ELECTRIC VEHICLE PERFORMANCE SIMULATION

GM Volt - Vehicle, Motor, Road, and Environmental Parameters:

Vehicle Velocity:		Gear Ratio (v_{CP}=60mph):	$GR := 7.59$
Motor Efficiency:	$Eff := 0.9$	Cruise Velocity:	$vc := 60 \cdot mph$
Max Motor Power:	$Power := 136 \cdot kW$		
Max Motor Torque:	$Tm := 273 \cdot ft \cdot lbf$	Tire Radius*:	$r_{tire} := \frac{27.2}{2} \cdot in$
Max Force, Fm	$Fm := GR \cdot \frac{Tm}{r_{tire}}$	$Fm = 1.83 \times 10^{3}\ lbf$	
Constant Power Motor Torque, ω:	$\omega_{CP} := \frac{Power}{Tm}$	$RPM_{CP} := \frac{\omega_{CP} \cdot min}{2 \cdot \pi}$	$RPM_{CP} = 3.509 \times 10^{3}$
Constant Power vehicle velocity, v_{CP}:	$v_{CP} := \frac{Power}{Fm}$	$v_{CP} = 37.383 mph$	
Time, in seconds:	$t := 0, 1 .. 31$	Curb Weight:	$M_{curb} := 3140 lb$
Time unit:	$\tau := 1 \cdot sec$	Average Wind Velocity:	$Vw := 7 \cdot mph$
Drag Coeff:	$Cd := 0.22$	Effective Cross Wind V:	$V_{cw} := 2 \cdot mph$
Cross Wind Drag Coff:	$Cd_{cw} := 0.00001$	Frontal Area*:	$Af := 70 \cdot in \cdot 52 \cdot in$
Air Density:	$\rho := 1.3 \cdot \frac{gm}{liter}$	Low Tire Rolling Resist:	$RR_{tire} := 0.004$
Road Rolling Resist:	$RR_{road} := 0.001$	Road Grade (radians): (0 degrees)	$\theta := 0.0870$
* Value presently unknown.		Tire Hysteresis*:	$Th := 0 \cdot \frac{sec}{m}$
$Passenger := 180 lb$	$M_{gross} := M_{curb} + Passenger$	Gross Weight:	$M_{gross} = 3.32 \times 10^{3}\ lb$

Vehicle Dynamics Equations:

Road Resistance, Ft: $Ft(v) := M_{gross} \cdot g \cdot \left[Th \cdot v \cdot \sin(\theta) + \left(RR_{tire} + RR_{road}\right) \cdot \cos(\theta) + \sin(\theta)\right]$

Air Drag Force, Fa: $Fa(v) := 0.5 \cdot \rho \cdot Af \cdot \left[(v + Vw)^{2} \cdot Cd + Cd_{cw} \cdot \left(v + V_{cw}\right)^{2}\right]$

Opposing Force, Fo: $Fo(v) := Fa(v) + Ft(v)$ $\qquad Fo(vc) = 87.319 lbf$

Torque Speed Relation: $F(v) := if\left(v \le v_{CP}, Fm, \frac{Power}{v}\right)$ $\qquad T(v) := F(v) \cdot \frac{r_{tire}}{GR}$

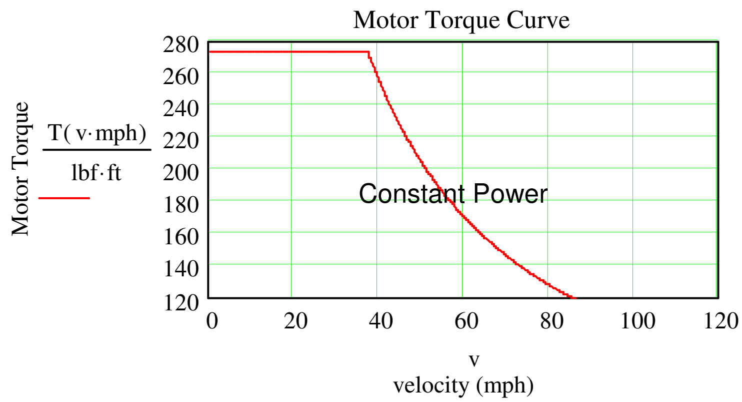
Third Law of Motion: (a is acceleration) $a(v) := \frac{F(v) - Fo(v)}{M_{gross}}$

