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Optimization and matching of components in HEV

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Abstract

Component optimization and matching is of great importance to improving fuel economy of HEV. Instead of choosing them only by experiences and formulas as we always do, a method which chooses the parameters by optimization algorithms is provided here. Thermostatic strategy and Power Following strategy are adopted as control strategies. Various optimization algorithms and control strategies can be easily added according to the need. At the end of this paper, a fuel cell electric vehicle is used as an example, and an optimized result is obtained, which proves that this is a reliable method to select and optimize components.

Keywords: HEV, component, optimization, simulation

1 Introduction

Hybrid electric vehicles have more than one energy sources, how to size these components and match them to reach a higher fuel economy is a concerned question. There are not as many papers concerning component sizing as papers on control strategies, but actually component sizing is a more fundamental problem. A great choice of components will take advantages of their potential. Nowadays engineers usually choose components by experiential formulations, usable components' combination can be found in this way, but not the optimized combination.

Keith Wipke recommends an advanced vehicle simulator Advisor to automatically size the main powertrain components subject to user-selectable performance constraints, and he used it to optimize a Hydrogen Fuel Cell SUV.[1] Advisor is a software written in the MATLAB/Simulink environment, and it is developed by the National Renewable Energy Laboratory; although it has the sizing function, it's based on only one algorithm, it only aims at adjusting and computing a few fixed parameters, and it can only be implemented on specific cycles and control strategies; that's not enough.

So a new platform to size vehicle components is provided here. You can add new control strategies and new vehicle configurations as you want, just need to build corresponding models in Simulink. New algorithms can also be easily added. First, the optimization procedure is introduced and it's compared with traditional optimization methods; then some details on how to deal with different vehicle configurations are described; at the end of this paper, an example of FCEV will be presented.

2 Optimization procedure

A traditional way to choose components is like this: basic targets such as acceleration time, fuel consuming rate, maximum speed and max grade are specified at first; in order to achieve these targets, a couple of formulas and some experiences are used to calculate ranges of components' parameters; finally components will be chosen based on the ranges. In this way we can find components which will satisfy the basic needs but the results can not be optimized.

The sizing method provided here can be summarized as following: using results from the traditional way as constraints or initial values, and using optimization algorithms to find adequate components' parameters which can maximize/minimize an objective value.

The optimization is operated under the circumstance of MATLAB/Simulink. To accomplish this task, some files should be created: Optimize.m, Parameters.m and Vehicle. mdl. The Vehicle.mdl file should be a model file built in Simulink, and it consists of models of components and control strategies; the Parameters.m file is in charge of storing up parameters like vehicle weight, wheel radius; Object function and performance targets are displayed in Optimize.m. These files are working as follows:

- Parameters.m runs at first, to initialize the working space.
- Optimize.m generates initial vehicle parameters and passes these parameters to Vehicle.mdl.
- Vehicle.mdl runs to get an objective value and some performance values, these values are feed back to Optimize.m.
- According to the information feed back, Optimize.m automatically adjust the former vehicle parameters depending on optima-zation algorithms.
- Then the new parameters are passed to the Vehicle.mdl to start a new simulation. The loop goes on and on till the objective result is good enough or the maximum recurrent number is achieved.

There are so many parameters in a vehicle; it's computational expensive and time-consuming to optimize all of them. So we should only choose a few critical parameters to optimize. Some parameters are fixed, such as vehicle mass, front face area and so on; they are determined by engineers at the very start, so they're not taken into consideration. The crucial parameters chosen by this paper are: power rate of the engine, power rate of the motor, capacity of the battery. