University of Waterloo
Department of Mechanical and Mechatronics Engineering

A MODULAR PLATFORM FOR MODELING, SIMULATION, AND HARDWARE-IN-THE-LOOP ANALYSIS OF PLANETARY ROVERS

SEPTEMBER 26, 2011.

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OUTLINE

- Objectives
- Dynamic Rover Model
- Path Planning by Minimizing
  - Power Consumption
  - Mission Time
  - Operation Risk
- Hardware-in-the-Loop Testing

PROJECT OBJECTIVES

A flexible and modular platform that allows for

1) Rover modeling
2) Optimizing trajectory based on power constraints
    - e.g., short and steep vs. longer and more level terrain
3) Optimizing speed based on power constraints
    - e.g., driving slow vs. fast through a shady area
4) Mission simulation and visualization
5) Hardware-in-the-Loop Testing

FRAMEWORK

Terrain Information
- Mission Start & End Points
- Elevation
- Surface Conditions and Obstacles

Path Planner
- Avoid obstacles
- Minimize travel length
- Minimize energy consumption
- Avoid excessive tilt

Rover Model

Full model consisting of:
- Rover Dynamics
- Tire Models

Hardware-in-the-Loop
- Software component library
- Hardware test bench for component testing

Visualization

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BACKGROUND

Components
Rover dynamics
Wheels
Solar cells
Wheel motors
Battery
Power Management System
Heaters
Robotic arms, other peripherals
Terrain
Environment

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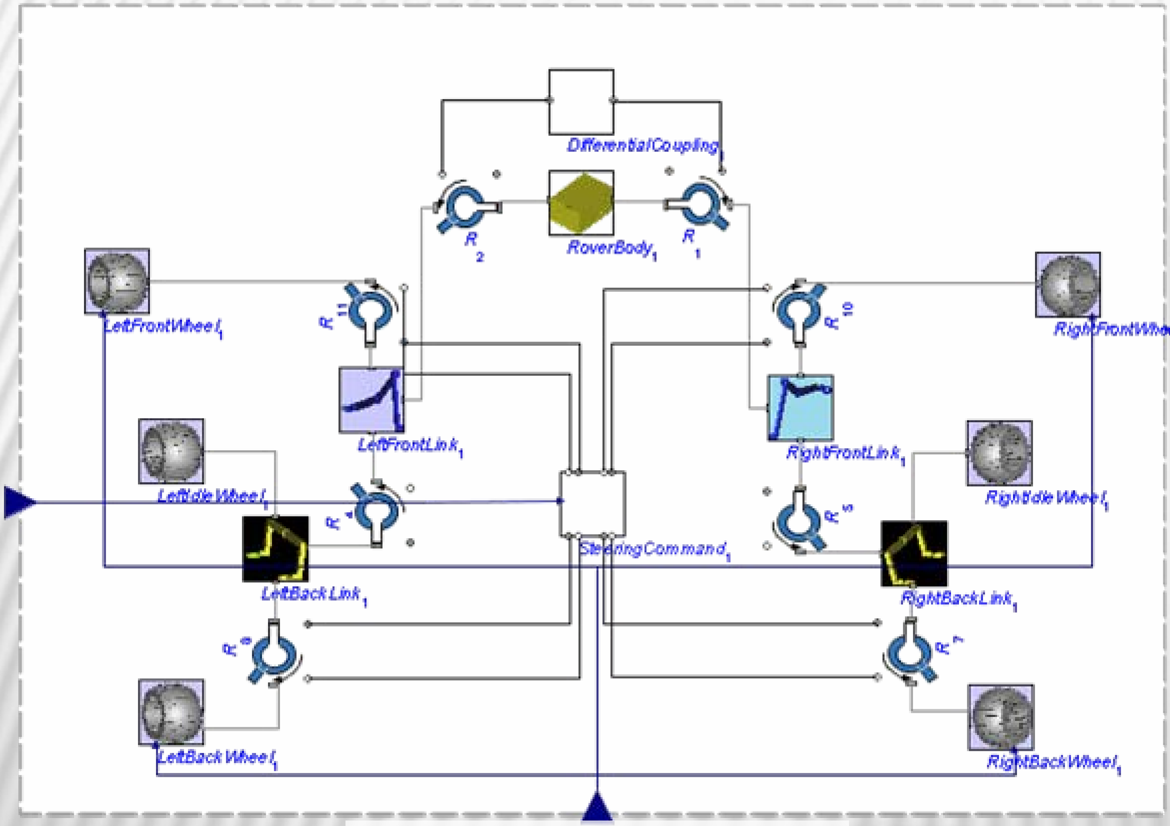
ROVER MODELING

DYNAMIC ROVER MODELING IN MAPLESIM

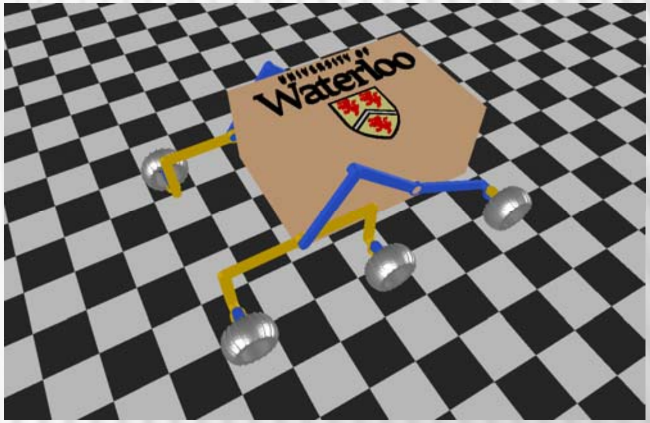
Six-wheeled Rocker-Bogie Rover

Modeling Environment



Steering angle input

Angular velocity input



Visualization Environment

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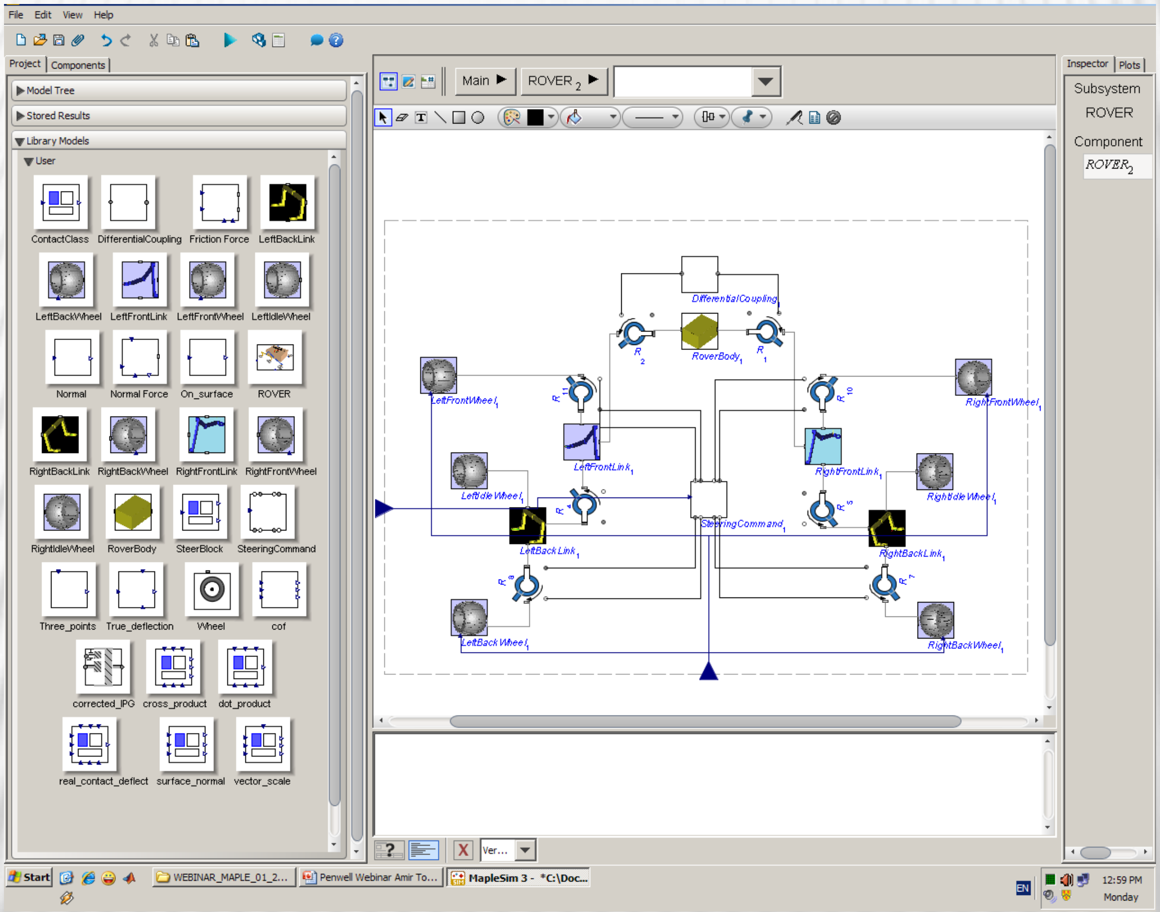
DYNAMIC ROVER MODELING IN MAPLESIM