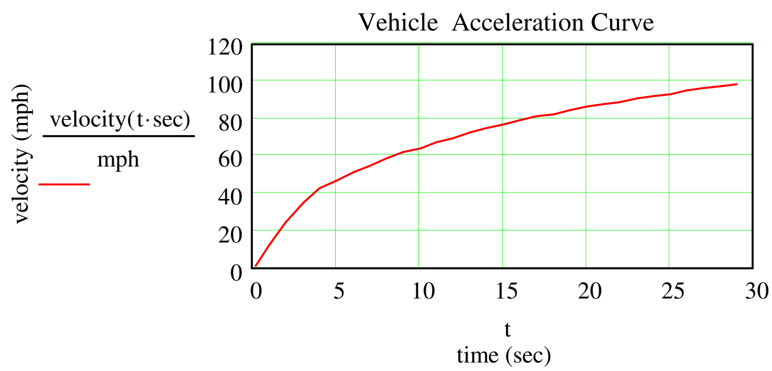
Applying maximum motor torque, find the velocity starting from initial velocity = 0 mph.

$V := 0 \cdot mph$ $\qquad velocity(t) := root\left(V - \int_{0}^{t} a(V) \cdot \tau\, dt, V\right)$ $\qquad velocity(8.56 \cdot sec) = 59.787 mph$

$Time := 0 \cdot sec$ $\qquad time(v) := root(v - velocity(Time), Time)$ $\qquad time(60 \cdot mph) = 8.627 s$

GM VOLT ESTIMATED PEFORMANCE CURVES





Find the Single Charge (@50% Full) Cruise Range for a given Velocity

Driving Pattern/Profile:

Assume we cruise at constant speed and start, stop, and regen breaking every 15 minutes.

Drive Train Power Efficiency - Battery Loss to Force Commanded Vehicle Velocity:

The Traction Inverter, DC-DC Converter, and gear power efficiency are each 90%. Brake Regen efficiency of kinetic energy is 50% . Accessory Power Dissipation is Po. Then the number of starts per hour as a function of velocity, NS, NumStarts(v, Po), is

$\text{InvXGearEff} := 0.9\cdot 0.9 \qquad \text{DCDCEfficiency} := 0.9 \qquad \text{Regen} := 0.5 \qquad k := 10^3 \qquad v := 0, 1 .. 80$

$$\text{Power}_{\text{dissLoss}}(v, P_o) := \frac{\text{Fo}(v)\cdot v}{\text{InvXGearEff}} + \frac{P_o\cdot \text{watt}}{\text{DCDCEfficiency}} \qquad \text{Energy}_{\text{accel}}(v) := \text{Power}\cdot\text{time}(v)$$

NSo and NS are iterative converging estimates of NumStarts

$$\text{NS}_o(v) := 3.35\cdot\left(\frac{50\cdot\text{mph}}{v}\right)^2 \qquad \text{NS}(v, P_o) := \frac{8\cdot k\cdot\text{watt}\cdot\text{hr} - \text{NS}_o(v)\cdot\left(\frac{\text{Energy}_{\text{accel}}(v)}{\text{InvXGearEff}} - \frac{\text{Regen}\cdot M_{\text{gross}}\cdot v^2}{2}\right)}{\text{Power}_{\text{dissLoss}}(v, P_o)\cdot 15\cdot\text{min}}$$

$$\text{NumStarts}(v, P_o) := \frac{8\cdot k\cdot\text{watt}\cdot\text{hr} - \text{NS}(v, P_o)\cdot\left(\frac{\text{Energy}_{\text{accel}}(v)}{\text{InvXGearEff}} - \frac{\text{Regen}\cdot M_{\text{gross}}\cdot v^2}{2}\right)}{\text{Power}_{\text{dissLoss}}(v, P_o)\cdot 15\cdot\text{min}}$$

