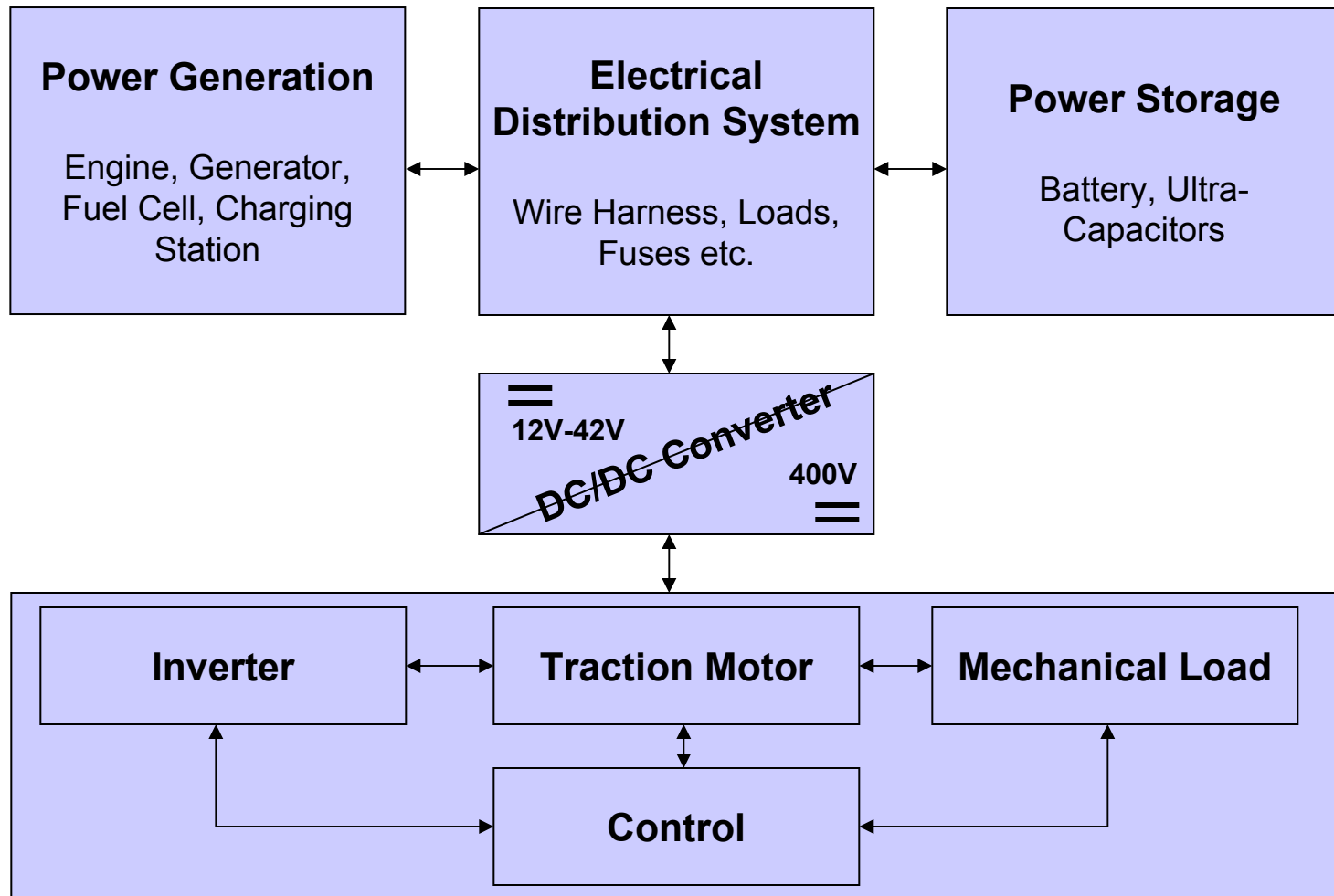


# EV/EHV Drive Train Design

Dr.-Ing. Uwe Knorr  
Product Marketing Director  
Ansoft Corporation  
Pittsburgh, PA

# System Structure



# Design Issues

- ▶ Electrical system design
- ▶ Power management
- ▶ Power electronics
  - ▶ DC/DC Converter
  - ▶ Inverter
- ▶ Controls
  - ▶ Fuel cell controller
  - ▶ Battery charger
  - ▶ Motion controller
- ▶ Machine design
- ▶ ...

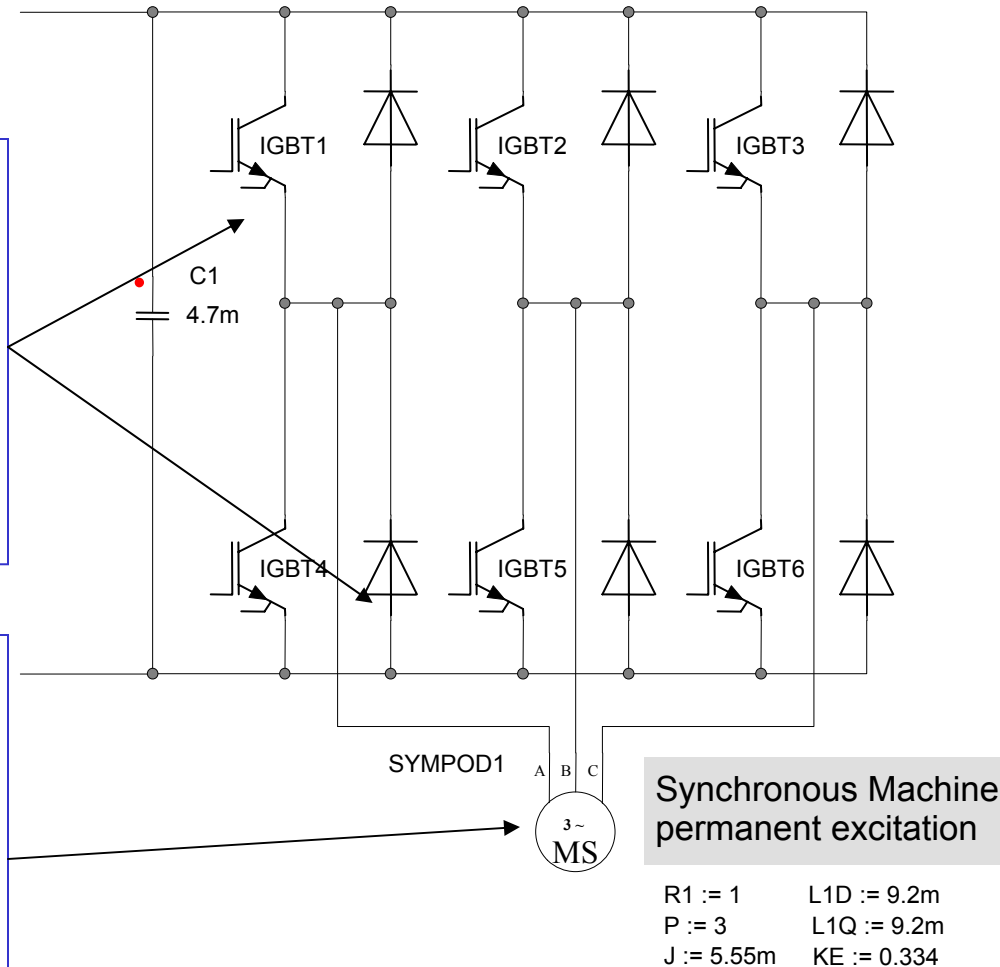
# Traction System Inverter & Machine

Static electrical component models are sufficient for system level analysis

- Speed
- Electrical behavior

Permanent Magnet Synchronous Machine from Basic Library

- Sufficient Accuracy for Controller design
- Fast



# Load Torque Definition

The image shows the configuration of a load torque in ANSYS. The 'Properties - M\_LOAD' dialog is set to 'Data Pairs' with a table of time intervals and torque values. The 'Properties - SYMPOD1' dialog shows the 'Load Torque [Nm]' parameter defined as  $SYMPOD1.N * 0.00065 + M\_LOAD.VAL$ . A graph titled 'M\_LOAD Characteristic' shows a square wave pulse. A blue box highlights the equation  $LOAD := SYMPOD1.N * 0.00065 + M\_LOAD.VAL$ .

No.	x-axis : t[s]	y-axis :
1	0	0
2	0.05	5
3	0.08	0
4	0.45	5
5	0.48	0
6	0.6	0

**LOAD := SYMPOD1.N\*0.00065 + M\_LOAD.VAL**

Speed Proportional Friction + External load Torque

# d-q-Phase Transformation

Vector control based on d-q transformation

- d-q transformation using built in math engine
- On-time computation for phase A and B for inverter control based on Controller output data

Control Signal Generation / Phase Transformation

ICA:

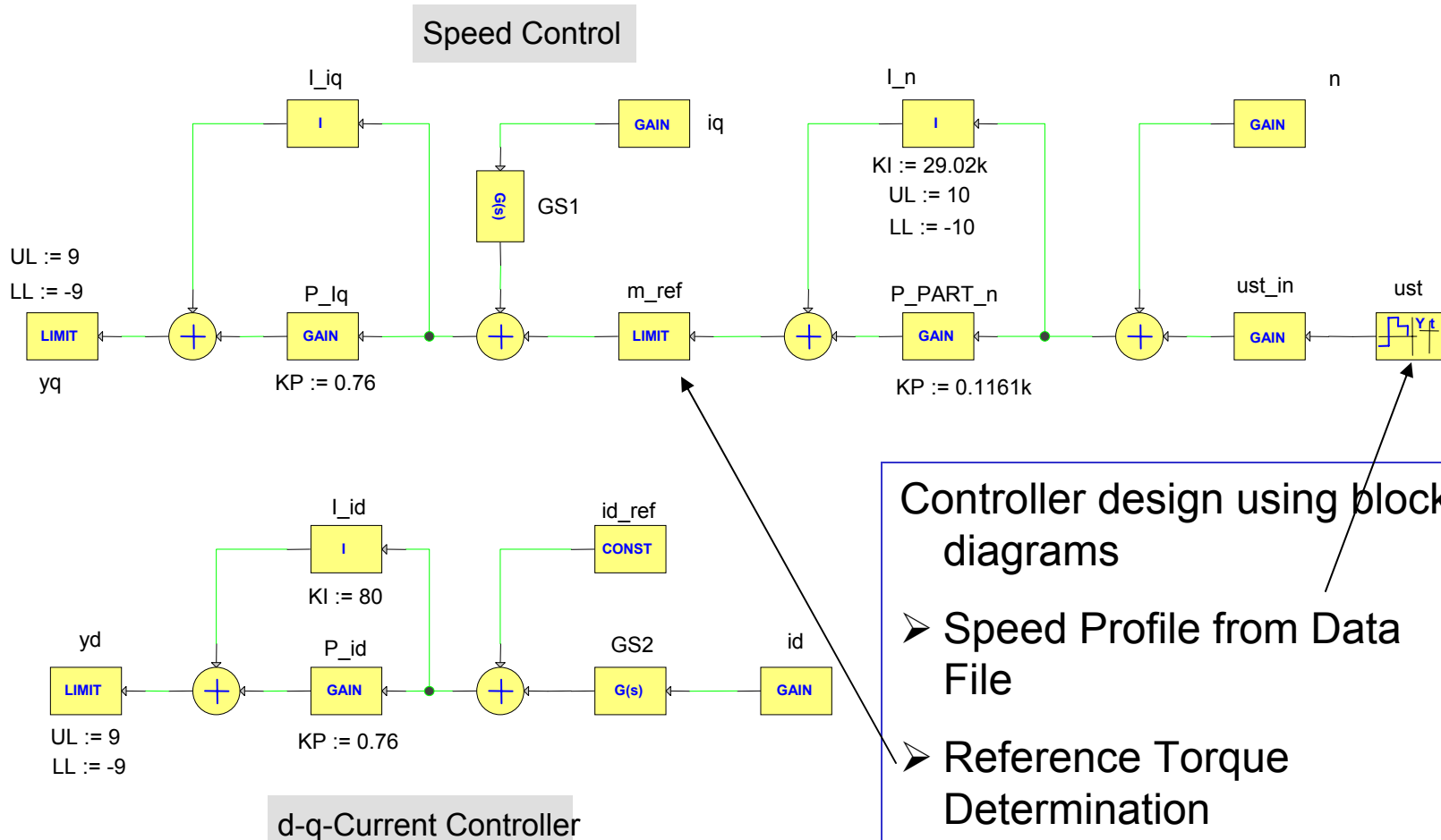
```
TP := 0.0002
ustmax := 10.
t0a := 0
t0b := 0
t0c := 0
```

EQU

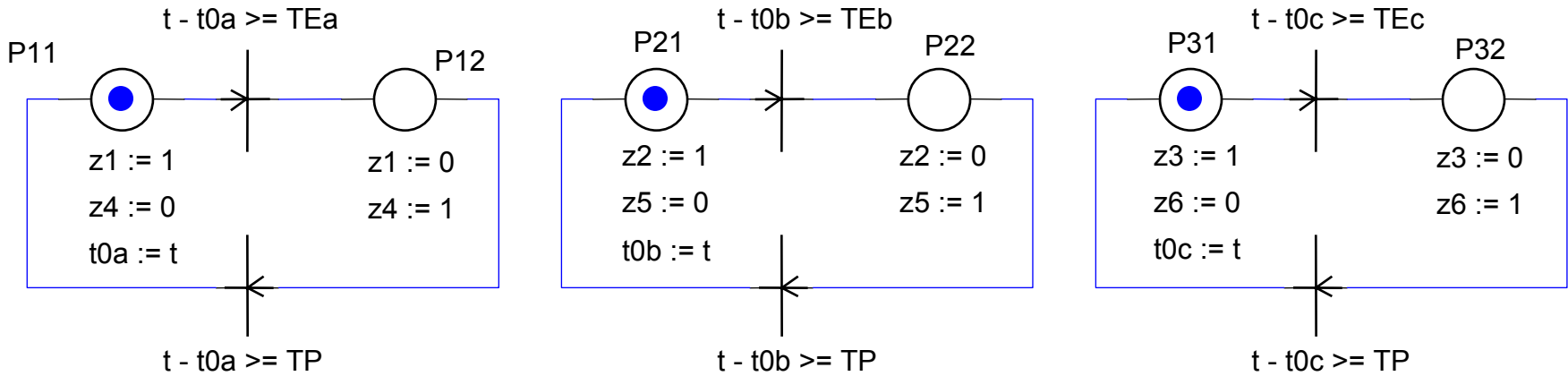
```
yalph := cos(theta_el) * yd.VAL - sin(theta_el) * yq.VAL
ybeta := sin(theta_el) * yd.VAL + cos(theta_el) * yq.VAL
ya := yalph
yb := -0.5 * yalph + ybeta * sqrt(3.) / 2.
yc := -ya - yb
TEa := (ya / ustmax + 1) * TP2
TEb := (yb / ustmax + 1) * TP2
theta_m := theta_el / 3.
```

```
theta_el := SYMPOD1.PHIDEG * PI / 180.
TEc := (yc / ustmax + 1) * TP / 2.
i1alph := SYMPOD1.I1A
i1beta := (SYMPOD1.I1A + 2 * SYMPOD1.I1B) / sqrt(3.)
i1d := i1alph * cos(theta_el) + i1beta * sin(theta_el)
i1q := i1beta * cos(theta_el) - i1alph * sin(theta_el)
```