Component Library in MapleSim

Component Library

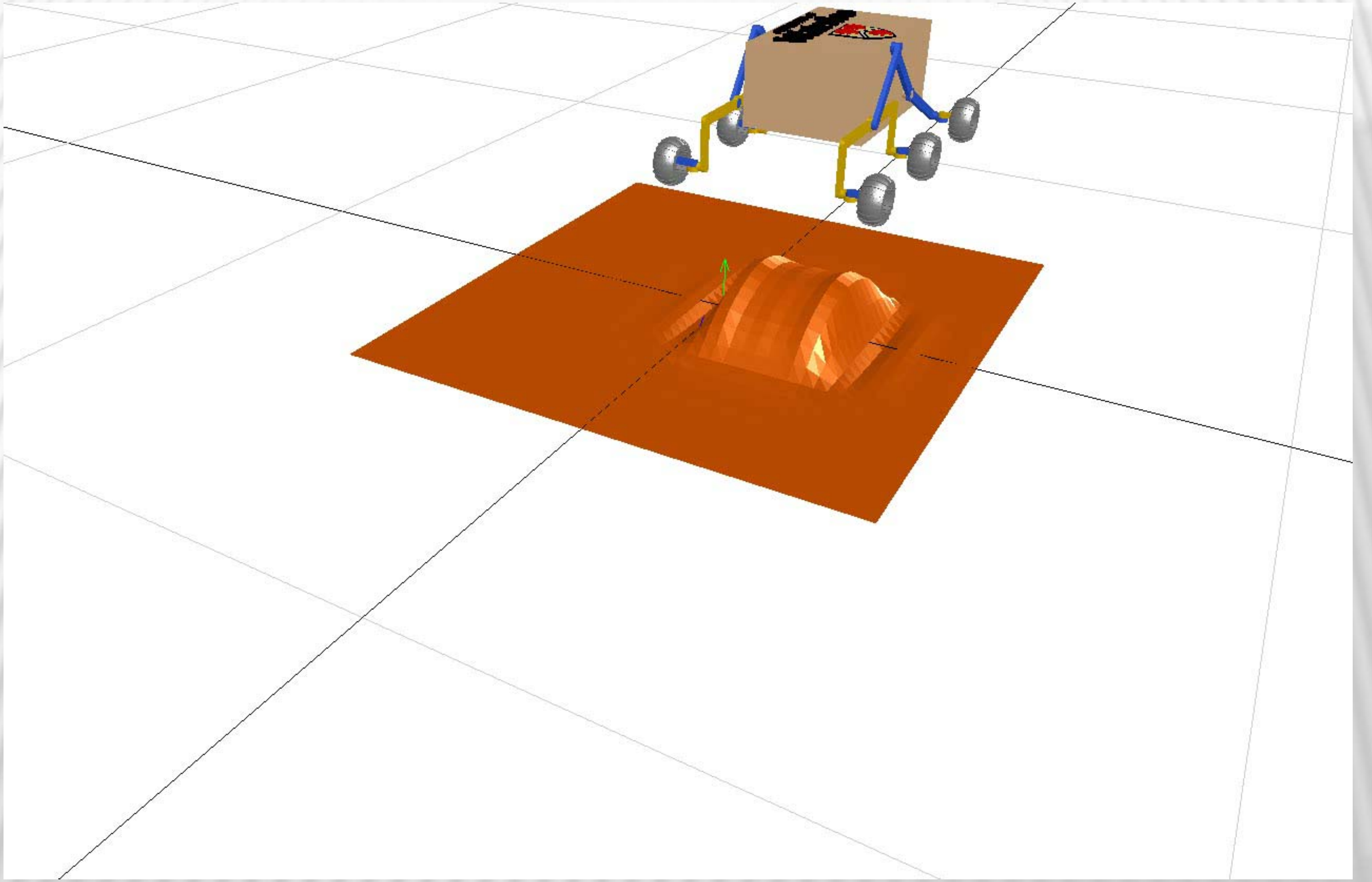
Dynamic Model



Rover Modeling

Dynamic Modeling in MapleSim

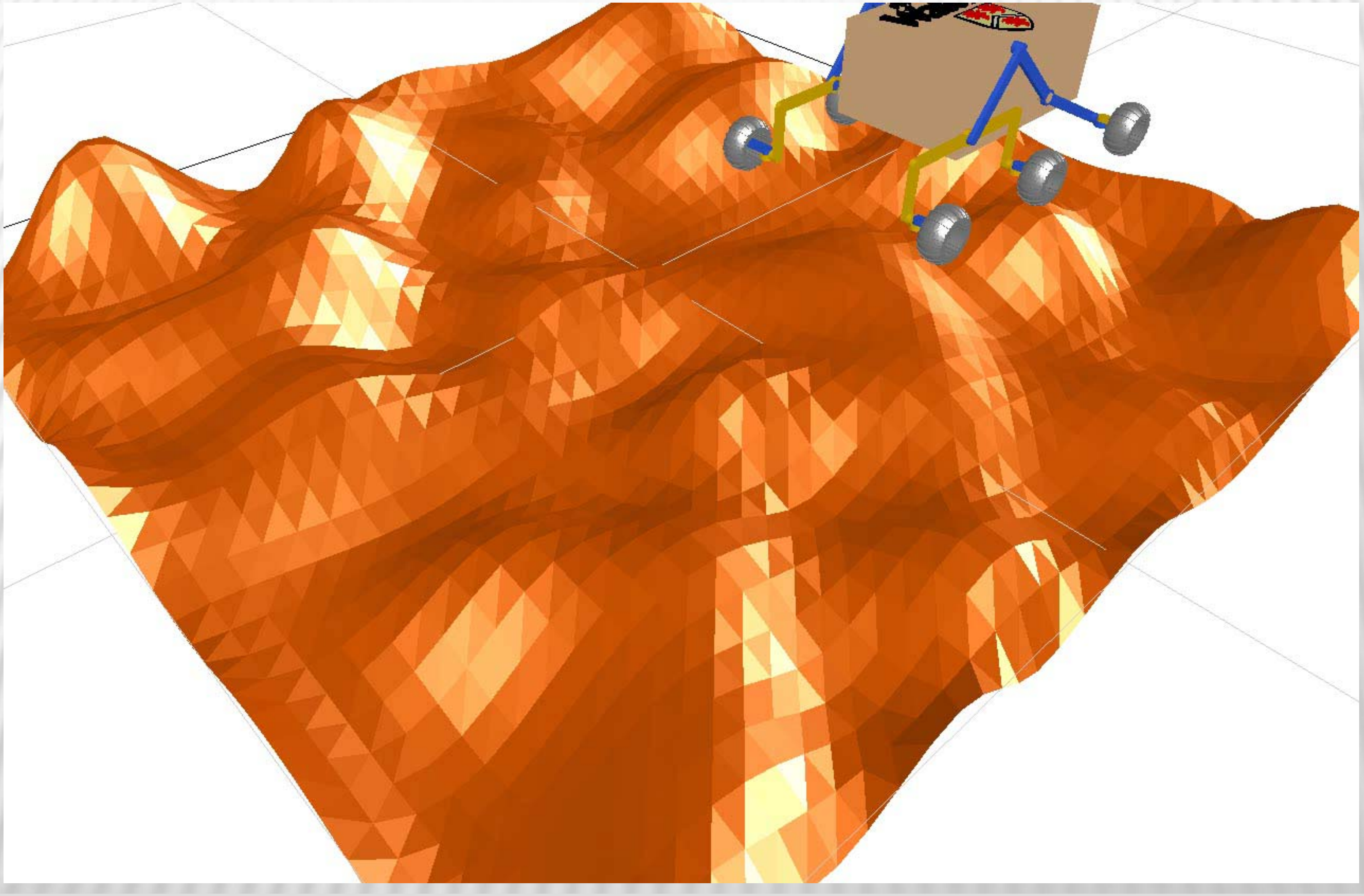
Sample Simulation – Passing a Bump



Rover Modeling

Dynamic Modeling in MapleSim

Sample Simulation – Uneven Terrain



Rover Modeling

Dynamic Modeling in MapleSim

Sample Simulation – Uneven Terrain

PATH PLANNING

Rover Path Planning Optimization

Featured Based Method

- Uses the dynamic rover model to consider energy consumption given different features (eg. Path slope, surface conditions)
- The pre-calculated data ... am initialization stage.
- The path is discretized a...
- the number of times eac... sed to estimate the total energ...

LOOK-UP TABLE FOR ROVER ENERGY CONSUMPTION

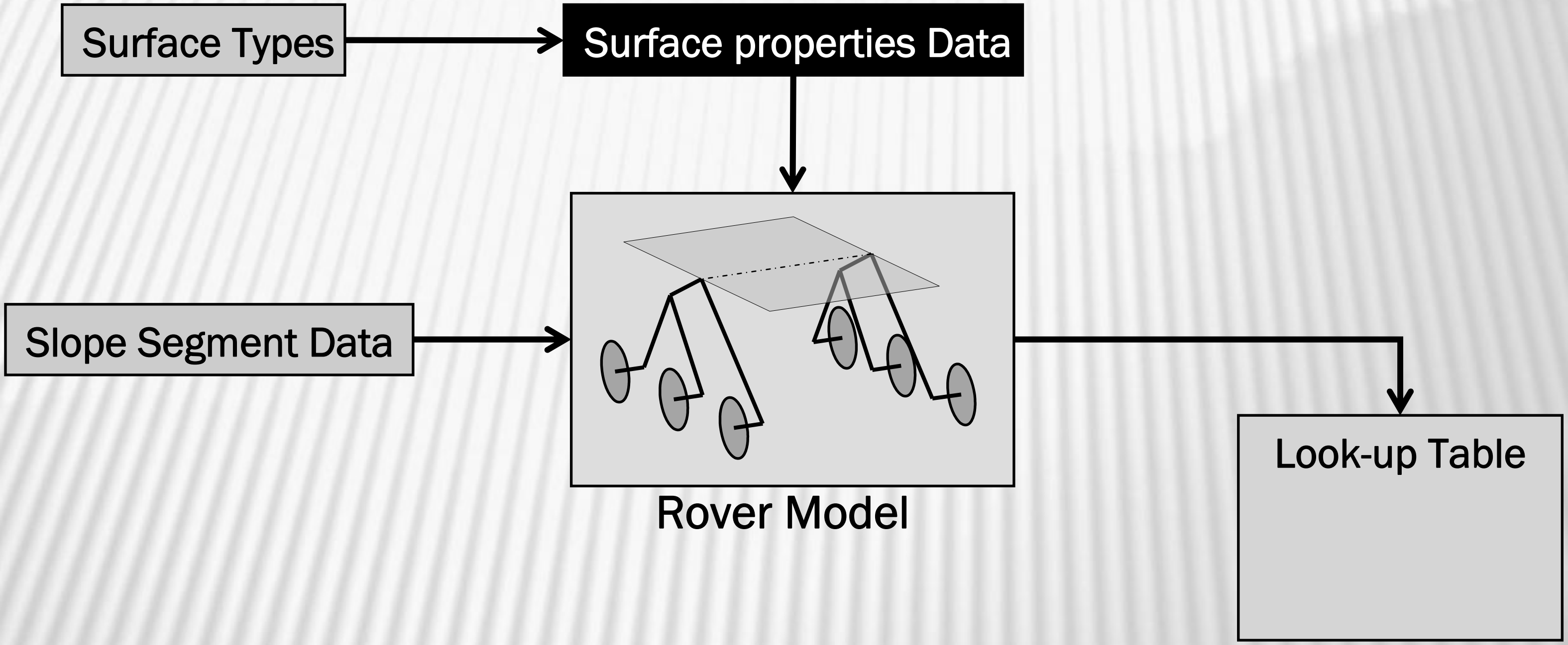
Slope (Degree)	Dry sand (type #1)	Sandy Loam (type #2)	clayed soil (type #3)
$-20 \leq \theta < -17$	-22.76	Infinity	-12.45
$-17 \leq \theta < -14$	-19.31	Infinity	-13.20
$-14 \leq \theta < -11$	-15.45	-9.26	-12.63
$-11 \leq \theta < -8$	-11.24	-8.88	-10.93
$-8 \leq \theta < -5$	-6.69	-7.08	-8.23
$-5 \leq \theta < -2$	-1.83	-3.90	-4.57

- the processing time is reduced significantly by avoiding the continuous integration of the energy function over the entire path.

Rover Path Planning Optimization

Global Optimization Path-Planner

Look-up Table Creation:



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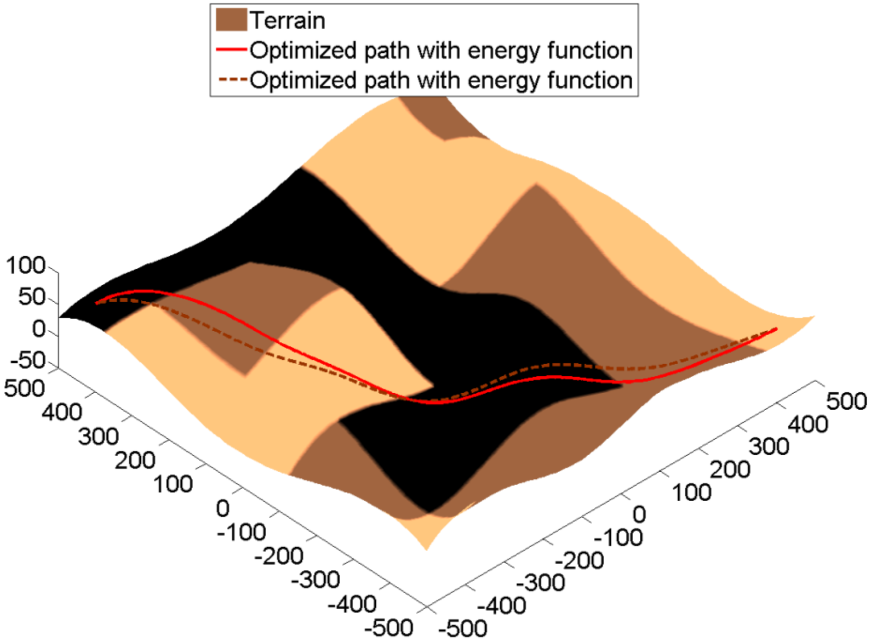
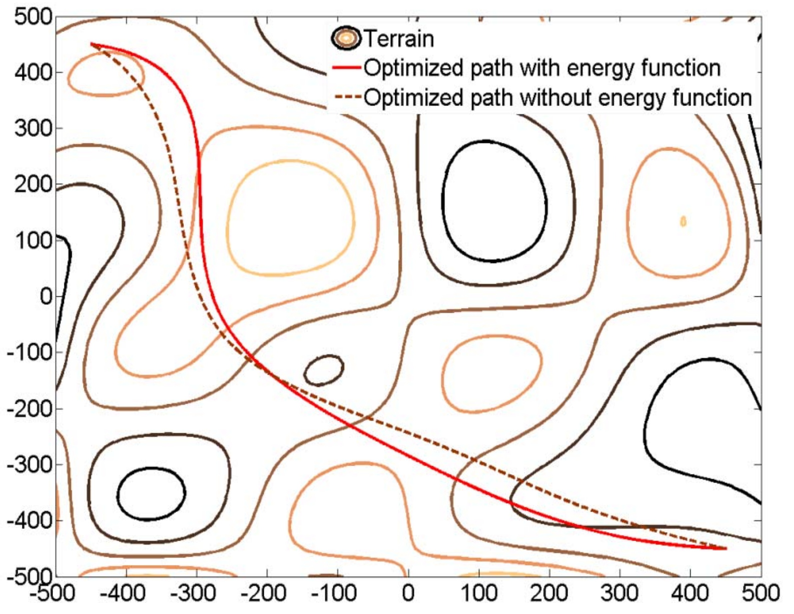
Rover Path Planning Optimization

Sample Results

Generated Paths on an Uneven Terrain

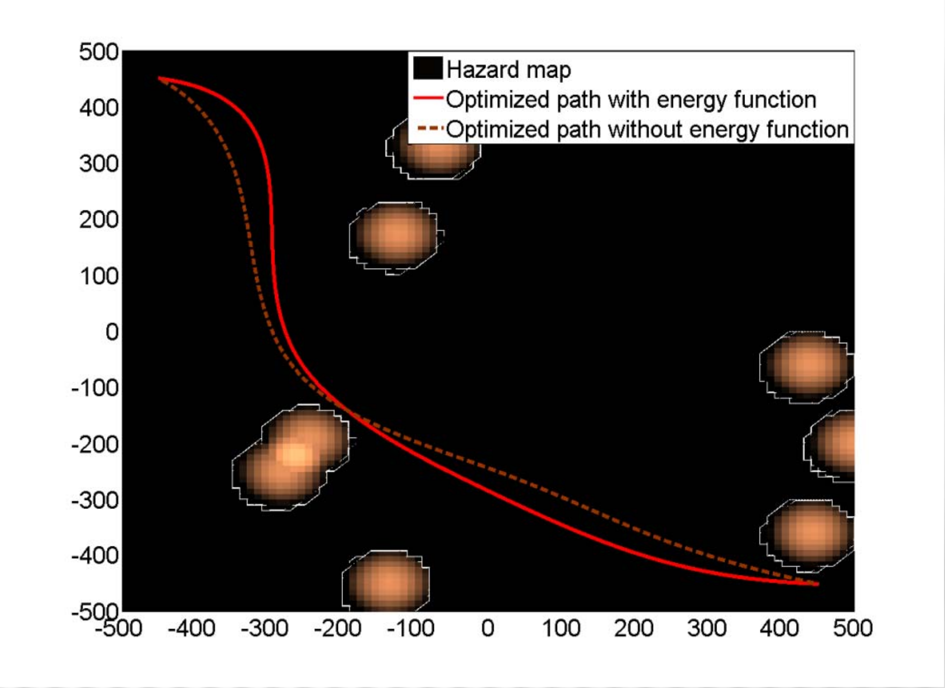




Rover Path Planning Optimization

Sample Results

Avoiding Hazards



HARDWARE-IN-THE-LOOP (HIL) TESTING

HIL OBJECTIVE

- Design a modular test platform to allow system level testing of power components of planetary rovers before a complete prototype is available
- Allows for hardware to be added progressively into the simulation loop as they become available

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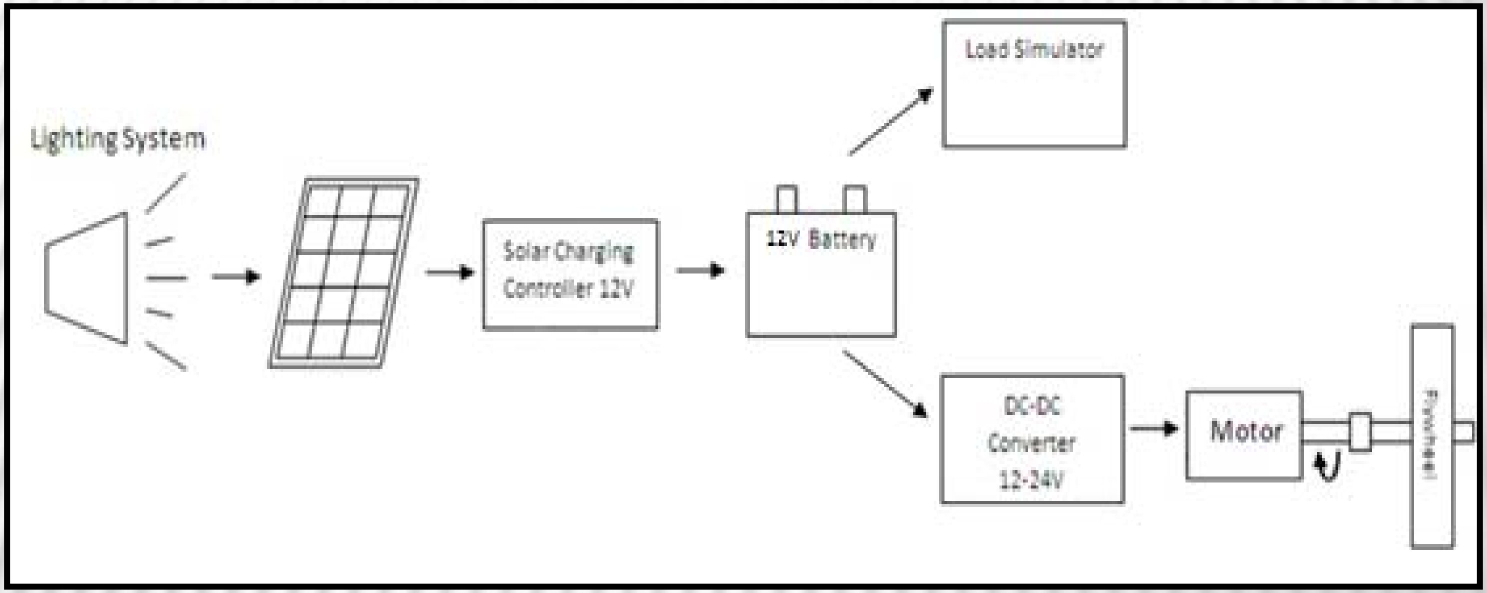
HIL TEST PLATFORM

- Library of mathematical models
- A test bench with a library of hardware components
- Program to connect hardware and software
- Graphical user interface

HARDWARE COMPONENT LIBRARY

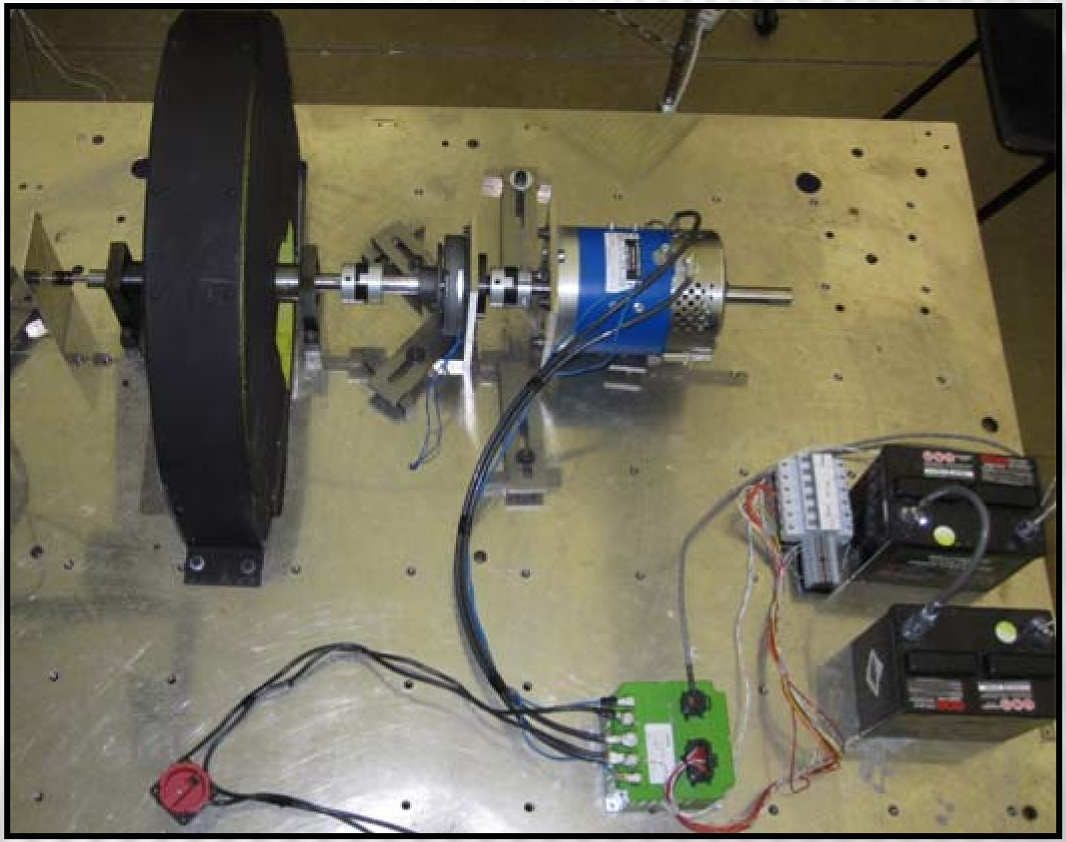


HARDWARE COMPONENT LIBRARY

- Lighting System
- Solar Arrays

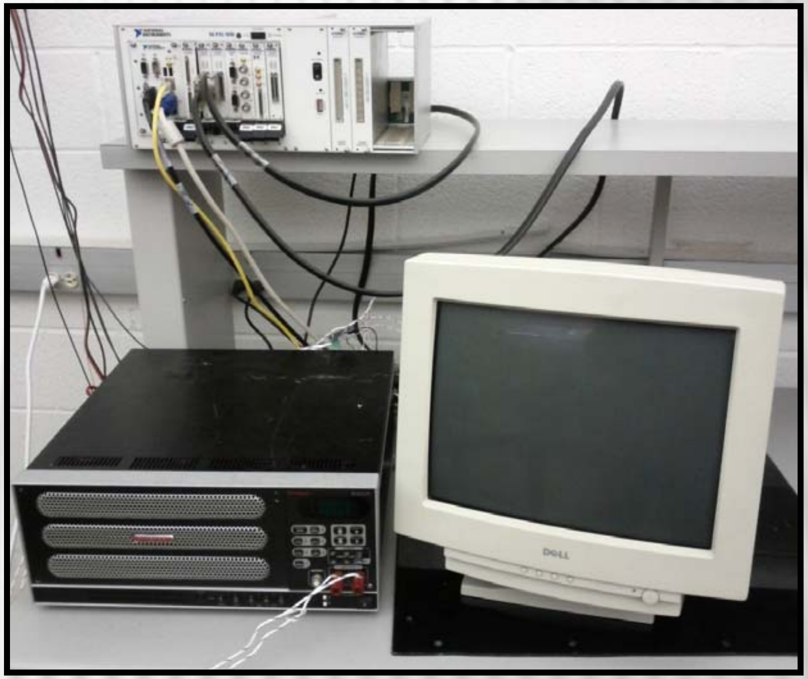
HARDWARE COMPONENT LIBRARY

- Battery
- Motor
- Flywheel



HARDWARE COMPONENT LIBRARY

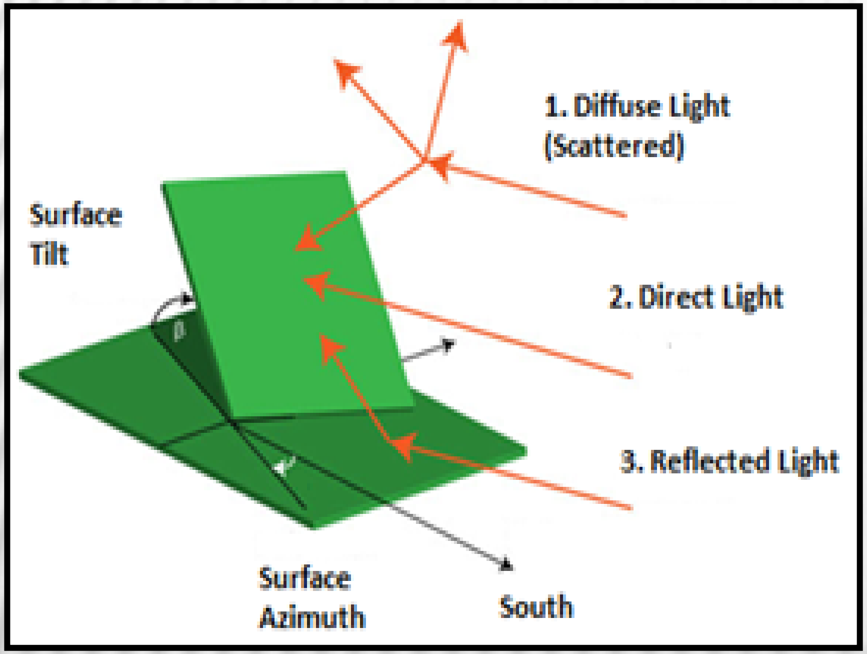
- Load simulator
- PXI
- Sensors



HIL MODELING

- Solar irradiance on a tilted surface

$$G_t = G_{bt} + G_{dt} + G_{rt}$$



- Season
- Opacity Depth
- Surface Albedo
- Vehicle tilt
- Vehicle orientation

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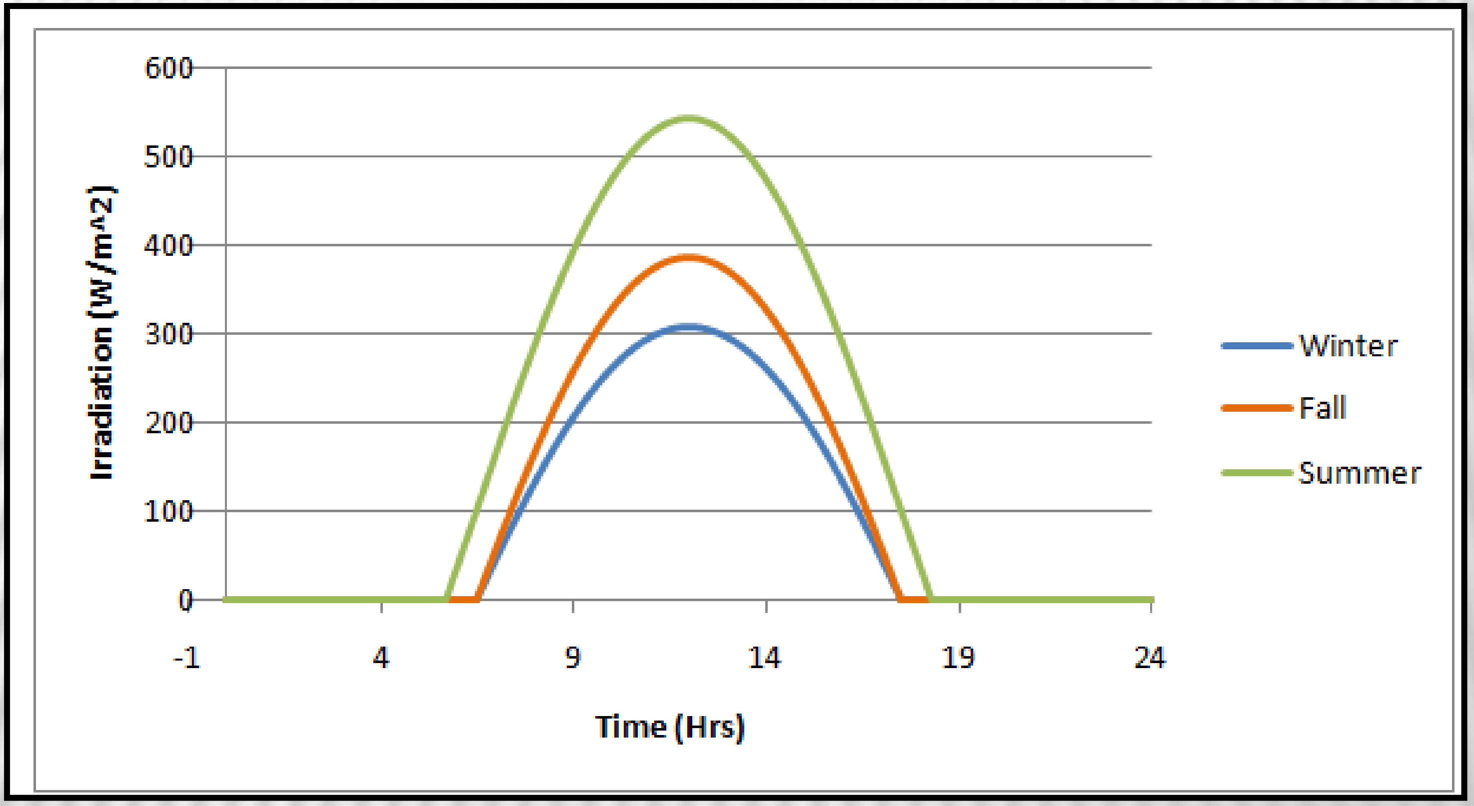
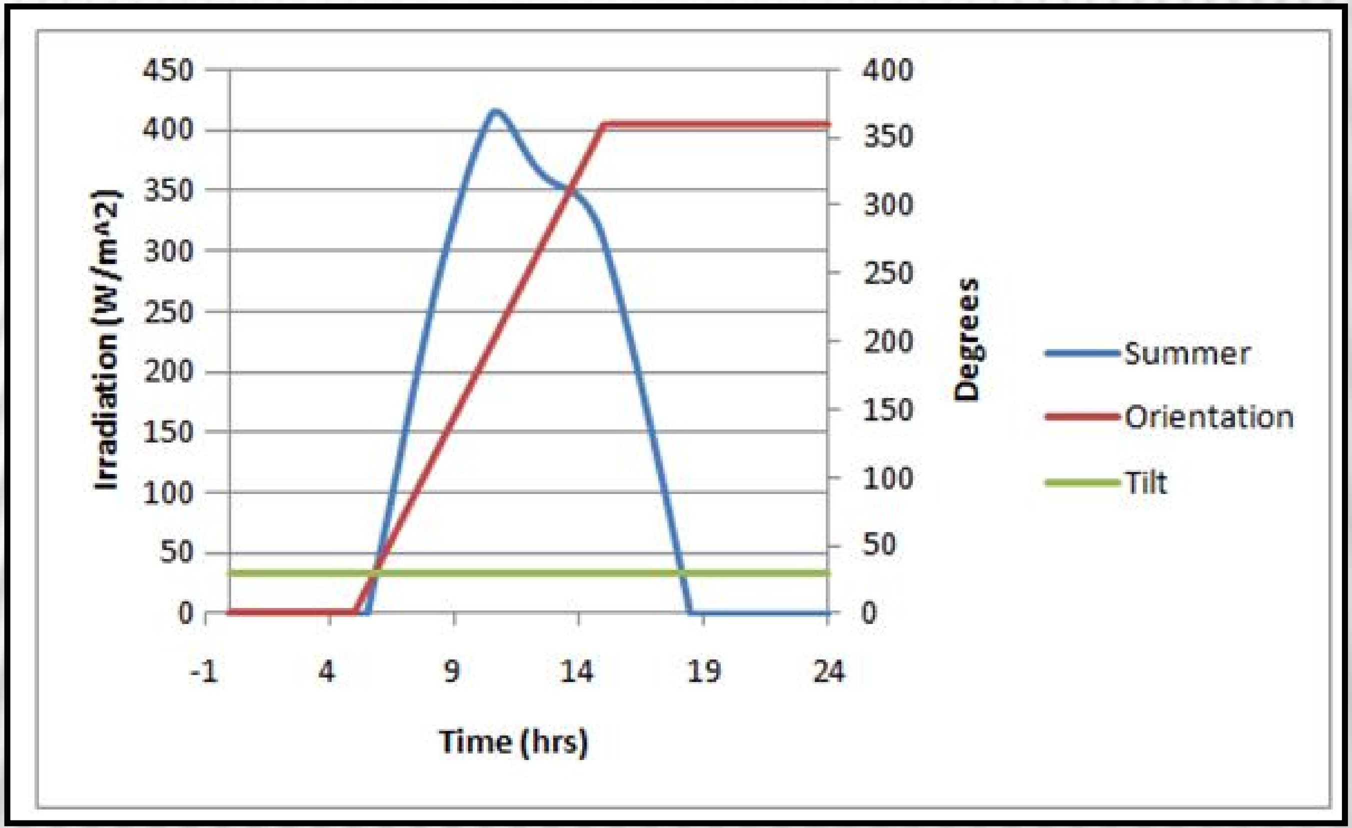
HIL MODELING

Seasonal Effect on Diurnal Irradiation Profile



HIL MODELING

Effects of Vehicle Orientation on Irradiation Profile



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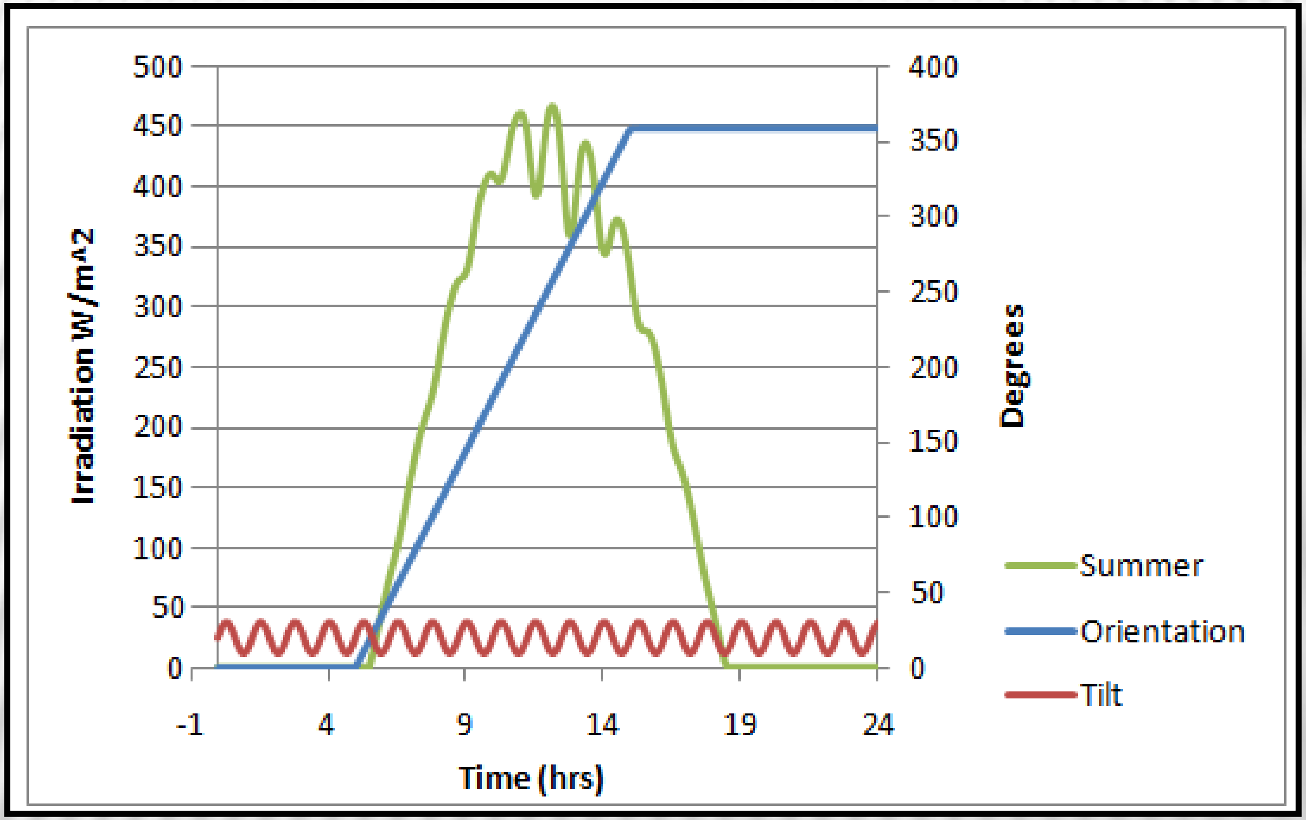
HIL MODELING

Effect of Vehicle Tilt on Irradiation Profile



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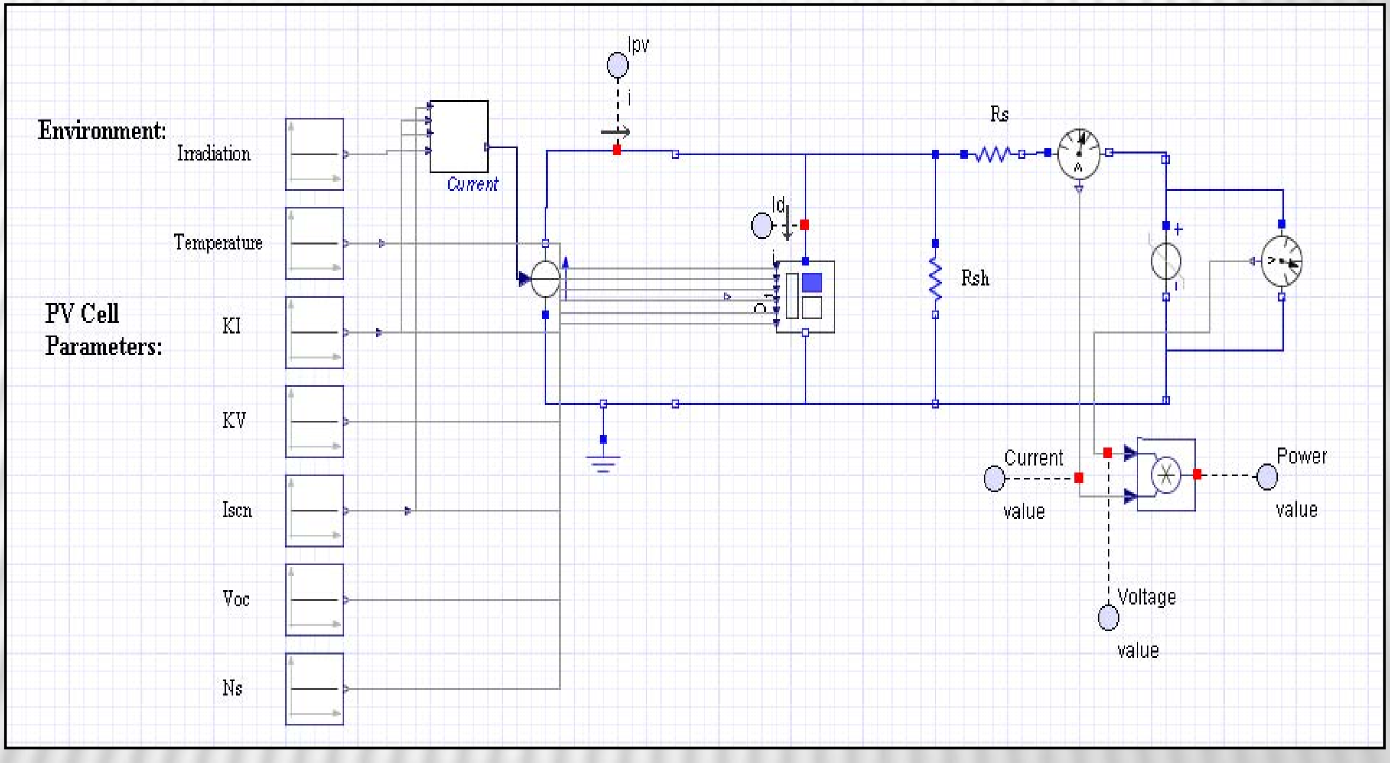
HIL MODELING

- Solar cells



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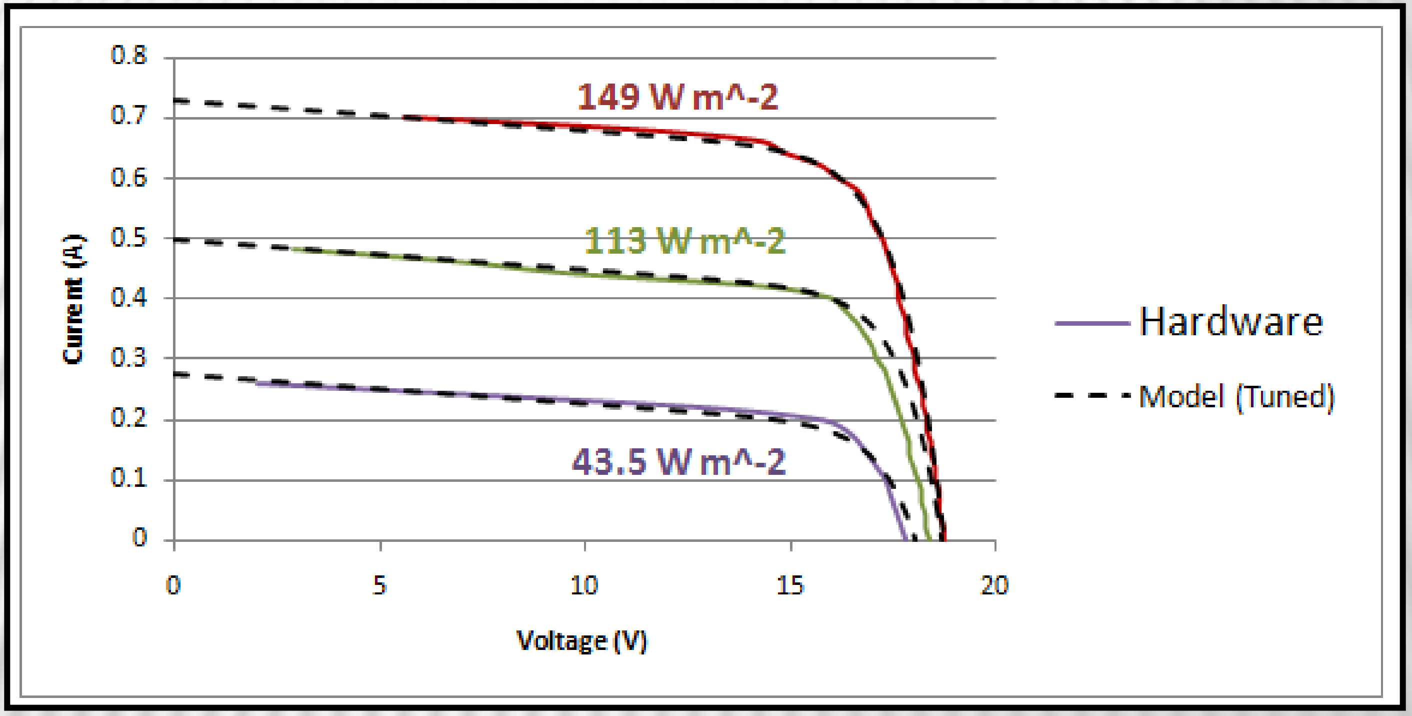
HIL MODELING

Hardware vs. Model IV curve



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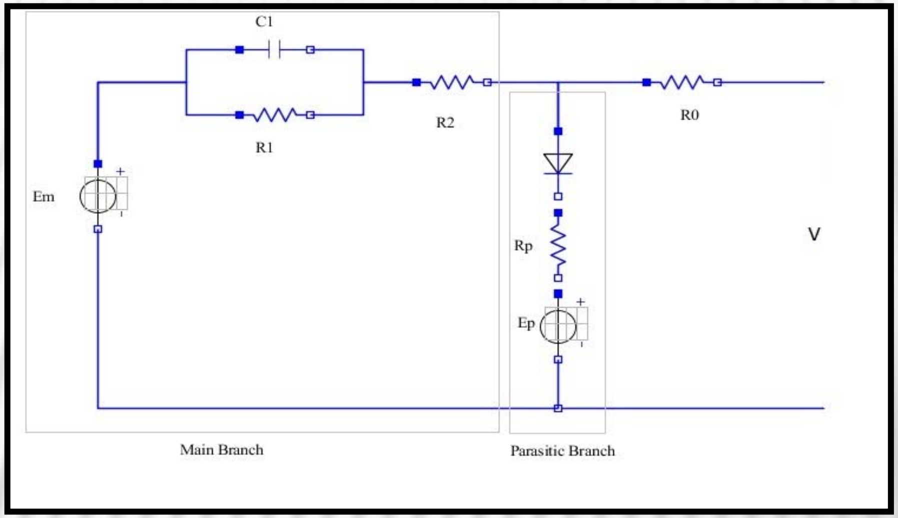
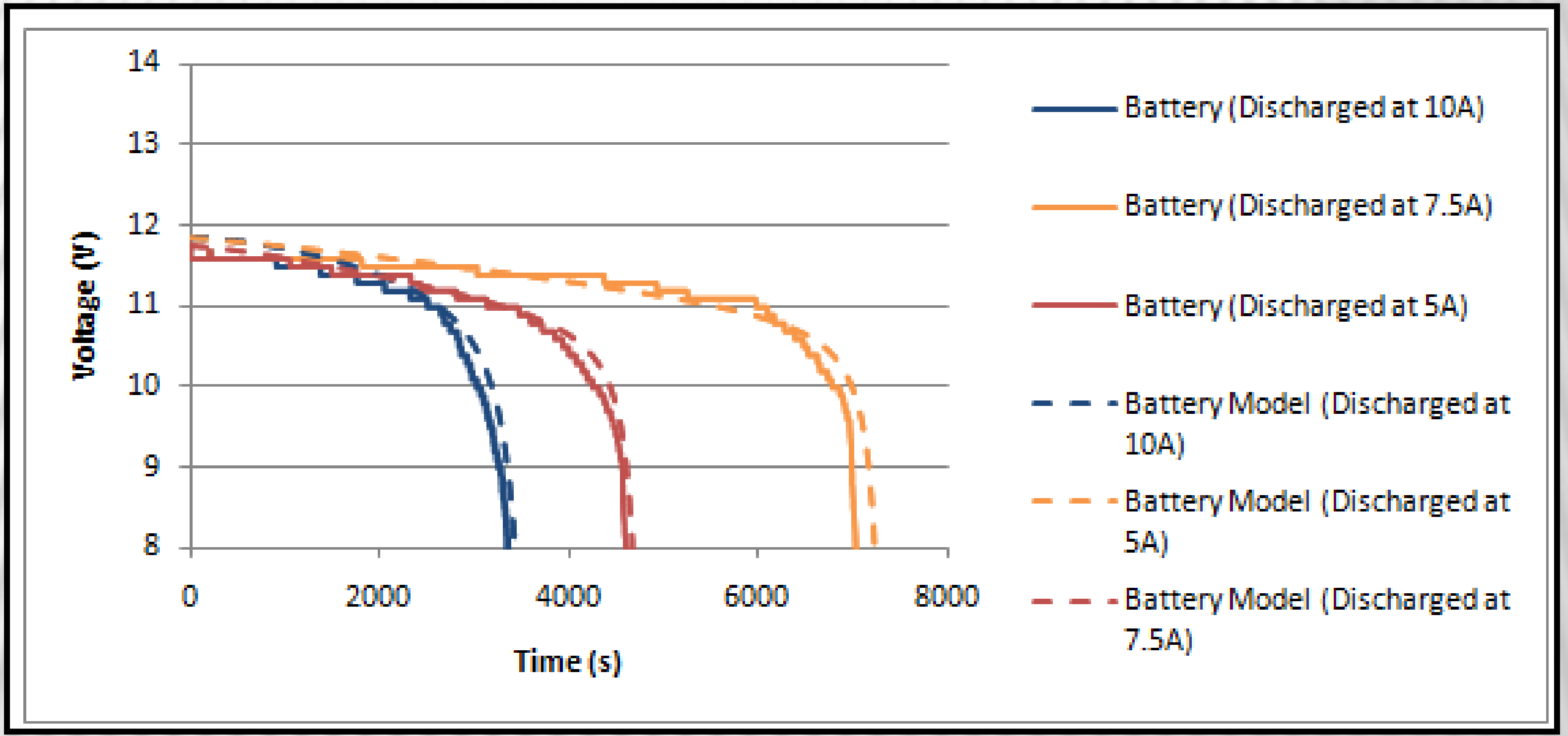
HIL MODELING

