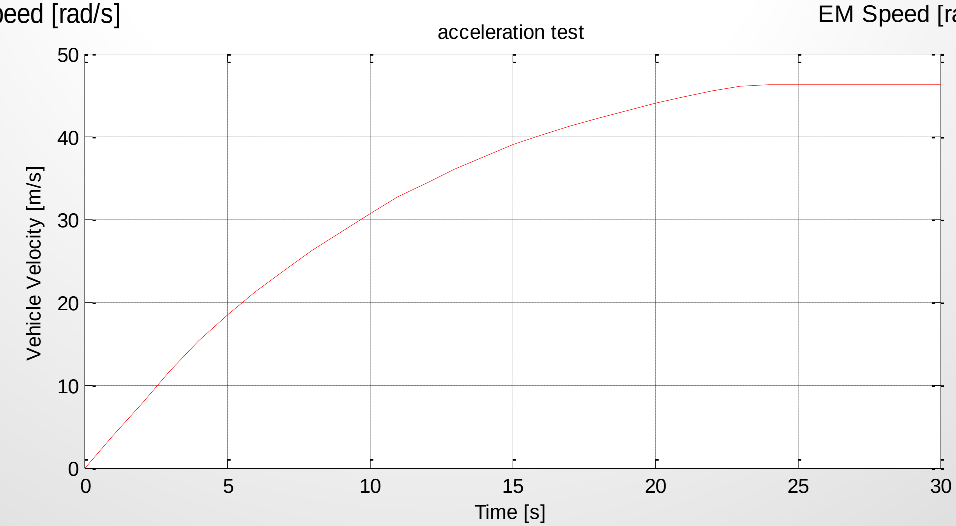


Results Accelerating (0-60 MPH)

Time: 8.29s







Summary Downsizing + EM Boosting

Specifications:

Engine specs	
Max power	64.7 kW @ 6000 RPM
Max Torque	114.9 Nm @4400 RPM
Displacement	1.3 L

Battery pack	
Single battery capacity	1729 Ah
Max power	187 Kw
Battery cell weight	*105 kg
Number of cells	247

*Note:
Weight factor 1.8

Motor specs	
Max Hp	143 kW
Max Torque	400 Nm (0-357 rad/s)
Radius	57.6 mm
Length	392 mm

Vehicle weight	
Curb wieght	1720 kg
Battery	105 kg
Driver	75 kg
Total	1900 kg

Testing Results:

Fuel economy test	
Cycles	MPG
UDDS	56.18
HWFET	53.61
combined	**54.99**
US06	**25.34
Cycle4.87 miles	49.53
Cycle10.6 miles	42.85

Goal:
Combined mpg
> 34.6

Acceleration test	
Top speed	103 mph
0-60 MPH	8.29 sec
0-20	2.32 sec
20-40	2.50 sec
30-50	2.94 sec
50-70	3.89 sec
1/4 mi time	19 sec
1/4 mi exit spd	92 mph

Goal:
Top speed >100 mph
0-60 mph: <9 sec

**Note: low mpg due to aggressive acceleration and deceleration in the cycle. Change exceeds the battery maximum capacity. Battery cannot recuperate all the energy in breaking.

Thank you!   *Questions?*