# Speed and Torque Control



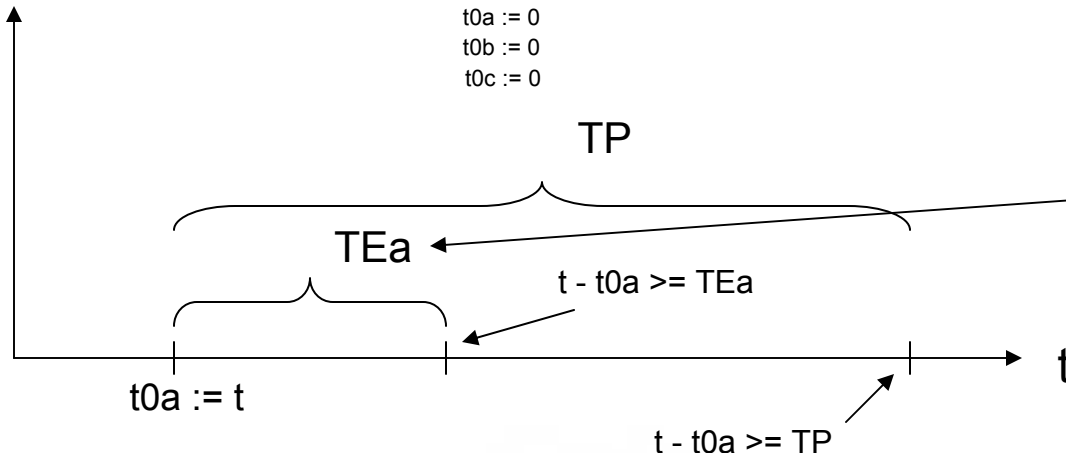
# State Machine Based PWM



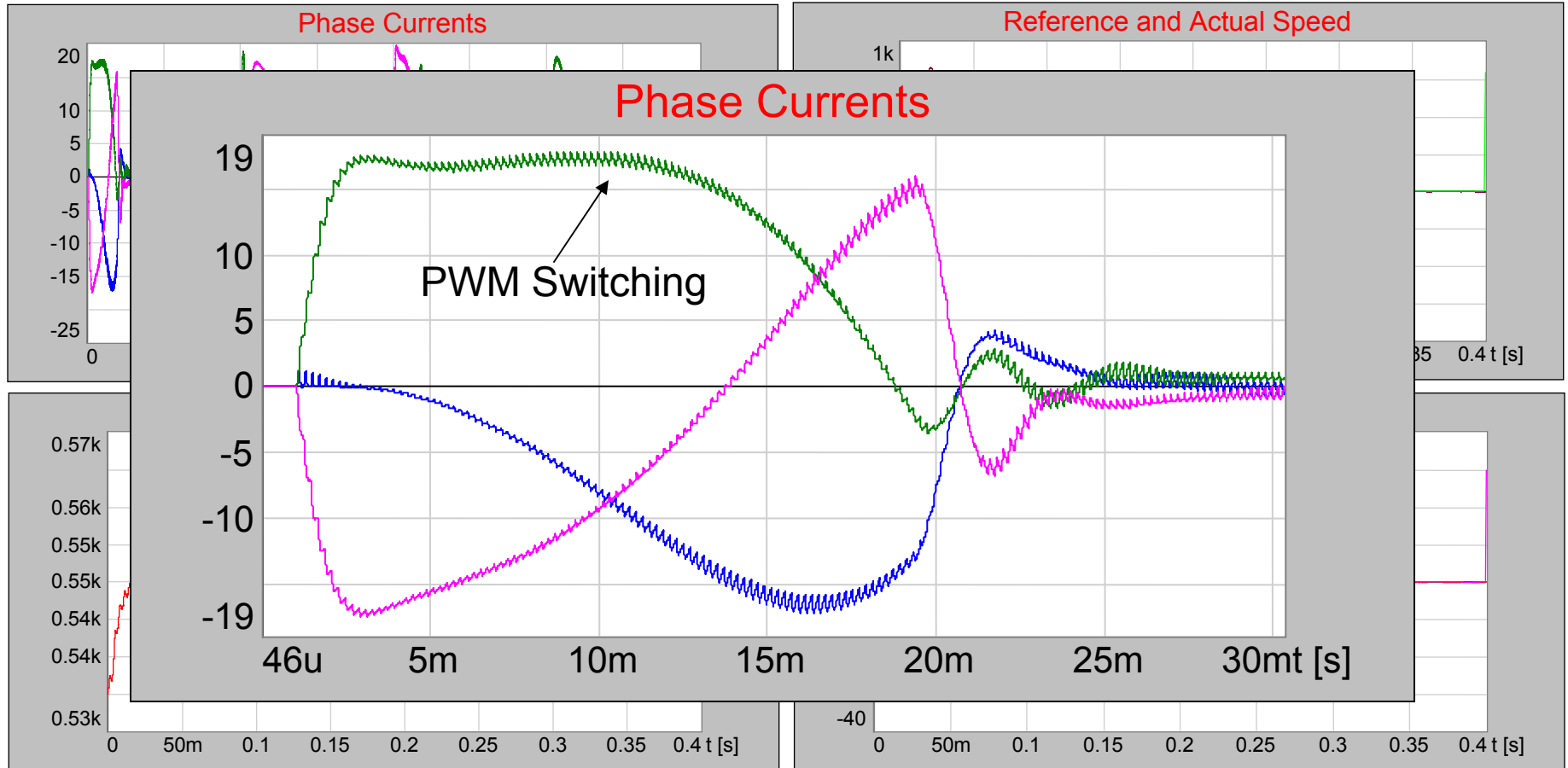
**ICA:**  
 $TP := 0.0002$   
 $ustmax := 10.$   
 $t0a := 0$   
 $t0b := 0$   
 $t0c := 0$

**EQU**

$yalph := \cos(\theta_{el}) * yd.VAL - \sin(\theta_{el}) * yq.VAL$   
 $ybeta := \sin(\theta_{el}) * yd.VAL + \cos(\theta_{el}) * yq.VAL$   
 $ya := yalph$   
 $yb := -0.5 * yalph + ybeta * \sqrt{3} / 2.$   
 $yc := -ya - yb$   
 $TEa := (ya / ustmax + 1) * TP2$   
 $TEb := (yb / ustmax + 1) * TP2$   
 $TEc := (yc / ustmax + 1) * TP / 2.$

