PHEV Control Strategy Optimization Using MATLAB
Distributed Computing: From Pattern to Tuning

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The MathWorks
Outline

- Introduction
- Setup
- Global Optimization for Patterns
- Real Time Controller
- DIRECT Optimization for Tuning
- Conclusion
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New Constraints = More Complex Vehicle

- Higher use of math-based tools before and during design:
  - Model-Based design
  - Physical modeling
  - Monte Carlo analysis
  - ...

- Caveat:
  - Increased detail of modeling, complexity
  - Increased number of simulations

=> Longer calculation, analysis and development time
More Complex Vehicle = More Sensitive Control

Higher Electric Energy  →  Higher Control Freedom  →  Fuel Savings Potential

- Depending on various driven distance, several modes are possible during charge depleting: Electric-only (EV) and Blended

**Common Strategy** = EV+CS

**Blended Strategy**

*Optimization Evaluates Control Strategy’s Potential*
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Tool: PSAT – Powertrain Systems Analysis Toolkit
Process: 3-Way Approach to Control Optimization

Global Optimization

Optimal Control Pattern, Minimal Fuel Cons.

Control Design

Various PSAT Control Strategies

Derivative Free Optimization

Optimally tuned Parameters

Backward model Bellman Principle

Optimally tuned Parameters

Rule-Based Control Design

Various PSAT Control Strategies

Control Logic

DIRECT Algorithm

Various Control Principles

Various PSAT Control Strategies

Global Optimization

Optimal Control Pattern, Minimal Fuel Cons.

Control Logic

DIRECT Algorithm

Optimally tuned Parameters
Hardware: Computation Time Requires Distributed Computing

MATLAB Distributed Computing Server
- 1 Header Node
- 2 Worker Nodes

MATLAB and Parallel Computing Toolbox

Server Rack:
- PSAT Software
- Simulation Results

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Finding Control Patterns Fast(er)

- Robustness:
  - Different Cycles (e.g.: Urban, Highway,…)
  - Different Distances
  - Different Initial SOC
    => Set of 45 simulations
    => Sequential computation time ~ 2 weeks

- Using Distributed Computing:
  - Simulations run in parallel
    => Running time ~ 12 hours
Global Optimization Showed Minimal Fuel Consumption Achieved in Blended Mode

3 cycles demonstrated blended strategy is optimal when knowing the distance

Example of EV+CS Mode for comparison

% of total distance

SOC

0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

0 10 20 30 40 50 60 70 80 90 100

Japan 10-15 x25 (PSAT)
Japan 10-15 x25 (gl. optim)
UDDS x10 (gl. optim)
NEDC x10 (gl. optim)
Global Optimization Showed Engine Starting Condition Almost Proportional to Electrical Consumption

![Graph showing electric energy consumption and power wheels](image)

- **Cycle:**
  - UDDS
  - HWFET
  - LA92

- **Driven Distance:**
  - 10 miles
  - 20 miles
  - 40 miles
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Engine ON/OFF Logic & Engine Torque Request

Engine ON / OFF Logic in Stateflow

Engine Torque Demand in Simulink
Blended Control Strategy Design Showed Significant Improvements Over EV Mode

Fuel Energy Increase Over EV/CS

Trip distance (km)

-10% -8% -6% -4% -2% 0% 2%

10 miles AER vehicle run on several UDDS cycles
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Control Parameter Tuning with DIRECT

- Robustness:
  - Different Cycles
  - Different Distances

- Iterative Process:
  - Control space is sampled at each iteration
  - One simulation is run for each sample
  - Control space is re-sampled around the ‘best’ Simulation
    => Convergence after 30 iterations ~ 400 simulations
    => Sequential computation time ~ 2 days

- Using Distributed Computing:
  - Simulations run in parallel
    => Running time ~ 5 hours
The Longer the Electrical Distance, the More Robust

Influence of cycles (distance = 23.7 km)

Tuned for a short distance (2xUDDS)

Influence of cycles (distance = 71.2 km)

Tuned for a longer distance (6xUDDS)
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Conclusion

Using a combination of optimization techniques and modeling based on PSAT and MATLAB, we were able to:

- single out control patterns,
- implement them in Simulink and Stateflow,
- tune their parameters.

Only the use of distributed computing allows this process to be performed in a timely manner:

- After setting up the MATLAB Parallel Computing Toolbox, and Distributed Computing Servers, it took only 1 hour of development to get the first simulations running.
- The optimization times were reduced from more than 2 weeks to less than a day.
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