- Battery Equivalent Circuit Model



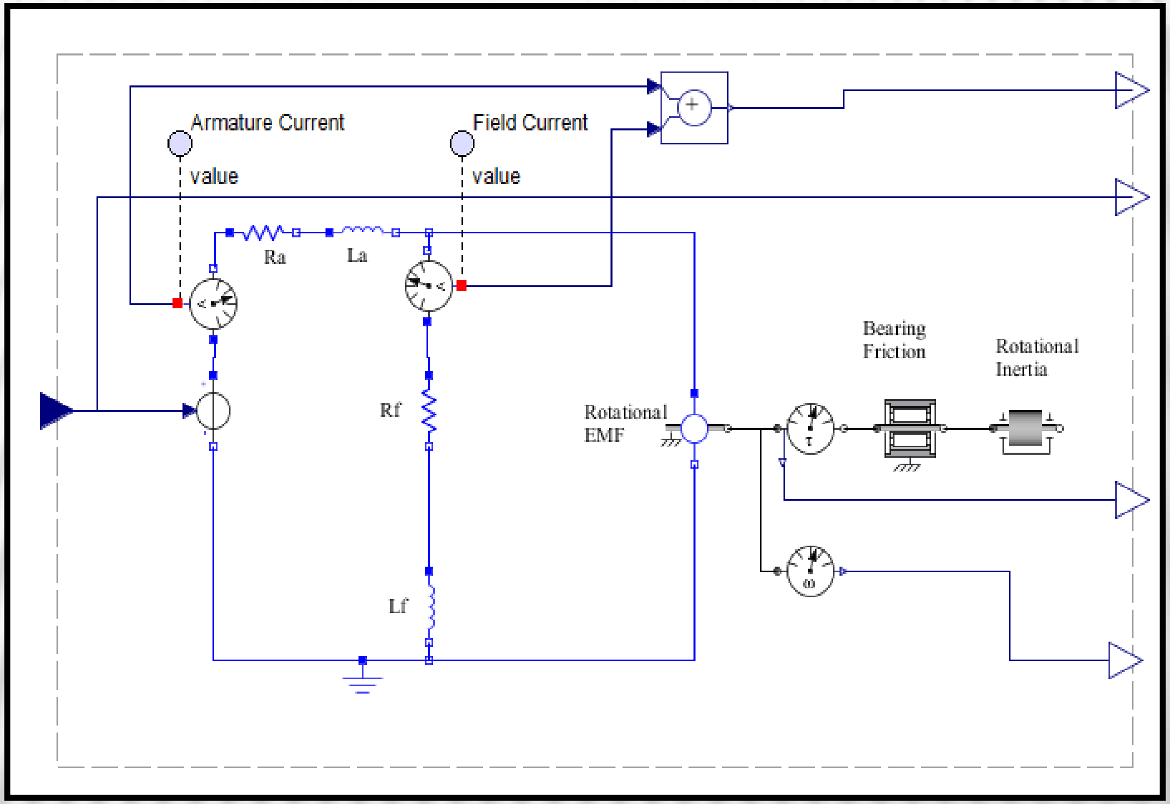
HIL MODELING

Lead Acid Battery Discharge Curve (Hardware Vs Software)



HIL MODELING

- Motor/ flywheel



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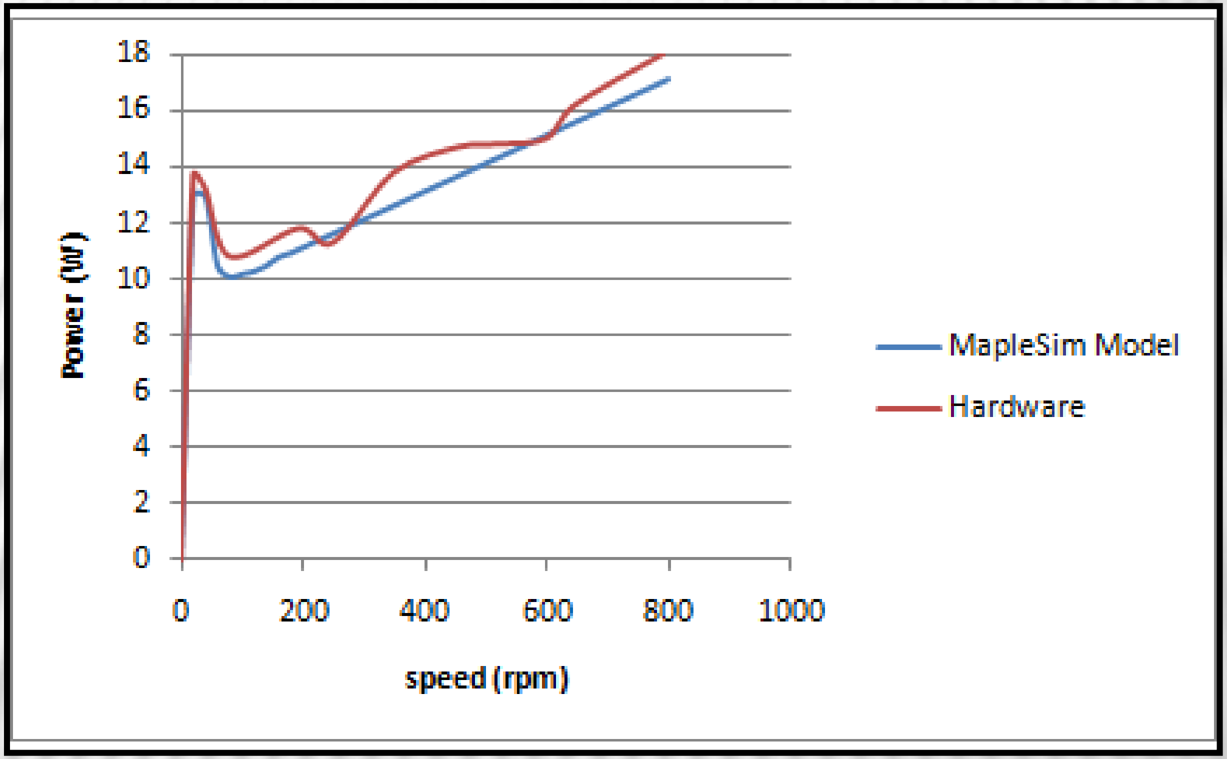
HIL MODELING

Motor/Flywheel Power Loss vs. Speed



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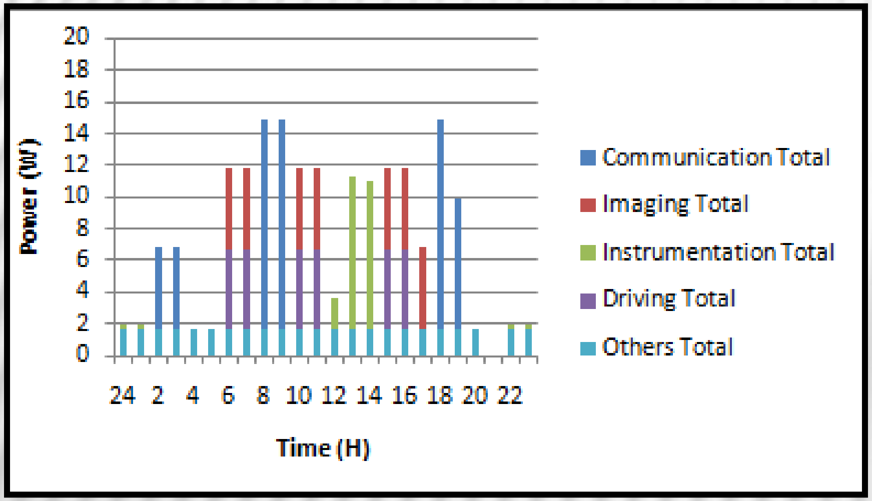
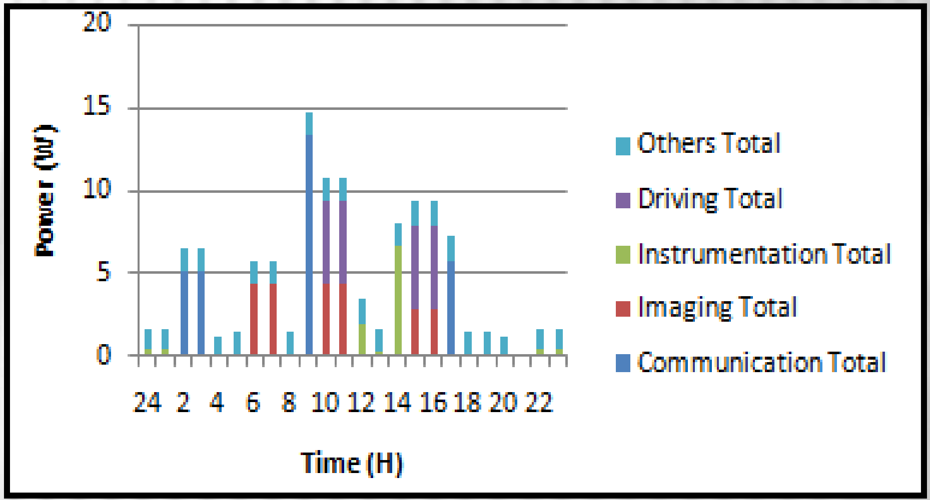
HIL MODELING

- Auxillary Power Consumption

Summer – Power Consumption Graph



Winter - Power Consumption Graph



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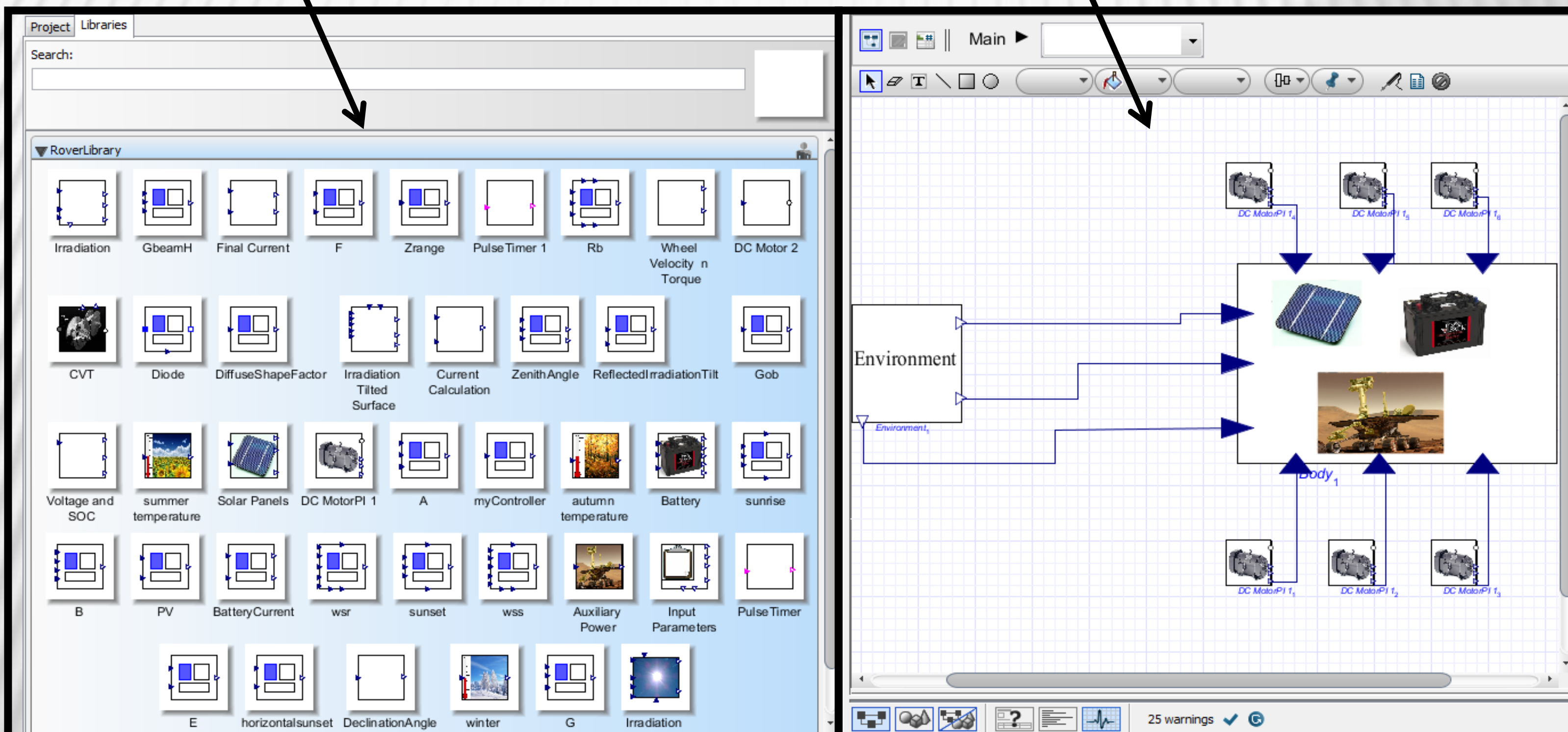
HIL MODELING