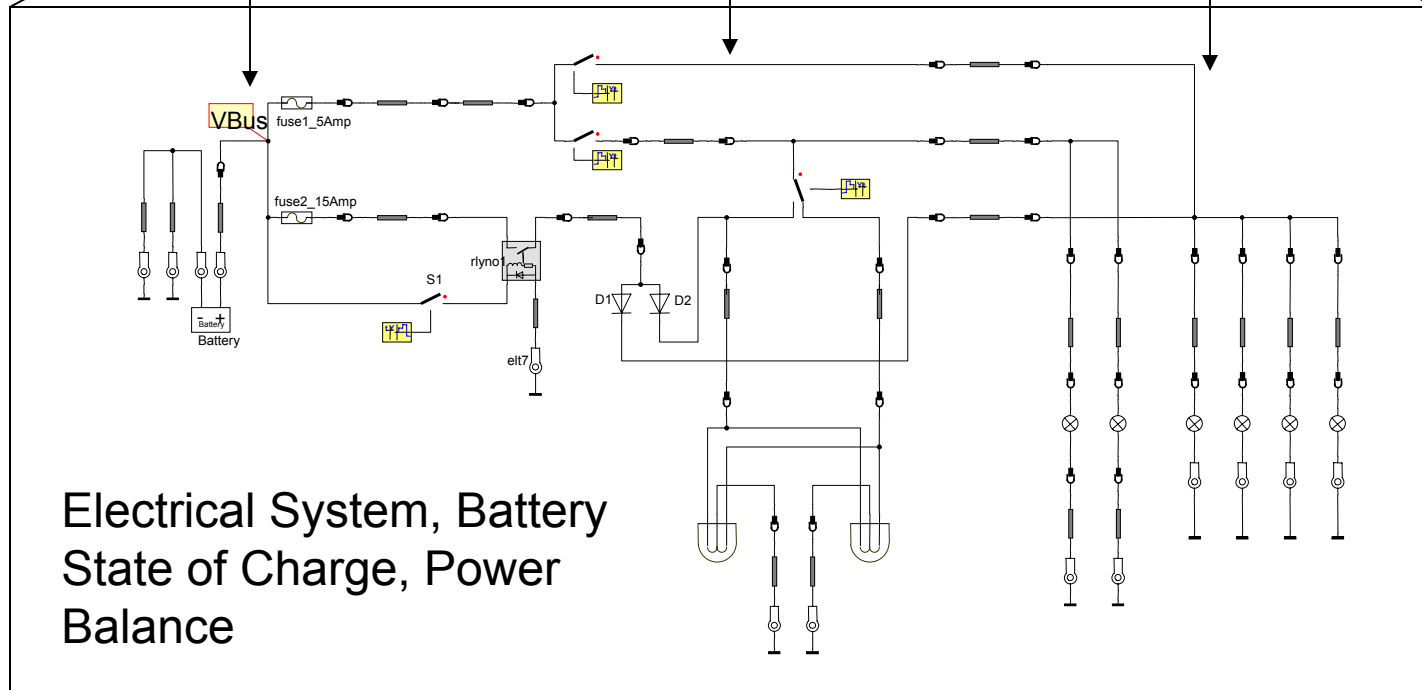
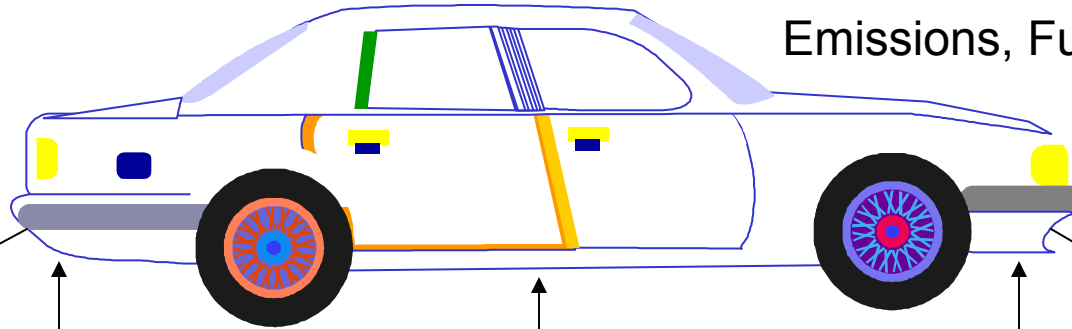


# Simulation Results

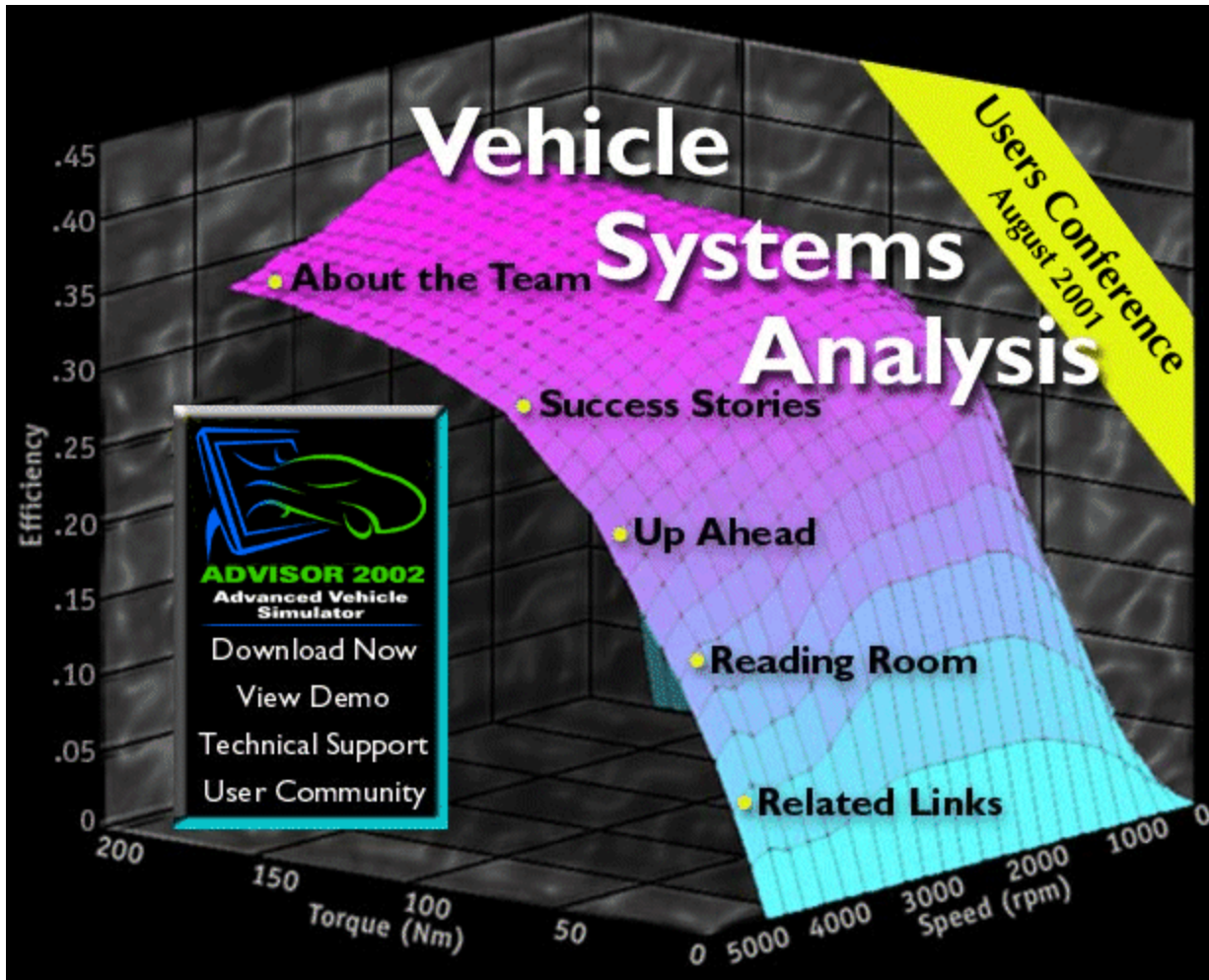


# System Level Analysis

Overall Vehicle Performance,  
Emissions, Fuel Economy ...



