PSAT Training

Part 05
Model Description
A - Components

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Nomenclature

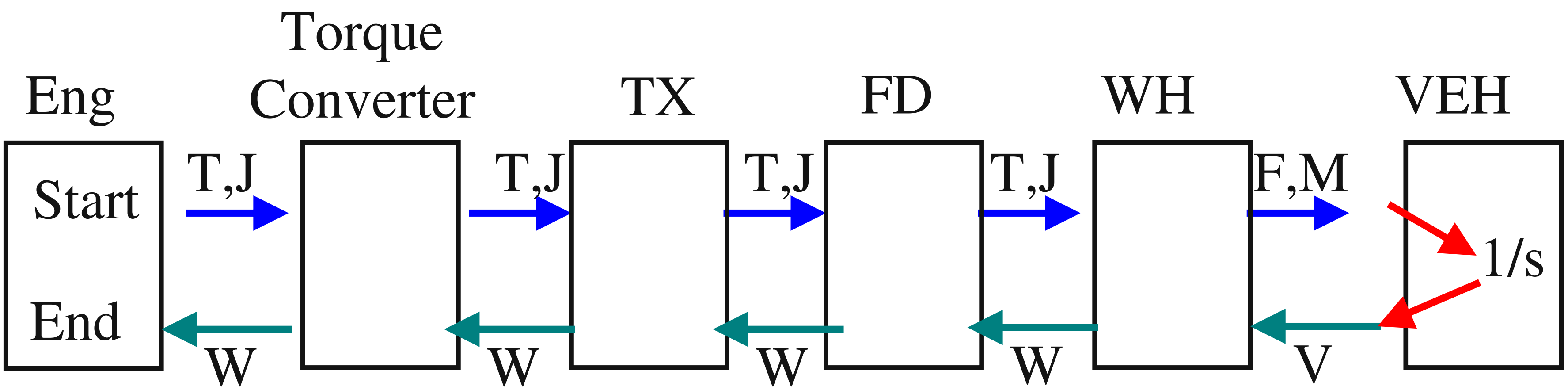
T	Torque (Nm)
W	Rotational Speed (rd/s)
V	Voltage (V)
I	Current (A)
F	Force (N)
V	Linear Speed (m/s)
P	Power (W)
J	Inertia (kg.m2)
M	Mass (kg)
PWM	Pulse Width Modulation (0->1)

Effort

Flow

Model outputs

Vehicle Simulation Loop (i.e., conv.)



Carrying the inertia to the vehicle allows to limit the number of integration (1/s) as well as avoid derivative equations

Engine Model (eng_map_hot, eng_map_hot_and_cold)

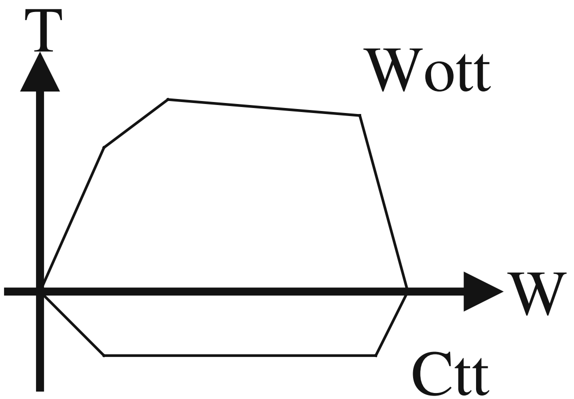
- Hypothesis: From a requested torque from the powertrain controller, the engine model provides the torque (if within the normal operating conditions) and determines the fuel rate and emissions associated with the torque and speed. Temperature correction factors have been incorporated for specific versions.

- Equations

$$Teng = (1 - PWM) * Tctt + PWM * Twott$$

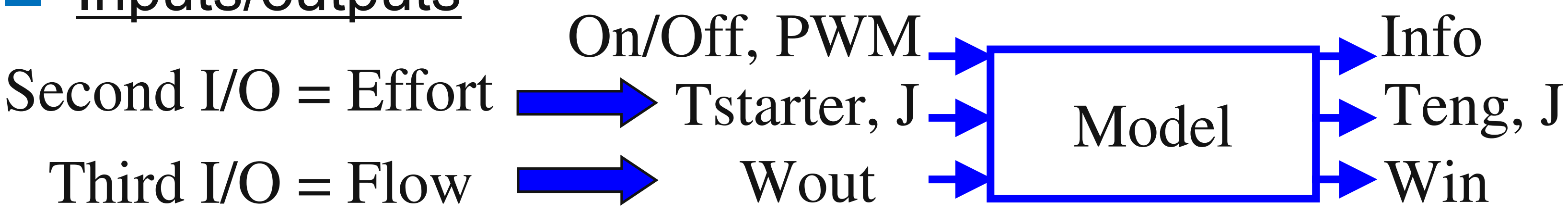
$$Fuelrate\,(g/s) = f(T, W)$$

$$Emission\,(g/s) = f(T, W)$$



Engine Model (Cont'd)

- Inputs/outputs



- Constraints

$$T\max = f(W)$$

- Other Models
  - •Neural Network engine model (1.7L MB CIDI) – eng_neuralnet_ANL

Engine Model (Cont'd)

- Warm-up
  - eng_map_hot : Hot conditions only
  - eng_map_hot_and_cold : Hot and cold maps are used. The model introduces a penalty for on cold conditions based on the engine block temperature.

$$Cold = Ktemp * Hot$$

$$Ktemp = 1 + (1 - \frac{cold\_map}{hot\_map}) * (\frac{Thot - Teng\_block}{Thot - Tcold})$$

  - eng_map_hot_corrected : Hot and cold maps are used. The model is based on the understanding that a portion of the fuel energy is used in warming-up the engine and this is balanced by the heat loss from the engine proportional to the warm-up state of the engine.

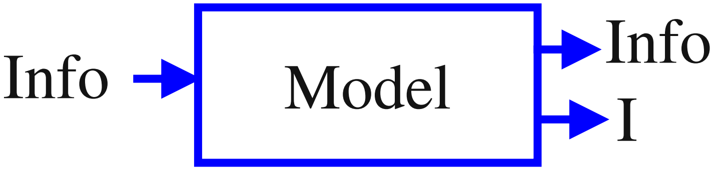
$$Cold = Ktemp * Hot$$

$$Ktemp = \int \left(\frac{fuel\_rate}{\max\_fuel\_rate} * \frac{1}{time\_warmup} - \frac{Ktemp_{n-1}}{time\_cooldown} \right)$$

Exhaust Model (ex_3way_cat_map, ex_electrically_heated_3way_cat_map, ex_oxidation_cat_map)

- Hypothesis: The catalyst temperature is computed using asymmetric first order linear model. Exhaust emissions are calculated using efficiency maps

- Equations



$$Emission\_cat = (1 - Eff) * Emission\_eng$$

$$Eff = f(Temp\_cat, Equivalent\_ratio)$$

$$Temp\_cat = \int \left[\frac{1}{\tau_{HOT}} * PWMeng * (Thot - Temp\_cat) + \frac{1}{\tau_{COLD}} * (1 - PWMeng) * (Thot - Temp\_cat) \right]$$

$$CO2 = \frac{44}{12} * \left[Eng\_fuel\_carbon\_ratio * (fuel\_flow - HC) - \frac{12}{28} * CO \right]$$

Exhaust Model

- Equations (Cont'd)

  If the catalyst is electrically heated (ex_electrically_heated_3way_cat_map):

$$Temp\_cat = \int \left[\begin{array}{l} \frac{1}{\tau_{HOT}} * PWMeng * Heat\_on * (Thot - Temp\_cat) \\ + \frac{1}{\tau_{HOT\_eng\_only}} * PWMeng * (1 - Heat\_on) * (Thot - Temp\_cat) \\ + \frac{1}{\tau_{HOT\_motor\_only}} * (1 - PWMeng) * Heat\_on * (Thot - Temp\_cat) \\ + \frac{1}{\tau_{COLD}} * (1 - PWMeng) * (1 - Heat\_on) * (Thot - Temp\_cat) \end{array} \right]$$

- Other Models

  •Catalyst temperature is calculated using a lumped-capacitance approach – ex_oxidation_cat_equation_curve_fit_ORNL

Fuel Cell Model (fc_H2_map_hot_and_cold & fc_reformer_map_hot_and_cold)

- Hypothesis: The model (based on power vs. efficiency curves) requires that the user provides the relationship between power out of the fuel cell system and the fuel use and emissions out of the system. Temperature correction factors have been incorporated

- Equations

$$Pout = \int \frac{Pavail - Pout_{n-1}}{Time\_response}$$

$$Pavail = \min\left[Pdmd, (P\max\_hot - P\max\_cold) * Ktemp + P\max\_cold\right]$$

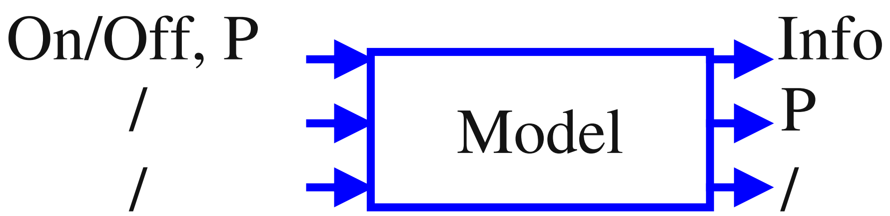
$$H2\_rate = (H2\_hot - H2\_cold) * Ktemp + H2\_cold$$

$$Ploss\_accessories = f(Pout)$$

Ktemp is handled similarly as eng_map_hot_corrected

Fuel Cell Model (Cont'd)

- <u>Inputs/outputs</u>



- <u>Constraints</u>

Pmax for Hot and Cold conditions

- <u>Other Models</u>
  - GCTool-Eng, equations based physic model for transient modeling – proprietary

Electric Motor Model (mc_map_Pelec_funTW_volt_in)

- Hypothesis: The motor/controller provides the demanded torque from the powertrain controller. The effect of losses and rotor inertia are taken into account on the electrical side when calculating the current corresponding to the produced torque. The temperature is taken into account by limiting the time allowed above continuous torque.

- Equations

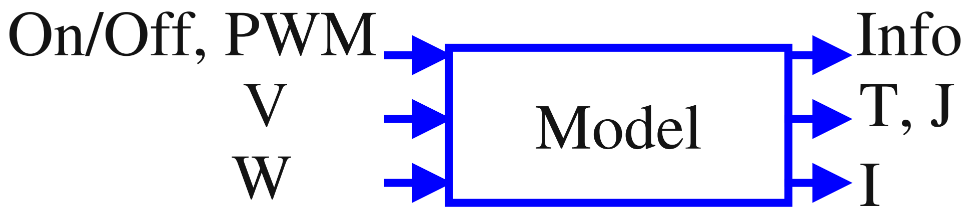
$$Tout = PWM * T\max$$

$$I = \frac{Pmeca - Ploss}{V}$$

$$Ploss = f(W, T)$$

Electric Motor Model (Cont'd)

- Inputs/outputs



- Constraints

$$T\max = \min\left[\left(1 - Ktemp\right) * T\max\_peak + Ktemp * T\max\_cont, T\max\_allowed\_by\_\mathrm{Im}\,ax\_at\_actual\_voltage\right]$$

$$Ktemp = \int \frac{1}{Time\_\max\_at\_overtorque} * \left(1 - \frac{Tactual}{T\max\_cont}\right)$$

- Other Models
  - •Map based model with power as input for fuel cell applications (mc_map_Pelec_funTW_pwr_in)
  - •Physics based electric motor model for transient modeling – under development

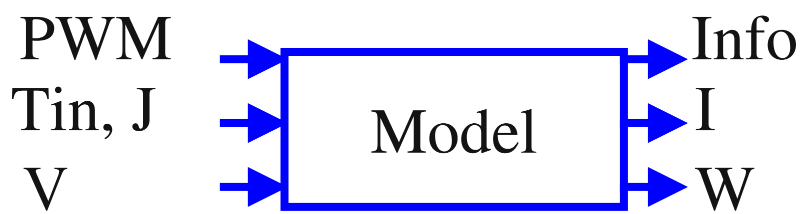
Generator Model (gc_generator_map_trq_in)

- Hypothesis: The generator/controller model includes the effects of losses, inertia, the generator's torque speed-dependent torque capability, and the controller's current limit. Power losses are handled as a 2-D lookup table indexed by rotor speed and input torque

- Equations

$$I = \frac{P}{V}$$

$$W = \int \frac{T - Tloss}{\sum J}$$



- Constraints

$$T\max = f(W)$$

For continuous and peak torque in propelling and regenerative conditions (4 limits)

Battery Model (ess_generic_map only)

- Hypothesis: Battery pack is modeled as a charge reservoir and an equivalent circuit whose parameters are a function of the remaining charge in the reservoir. The equivalent circuit accounts for the circuit parameters of the battery pack as if it were a perfect open circuit voltage source in series with an internal resistance.

- Equations

$$V = Num\_cell * (Voc - R\,\mathrm{int})$$

$$Voc = f(SOC, Temp)$$

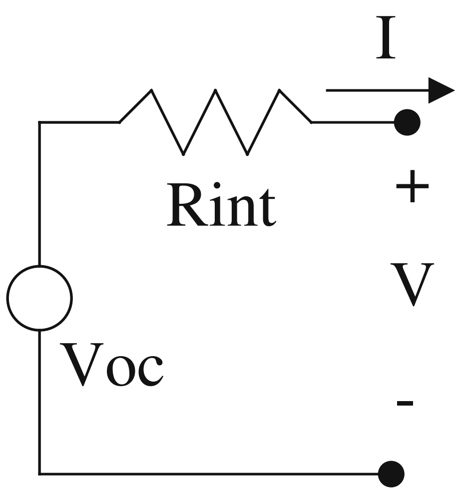
$$R\,\mathrm{int} = f(SOC, Temp)$$

$$Temp = \int \frac{Qess\_gen - Qess\_case}{Mass * Cp}$$

$$SOCabs = Ah\_\max - \int \frac{I * Coulomb\_eff}{3600}$$

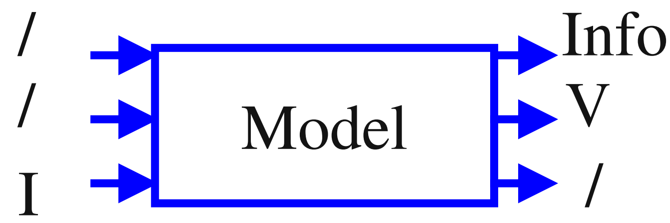
$$Ah\_\max = f(Temp)$$

$$SOCusb = \frac{SOCabs - SOC\min}{SOC\max - SOC\min}$$



Battery Model (Cont'd)

- Inputs/outputs



- Constraints

$$P\max\_dis = \min\left[\frac{Voc^2}{4*R\text{int}}, \frac{(Voc - V\min)*V\min}{R\text{int}}\right]$$

$$P\max\_ch = \frac{(V\max - Voc)*V\max}{R\text{int}}$$

- Other Models
  - •Lumped parameter model of ANL Li-ion battery – ess_liion_equation_curve_fit_ANL
  - •RC model, developed by Ford, based on PNGV requirements – integrated(proprietary version)
  - •Physics based battery model for transient modeling from PennState

Torque Converter Model (cpl_torque_converter_map)

- Hypothesis: The torque converter is modeled as two separate rigid bodies when the coupling is unlocked and as one when the coupling is locked. The downstream portion of the torque converter unit is treated as being rigidly connected to the drivetrain. Therefore, there is only one degree of dynamic freedom and thus the model has only one integrator.

- Equations

$$During\_Steady\_state$$

$$Tturb = Tratio * Wimp^2 * sign(Wimp) * Kclutch$$

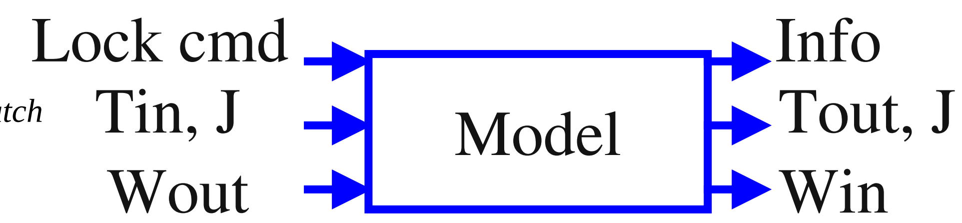
$$Tratio = f\left(\frac{Wturb}{Wimp}\right)$$

$$Wimp = \int \frac{Timp}{J}$$

$$Timp = Tin - Wimp^2 * sign(Wimp) * Kclutch$$

$$Kclutch\ (Nm/rd/s^2) = f(Wratio)$$

$$Wratio = \frac{Wturb}{Wimp}$$



Equations for transient and idle conditions are different

Clutch Model (cpl_clutch_map)

- Hypothesis: The clutch has three states: disengaged, slipping, and fully engaged. When disengaged, the clutch requests and transmits no torque. When engaged, the entire torque is transmitted. When slipping, the transmitted torque depends on the input torque and the speed difference.

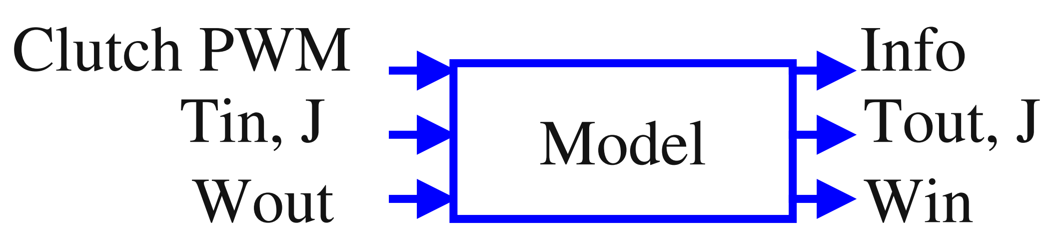
- Equations (for transients only)

$$Tout = Tslip\_max * PWM * sign(Win - Wout) \quad \text{when clutching}$$

$$or.... = \min(Tslip\_max, Tin) * PWM * sign(Win - Wout) \quad \text{when declutching}$$

$$Win = \int \frac{Tin - Tout}{Jin}$$

$$Jout = Jin * PWM + Jcpl$$



Gearbox Model

- Hypothesis: The gearbox model allows the torque multiplication and speed division based on the gear number or ratio (for CVT) command from the powertrain controller. As for all the other models, the losses are taken into account using torque losses to easily deal with regenerative conditions.

- Equations

$$Tout = Ratio * (Tin - Tloss)$$

$$Tloss = f(Tin, Win, Ratio)$$

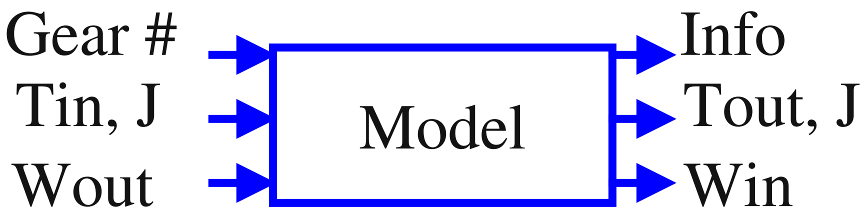
$$Win = Ratio * Wout$$

$$Jout = (Jin + Jtx_{shaft\ 1}) * Ratio^2 + Jtx_{shaft\ 2}$$

$$For\_neutral\_conditions$$

$$Win = \int \frac{Tin - Tloss}{Jin}$$

$$Jout = Jtx_{shaft\ 2}$$



Final Drive and Torque Coupler Models

- Hypothesis: Physically, a torque coupler is a three-sprocket belt or chain drive whereby two torque sources combine their torques to provide to a drivetrain component such as the transmission or final drive. Both final drive and torque coupler models are similar in a sense that their functionality is to apply a fixed reduction ratio to both torque and speed by taking into account the losses.

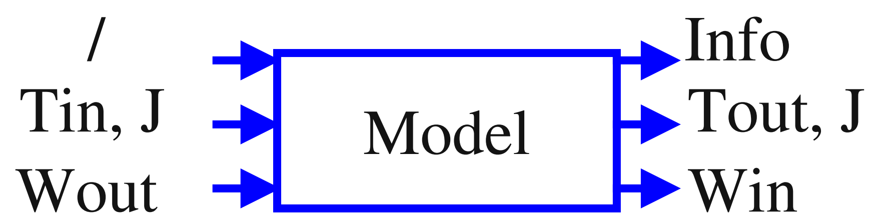
- Equations

$$Tout = Ratio * (Tin - Tloss)$$

$$Tloss = f(Tin, Win)$$

$$Win = Ratio * Tout$$

$$Jout = Jin * Ratio^2 + Jcompo$$



Transfer Case Model

- Hypothesis: The transfer case model contains blocks that calculate inertia, torque loss, and front and rear torque split for four-wheel drive vehicles. The transfer case model also implements the gear ratio effect on torque, inertia, and speed.

- Equations

$$Tout = Ratio * (Tin - Tloss)$$

$$Tout\_front = Tout * Kfront$$

$$Tout\_rear = Tout * Krear$$

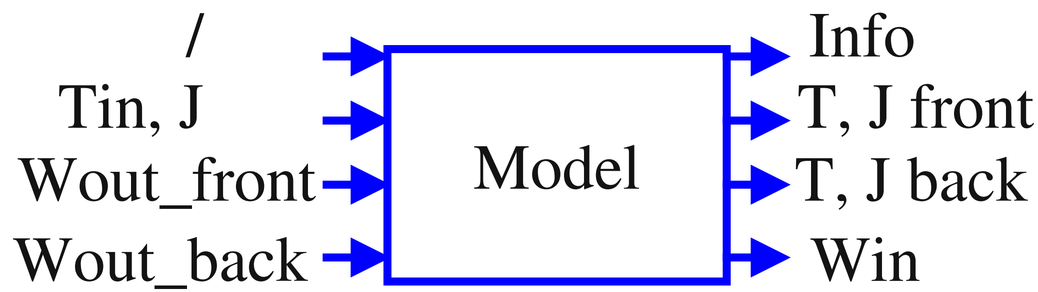
$$Krear = f(Wratio\_rear)$$

$$Wratio\_rear = 0.5 + \frac{Wrear - Wfront}{0.5 * (Wrear + Wfront)}$$

$$Kfront = 1 - Krear$$

$$Win = Ratio * Wout$$

$$Wout = \frac{Wout\_front + Wout\_rear}{2}$$



Mechanical Accessories Model

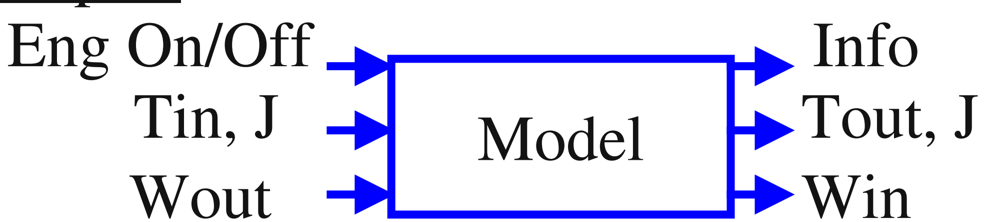
- <u>Hypothesis:</u> The model takes into account the mechanical losses associated with the powertrain. The torque losses are subtracted from the engine torque.

- <u>Equations</u>

$$Win = Wout$$

$$Tout = Tin - \frac{Pacc * Eng\_ON * (Weng > Widle)}{Win}$$

- <u>Inputs/outputs</u>



- <u>Other models:</u>
  - Use detailed model for each accessory – integrated

Electrical Accessories Model

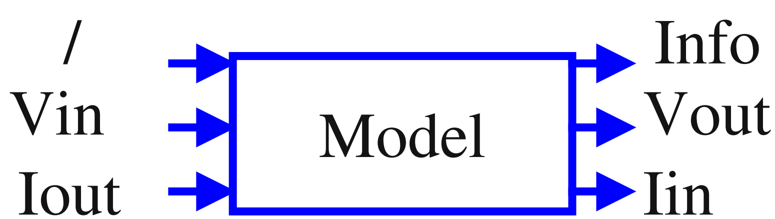
- Hypothesis: The model takes into account the electrical losses associated with the powertrain. The current losses are taken from the energy storage.

- Equations

$$Vout = Vin$$

$$Iout = Iin - \frac{Pacc}{Vin}$$

- Inputs/outputs



- Other models:
  - •Use power instead of voltage for fuel cell – integrated
  - •Use detailed model for each accessory – integrated

Wheel Model

- Hypothesis: The wheel models transform rotational energy to linear (W to V and T to F). The losses due to mechanical brakes and the tire friction are taken into account in this model.

- Equations

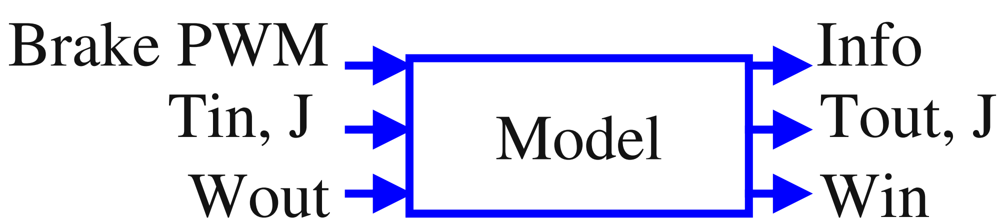
$$F = \frac{T}{Radius}$$

$$T - Tin - Tbrake * PWM$$

$$V = \frac{W}{R}$$

$$Mdynamic = \frac{\sum J + Jwh}{Radius^2}$$

- Inputs/outputs



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Vehicle Model

- Hypothesis: The classic equation for longitudinal vehicle dynamics is implemented in the model: ∆F=ma, where among the forces are aerodynamic drag, and the force of gravity that must be overcome to climb a grade. The force provided by the powertrain as well as the vehicle losses are used to calculate the actual vehicle speed.

- Equations

$$V = \int \frac{Fin - Floss}{Mstatic + Mdynamic}$$

$$Floss = 0.5 * \rho * Cd * FA * V^2 + mg \sin(\alpha)$$

- Inputs/outputs