- MapleSim component library

Software Component Library

Modeling Workspace



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HIL IMPLEMENTATION

Software

MapleSim

Component Modeling

- Irradiation Model
- Solar Panels
- Battery
- Motor

LabVIEW 2009

Rover Model
HiL Graphical User Interface

NI PXI

Hardware (Test Bench)

- Lighting System
- Solar Panels
- Charge Controller
- Battery
- Inverter
- Load Simulator
- Motor
- Flywheel

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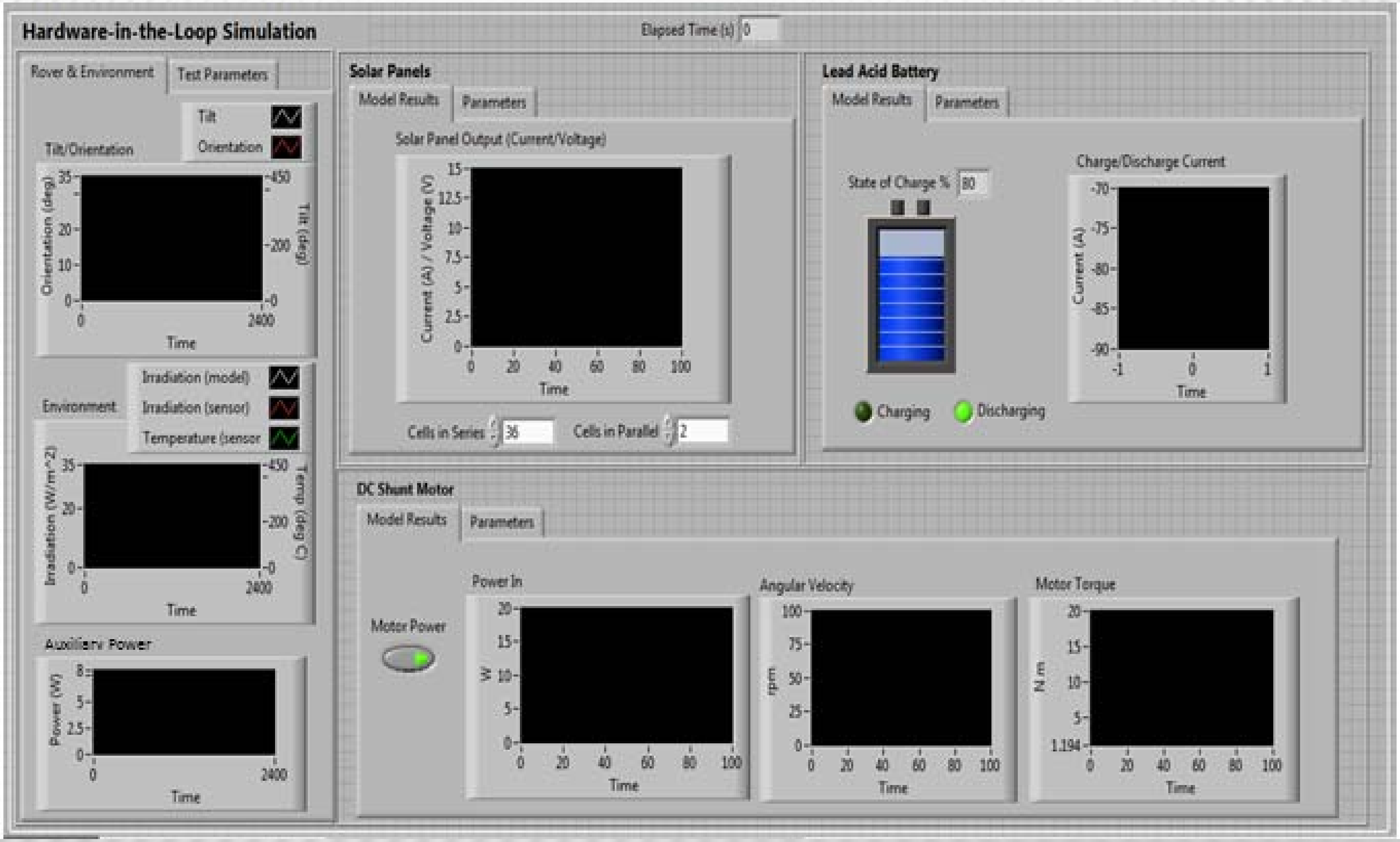
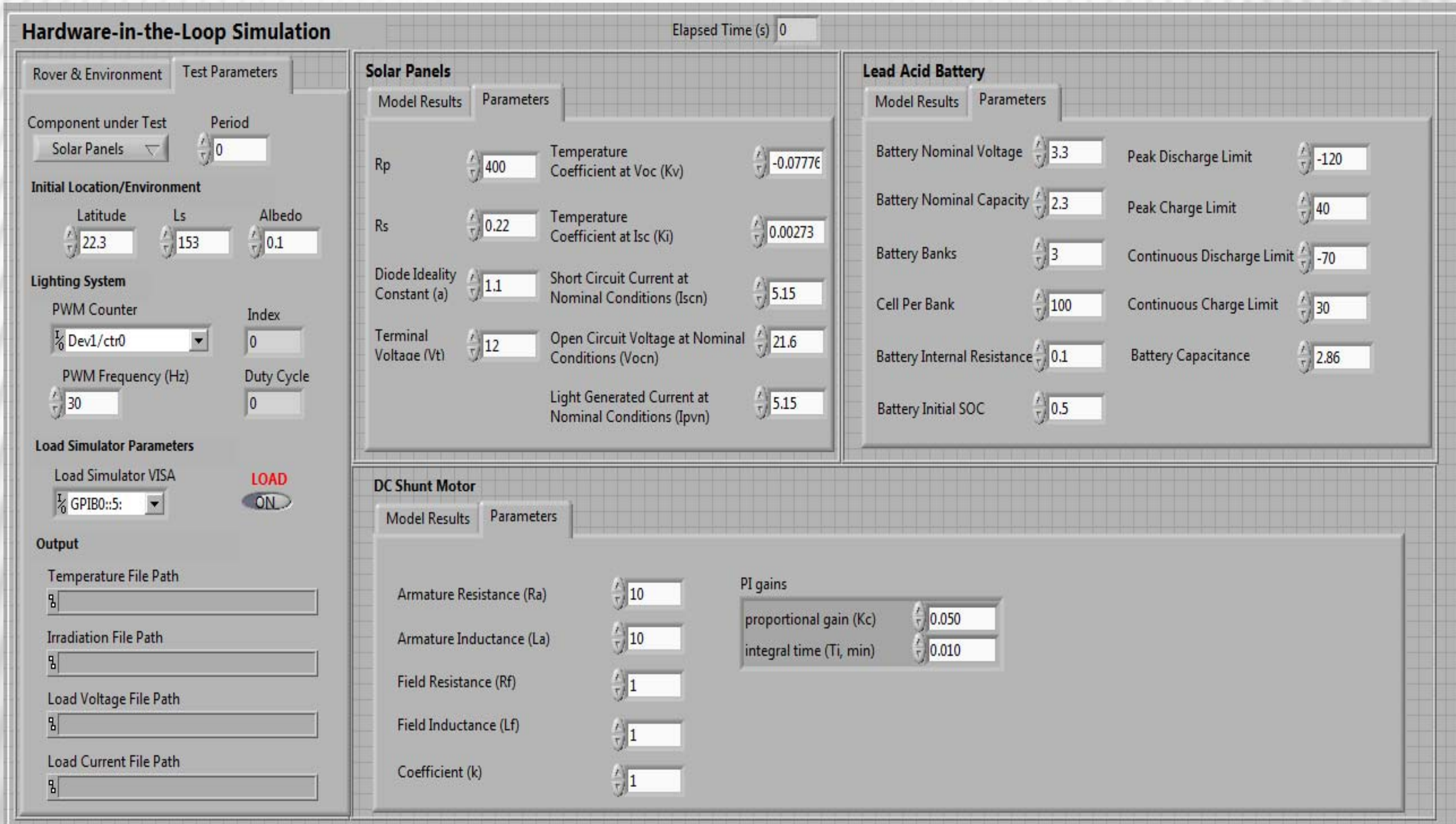
HIL IMPLEMENTATION - GUI