# Advisor 2002



- General Vehicle Simulation Program
- Emissions, Fuel Economy
- Simulink based Application
- Graphical User Interface
- Lots of predefined Vehicle Components
- Drive Cycle Data Base

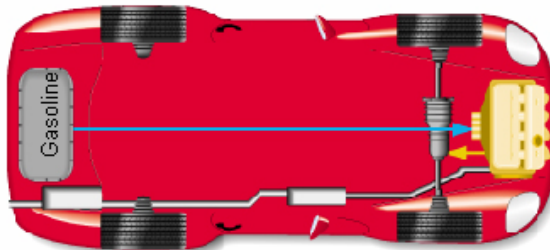
# Vehicle Setup

- conventional
- series
- parallel
- parallel\_sa
- fuel\_cell
- ev
- prius\_jpn
- insight
- custom

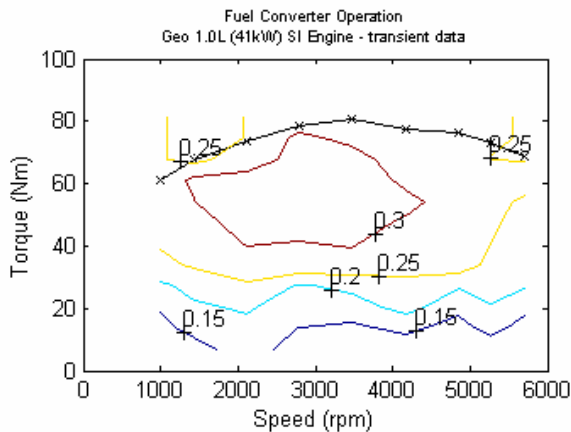
Vehicle Input--ADVISOR 2002

Units Help

Vehicle Input



Component: fuel\_converter  
Plot Selection: fc\_efficiency



Load File: CONVENTIONAL\_defaults\_in

Drivetrain Config: conventional

Component	version	type	Value
Vehicle	?	VEH_SMCAR	592
Fuel Converter	ic	FC_SI41_emis	41, 0.34, 131
Exhaust Aftertreat	?	EX_SI	11
Energy Storage	?	ess options	
Energy Storage 2	?	ess 2 options	
Motor	?	MC_AC124_EV1_draft	
Motor 2	?	motor 2 options	
Starter	?	starter options	
Generator	?	gc options	
Transmission	man	TX_5SPD	1, 114
Transmission 2	?	trans 2 options	
Clutch/Torq. Conv.	?	clutch/torque converter c	
Torque Coupling	?	TC_DUMMY	
Wheel/Axle	Crr	WH_SMCAR	0
Accessory	Const	ACC_CONV	
Acc Electrical	?	acc elec options	
Powertrain Control	conv	PTC_CONV	

Scale Components: max pwr (kW), peak eff, mass (kg)

Cargo: 136

Calculated. Mass: 984

View Block Diagram: BD\_CONV

Variable: fuel\_converter, Edit Var., Variables: fc\_acc\_mass, 32.8056

Buttons: Save, Help, Back, Continue

# Drive Cycle and Electrical System

- CYC\_1015
- CYC\_1015\_6PRIUS
- CYC\_5PEAK
- CYC\_ARB02
- CYC\_ARTERIAL
- CYC\_BUSRTE
- CYC\_CBD14
- CYC\_CBDTRUCK
- CYC\_CLEVELAND
- CYC\_COAST
- CYC\_COMMUTER
- CYC\_CONSTANT
- CYC\_CONSTANT\_45
- CYC\_CONSTANT\_60
- CYC\_CSHVR
- CYC\_ECE
- CYC\_ECE\_EUDC
- CYC\_ECE\_EUDC\_LOW
- CYC\_EUDC
- CYC\_FTP
- CYC\_HL07
- CYC\_HWFET
- CYC\_HWFET\_MTN
- CYC\_IM240
- CYC\_INDIA\_HWY\_SAMPLE
- CYC\_INDIA\_URBAN\_SAMPLE
- CYC\_INTERACTIVE
- CYC\_L60MPH
- CYC\_LA92
- CYC\_MANHATTAN
- CYC\_NEDC
- CYC\_NREL2VAIL
- CYC\_NYCC
- CYC\_NYCCOMP
- CYC\_NYCTRUCK
- CYC\_NYGTG
- CYC\_NewYorkBus
- CYC\_NurembergR36
- CYC\_REP05
- CYC\_SC03
- CYC\_SKELETON
- CYC\_STEP
- CYC\_TEST\_10sec
- CYC\_UDDS**
- CYC\_UDDSHDV
- CYC\_UKBUS\_MASS\_VAR1
- CYC\_UNIF01
- CYC\_US06
- CYC\_US06\_HWY
- CYC\_VAIL2NREL
- CYC\_WVUCITY
- CYC\_WVUINTER
- CYC\_WVUSUB
- CYC\_const\_65

**Simulation Parameters--ADVISOR 2002**

File Edit Units Help

CYC\_UDDS

Speed/Elevation vs. Time

Description     Statistics

time:	1369 s
distance:	7.45 miles
max speed:	56.7 mph
avg speed:	19.58 mph
max accel:	4.84 ft/s <sup>2</sup>
max decel:	-4.84 ft/s <sup>2</sup>
avg accel:	1.66 ft/s <sup>2</sup>
avg decel:	-1.9 ft/s <sup>2</sup>
idle time:	259 s
no. of stops:	17
max up grade:	0 %
avg up grade:	0 %
max dn grade:	0 %
avg dn grade:	0 %

Percentage (%)

Speed (mph)

Drive Cycle: **CYC\_UDDS**

Trip Builder

Time Step:  # of cycles:

SOC Correction     Cycle Filter

Constant Road Grade

Interactive Simulation

Multiple Cycles:

Test Procedure: **TEST\_CITY\_HWY**

Acceleration Test   

Gradeability Test   

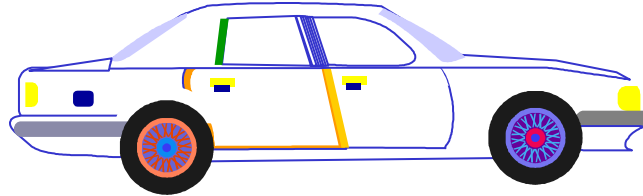
Parametric Study    # of variables:

Variable	Low	High	# Pts
veh_mass	984	1384	3
veh_CD	0.335	0.535	3
veh_FA	2	4	3

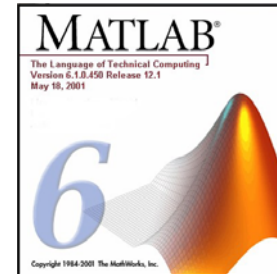
Elec. Aux. Loads

Electrical Auxiliary Load Definition

# Co-Simulation

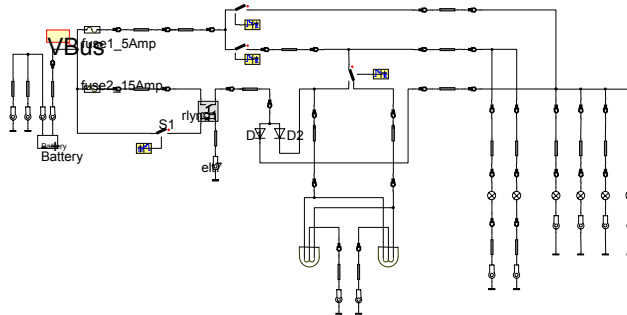


- Constant Time Step (usually 1s)
- Power Balance, Fuel Economy etc.