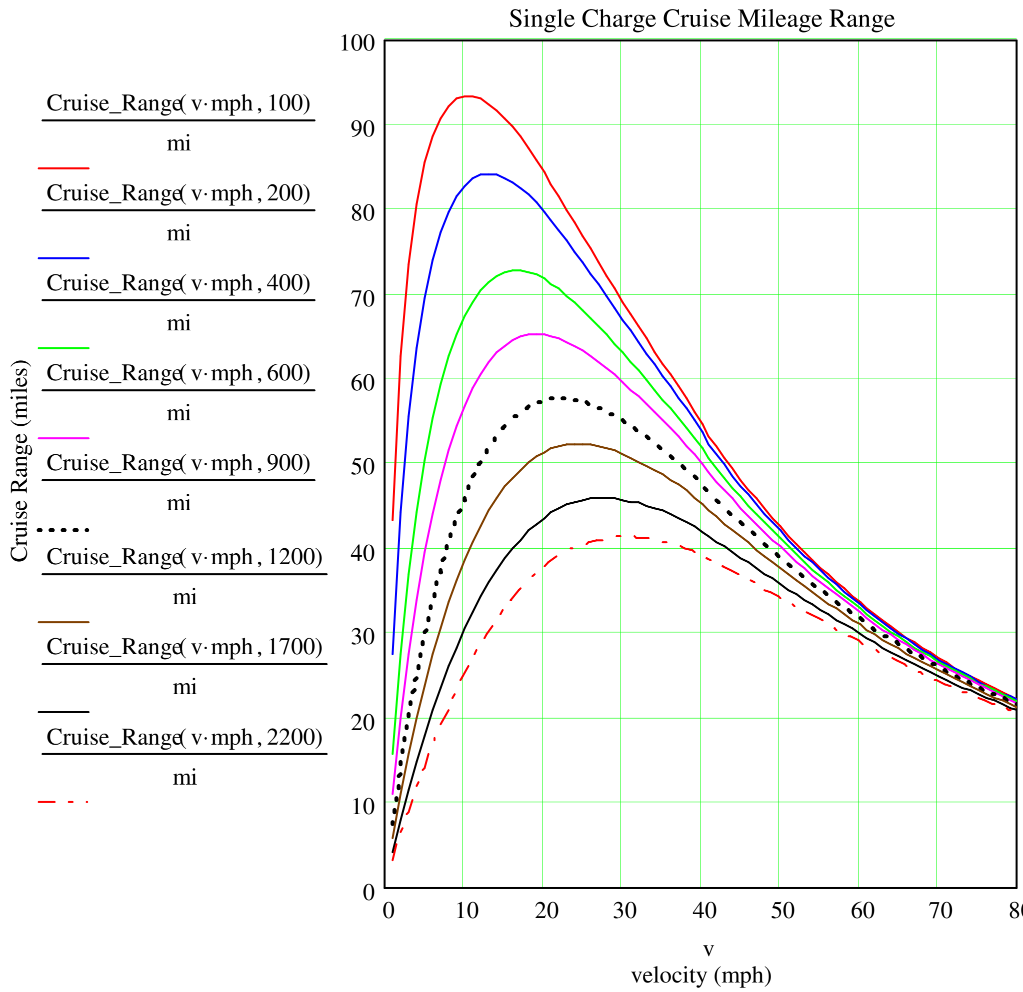
$$\text{Cruise\_Range}(v, P_o) := \frac{\left[8\cdot k\cdot\text{watt}\cdot\text{hr} - \text{NumStarts}(v, P_o)\cdot\left(\frac{\text{Energy}_{\text{accel}}(v)}{\text{InvXGearEff}} - \frac{\text{Regen}\cdot M_{\text{gross}}\cdot v^2}{2}\right)\right]\cdot v}{\text{Power}_{\text{dissLoss}}(v, P_o)}$$

$Heater := 2 \cdot k \cdot watt$

$HeatPumpAC := 700 \cdot watt$

Single Charge Highway Cruise Range Estimate

$Cruise\_Range\,(70 \cdot mph, 900) = 25.915\,mi$



Single Charge "Highway" Cruise Range @70 mph is 26 mph.
Conclusion: I need a bigger or a better battery!

A123 Systems NanoPhosphate m1 Cell Characterization / GM Volt Battery:

$SpecificEnergy_{A123m1} := \frac{3.3 \cdot volt \cdot 2.3 \cdot amp \cdot hr}{70 \cdot gm}$

$SpecificEnergy_{A123m1} = 108.429 \frac{watt \cdot hr}{kg}$

Weight Aux: Case, Blower, Relays, Electronics

$Weight_{Aux} := 25 \cdot lb$ $\quad Weight_{bat} := 350 \cdot lb$

$Energy_{A123Bat} := Weight_{bat} \cdot SpecificEnergy_{A123m1}$

$Energy_{A123Bat} = 17.214\,k \cdot watt \cdot hr$

$SpecificEnergy_{GoalBat} := \frac{150 \cdot k \cdot watt \cdot hr}{kg}$

$Energy_{Goal} := Weight_{bat} \cdot SpecificEnergy_{GoalBat}$

$Energy_{Goal} = 2.381 \times 10^{4}\,k \cdot watt \cdot hr$