HIL IMPLEMENTATION - GUI



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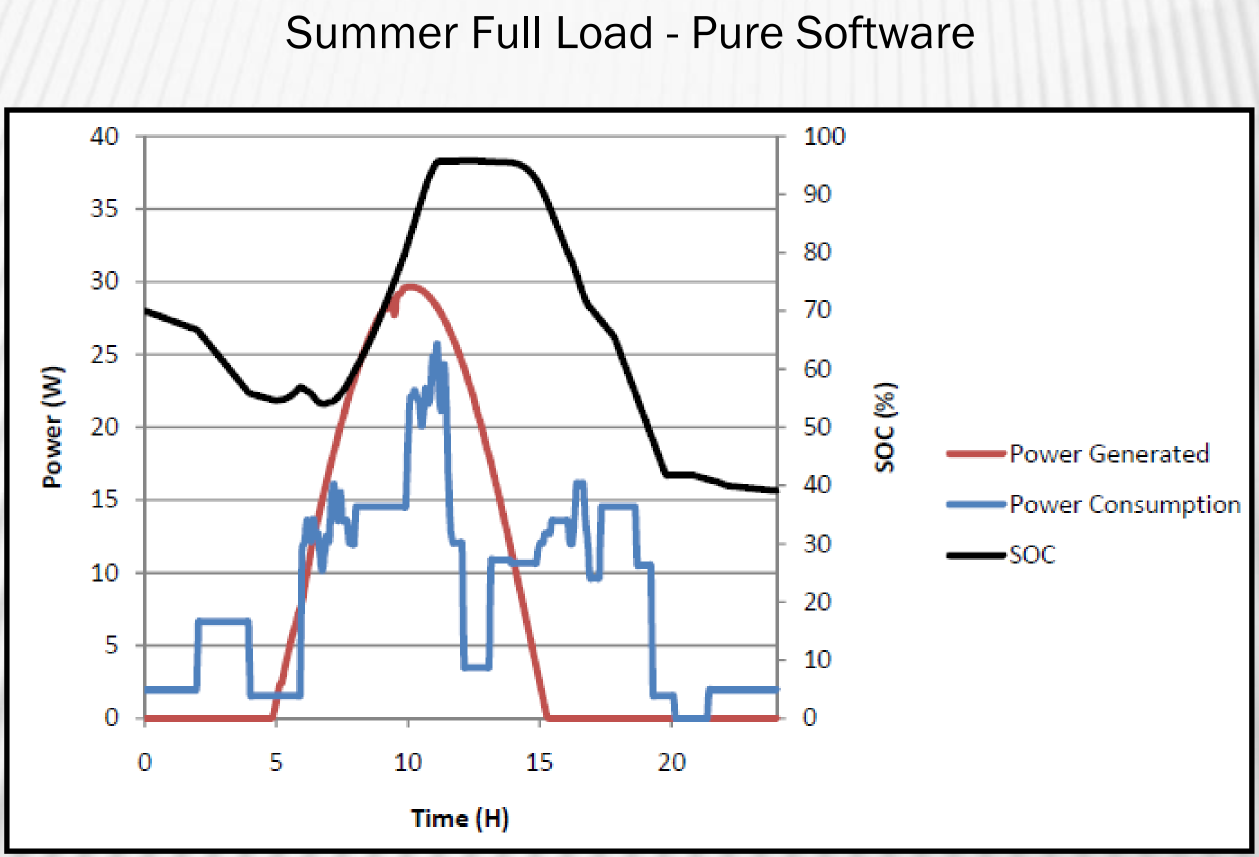
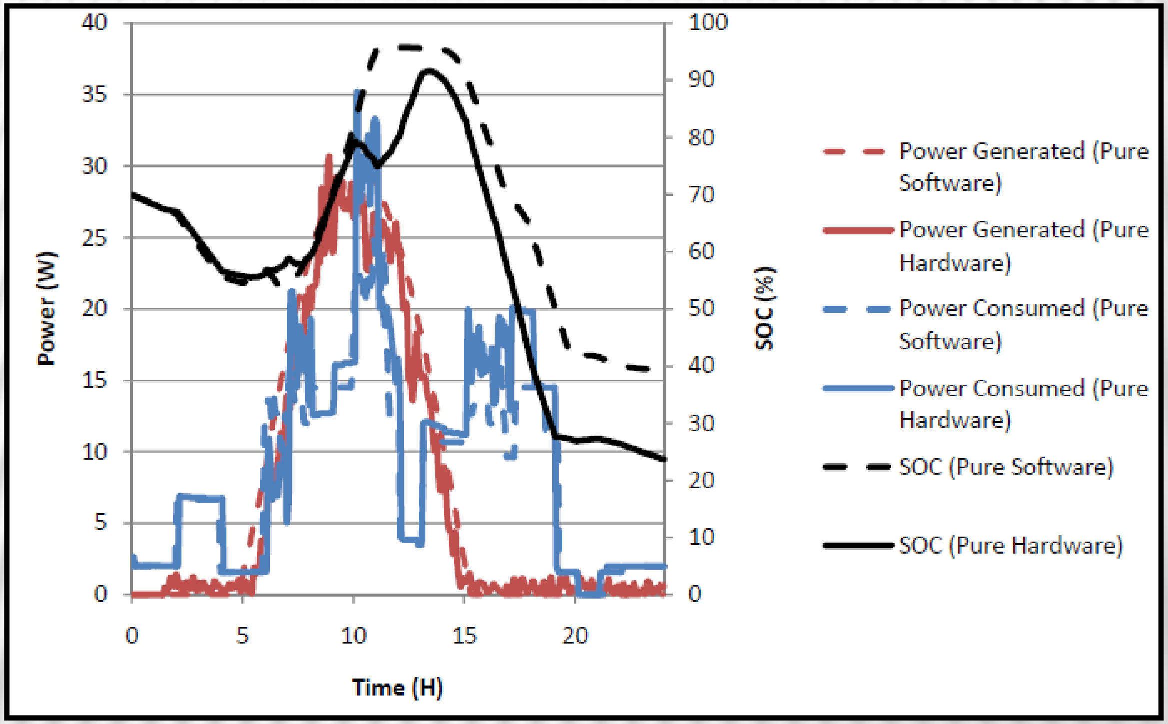
HIL AND SIMULATION RESULTS



HIL AND SIMULATION RESULTS

Summer Full Load - Pure Hardware vs. Pure Software



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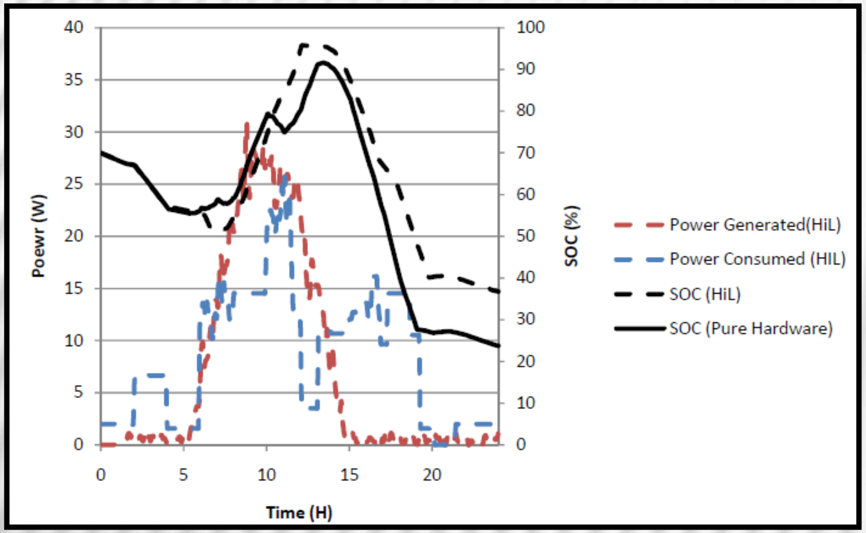
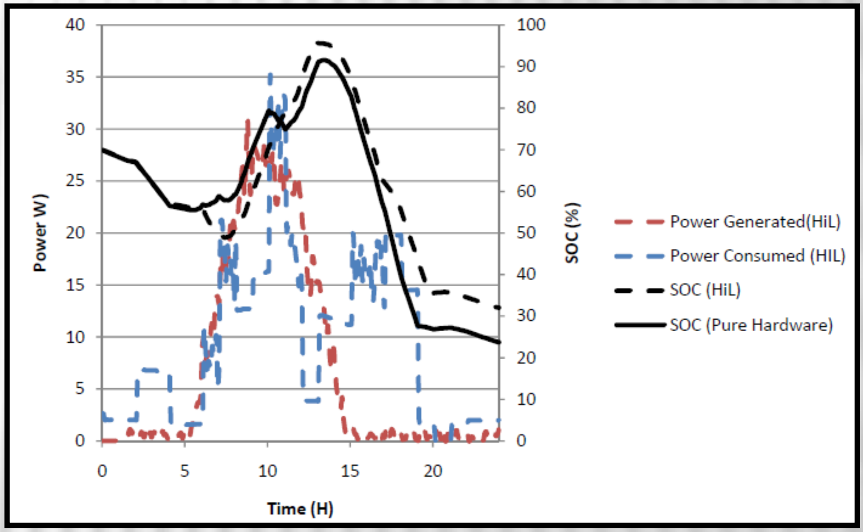
HIL AND SIMULATION RESULTS

Summer Full Load - Pure Hardware vs. Solar Panel in the Loop



Summer Full Load - Pure Hardware vs. Solar Panel, Motor, Load Simulator in the loop



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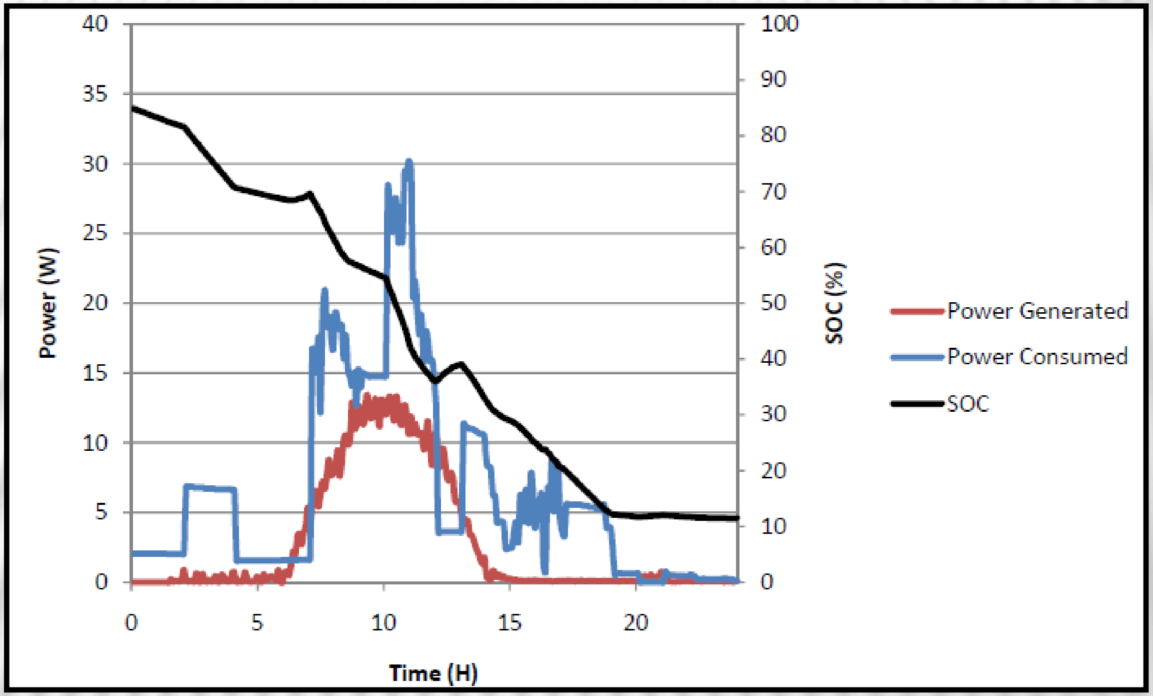
HIL AND SIMULATION RESULTS

Winter Full Load (Pure Hardware)



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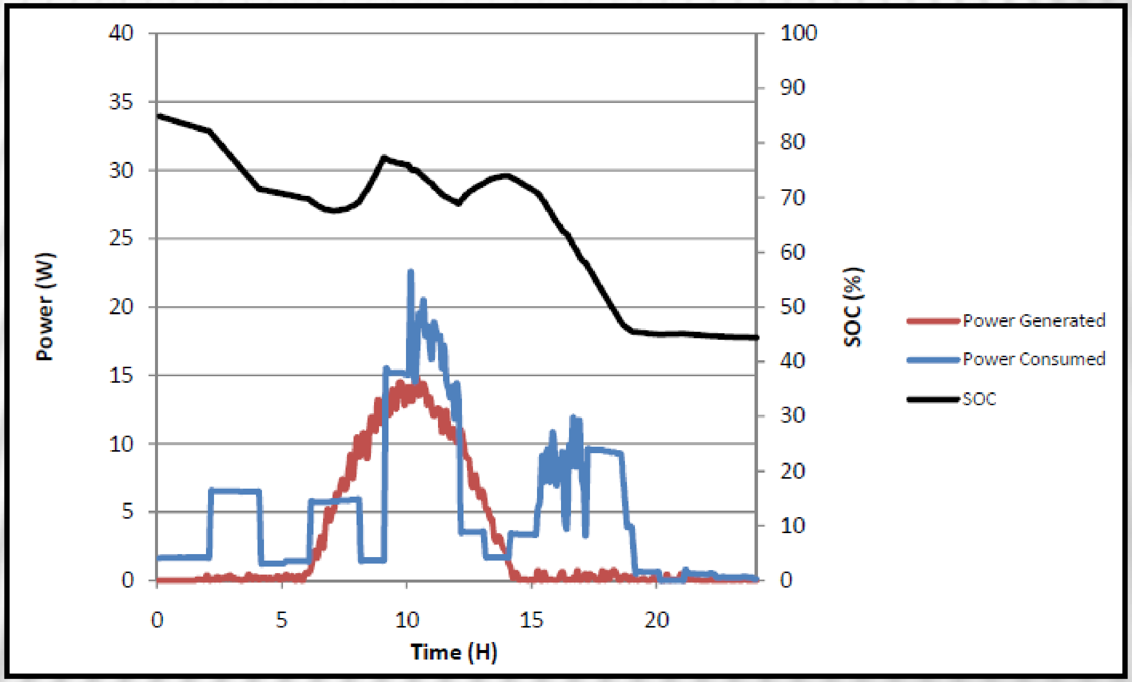
HIL AND SIMULATION RESULTS

Winter Reduced Load (Pure Hardware)



SUMMARY

- Demonstrated a flexible and modular platform
- Efficient path planning
- Rover dynamic modeling
- Custom component library for both dynamic model and powertrain model
- Hardware in the loop Testing
- Animation and simulation capability

Thank You!