Engine Speed, Control Signals for Electrical Loads

SOC, Load Power, Battery Power, Generator Power

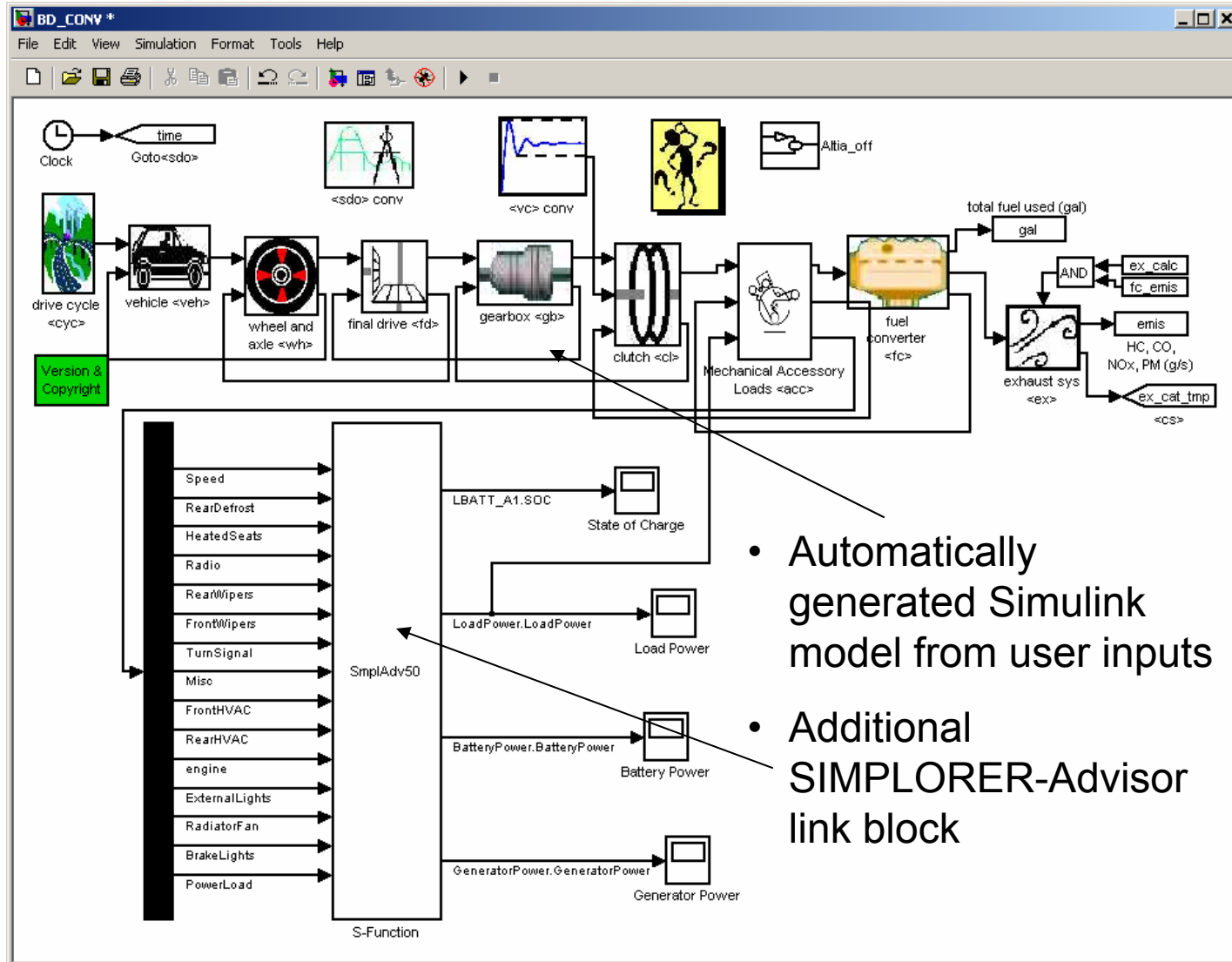


**simulink** **plorer**<sup>®</sup>  
The Multi Domain Simulator

- Variable Time Step (10us to 100ms)
- Complete Electrical Analysis

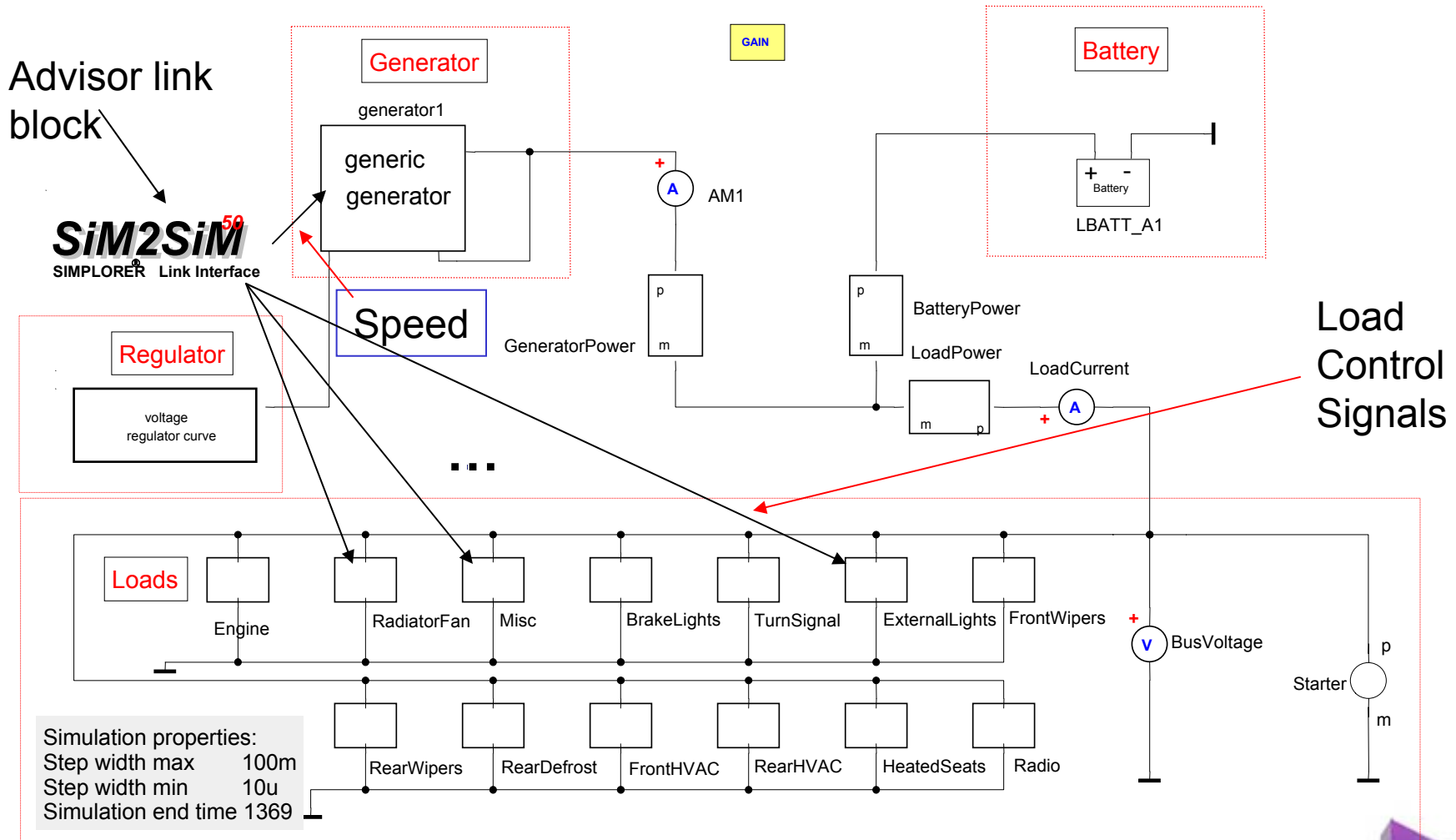
Both Simulators run simultaneously

# Vehicle System Setup

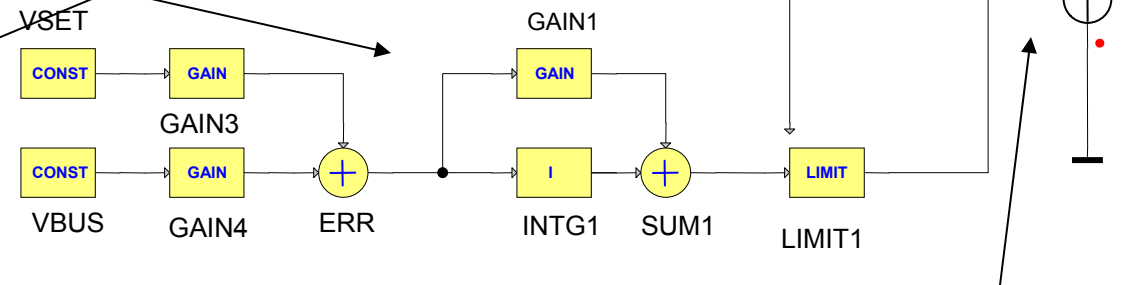
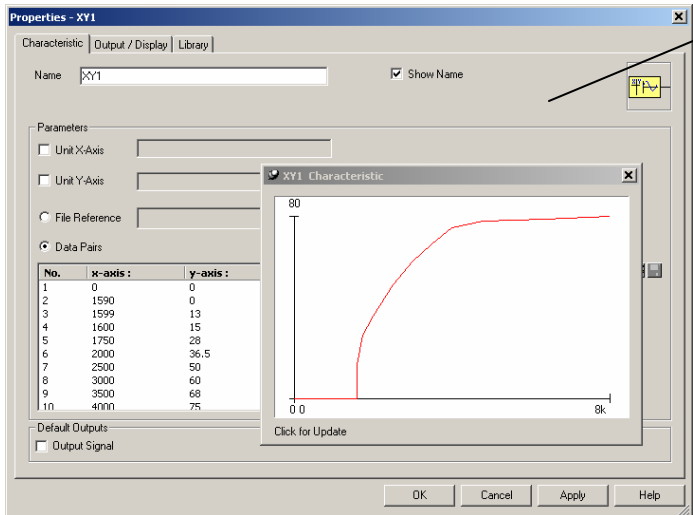
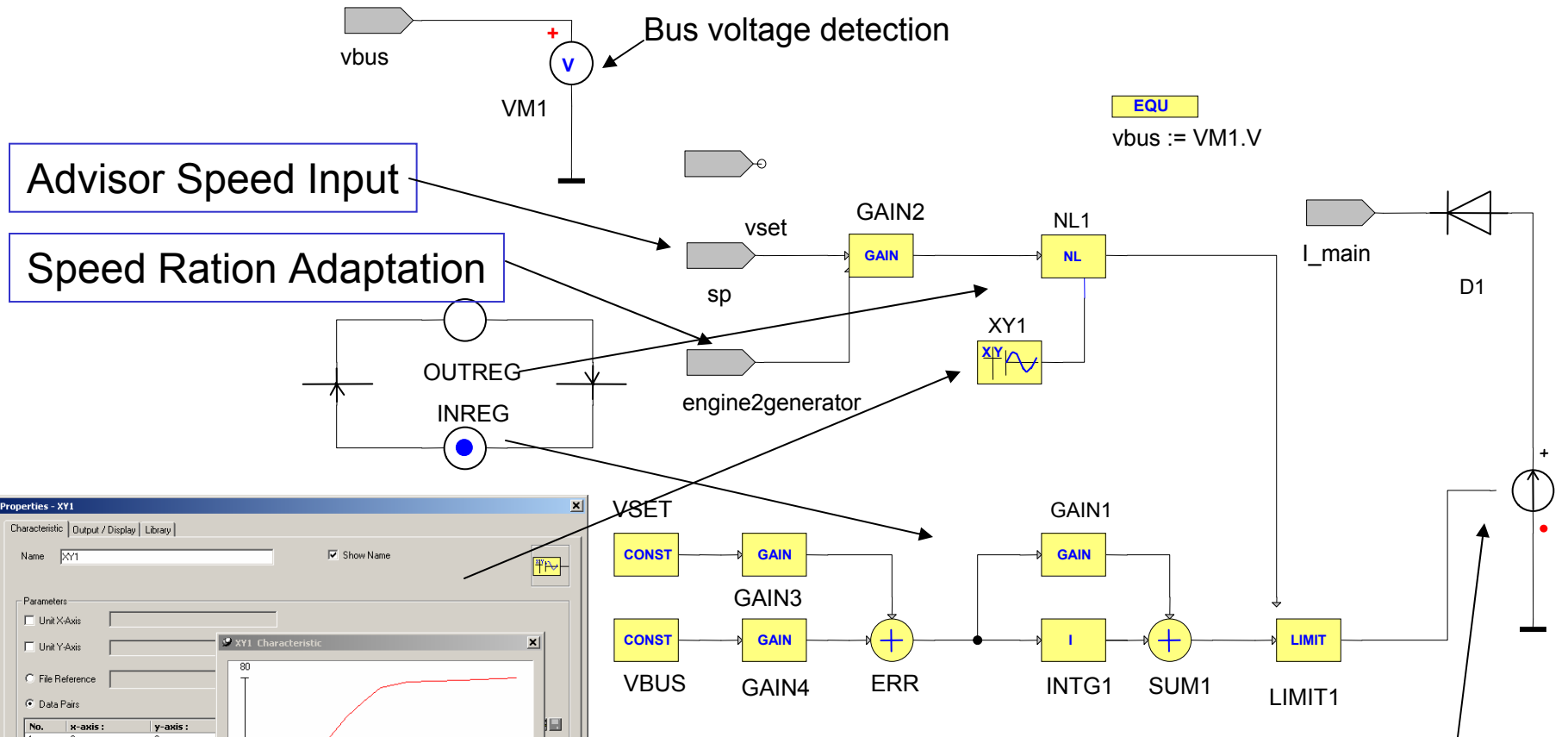


- Automatically generated Simulink model from user inputs
- Additional SIMPLORER-Advisor link block

# Electrical System Setup



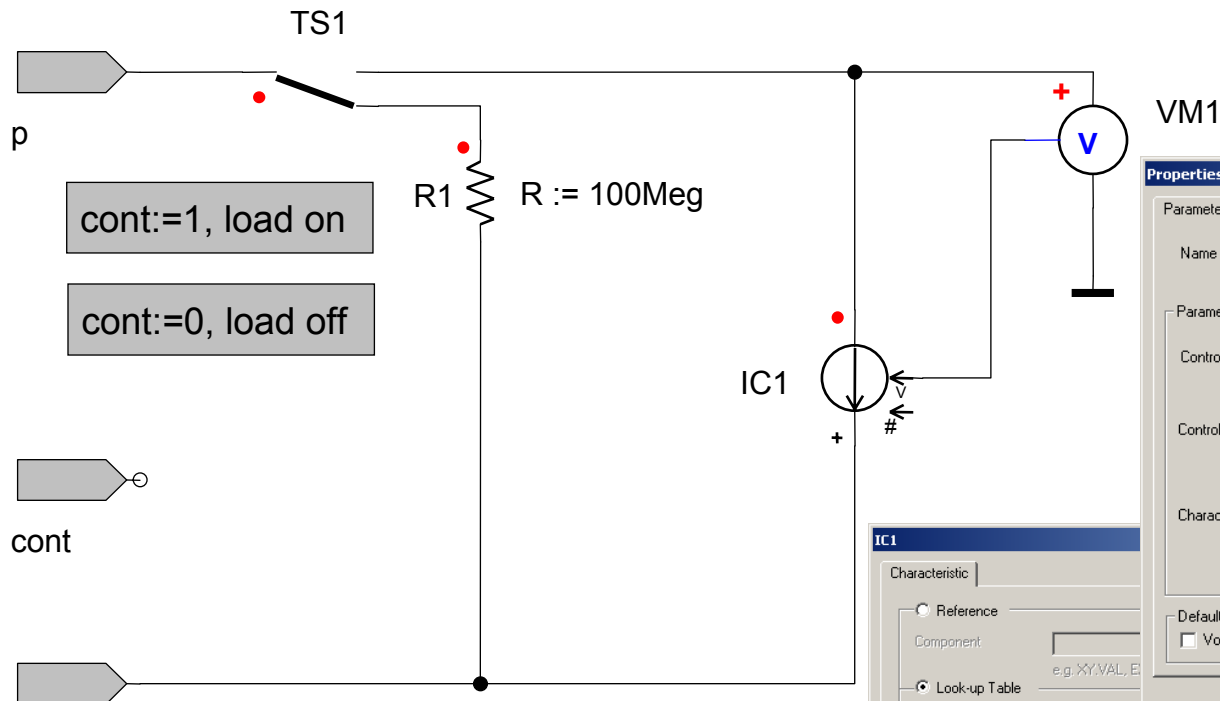
# Generator Model



Transfer of control quantity to the electrical network

Max. current vs. speed characteristic of the generator

# Load Models



**Properties - IC1**

Parameters | Output / Display | Library

Name: IC1  Show Name

Controlled: Nonlinear Voltage Controlled

Control Component: VM1.V Factor: 1

Use Pin  Use Pin

Characteristic:

Use Pin

Default Outputs:  Voltage [V]  Current [A]

**IC1**

Characteristic

Reference

Component:

Look-up Table

File Reference

Variable Name:

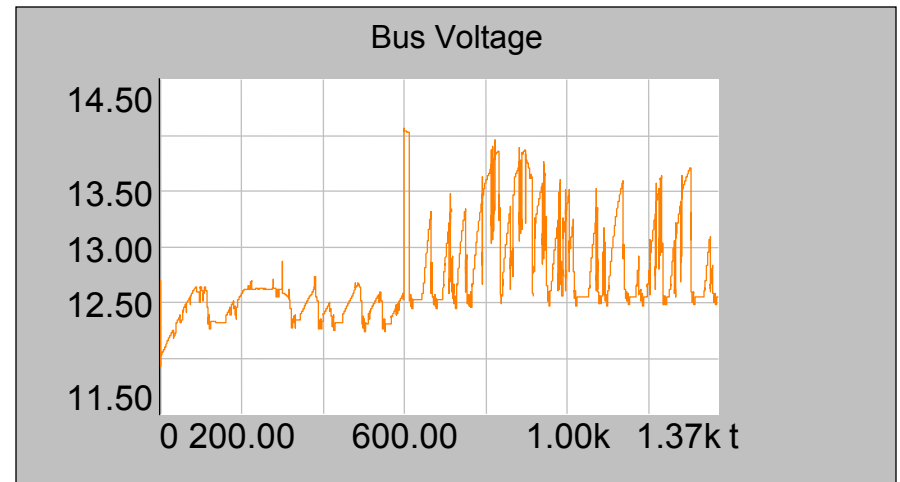
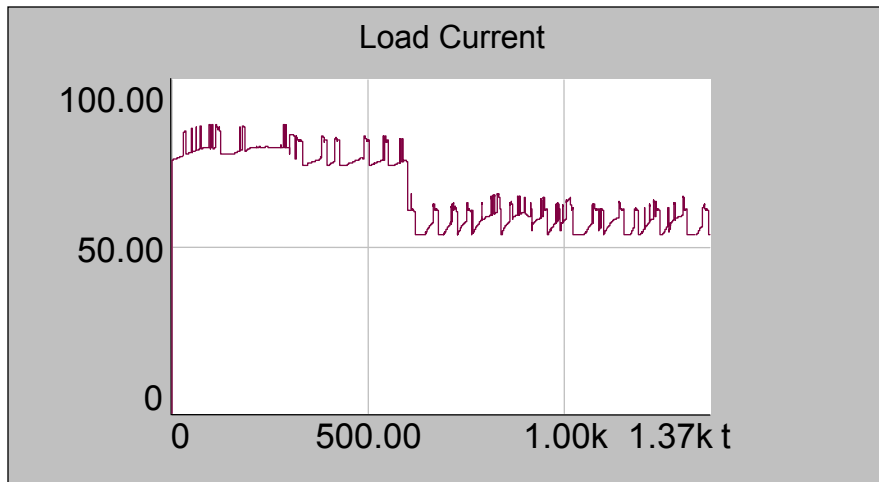
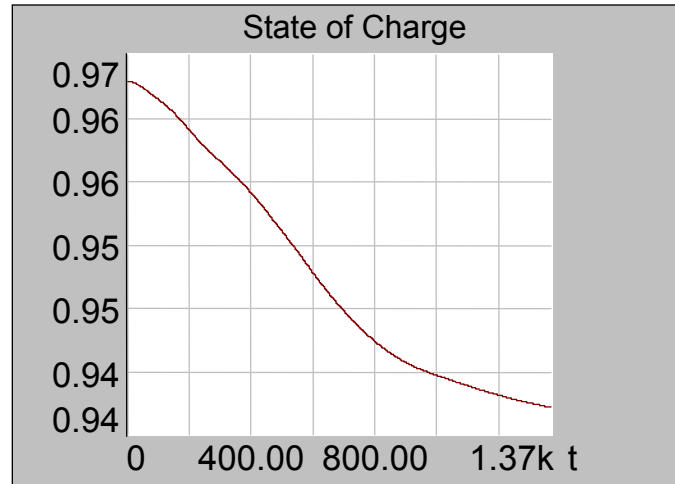
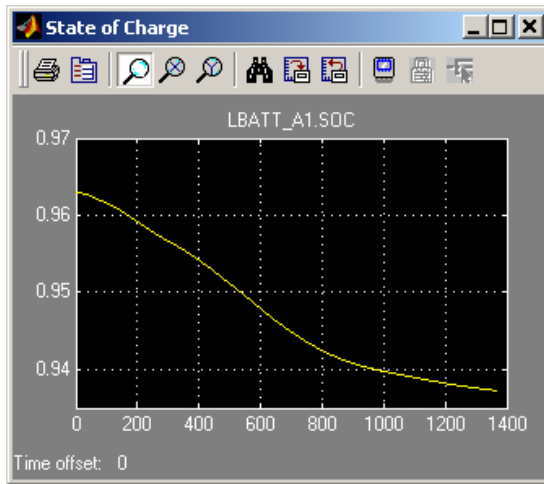
Data Pairs

No.	x-axis : v [V]	y-axis : Is [A]
1	12,5	3,8
2	14,5	4

File Name: delphi\_system\_ssh\_ExternalL

- Switch controlling ON or OFF
- Non-Linear Voltage Controlled Current Source for Load Characteristic

# Simulation Result



# Conclusion

- ▶ Easy drive system modeling with direct model import capability from Maxwell
- ▶ Control, electrical and mechanical effects in one model
- ▶ Direct Co-Simulation capabilities with Advisor
- ▶ Comprehensive evaluation of complex vehicle setups and interactions
- ▶ Fast
- ▶ Easy to use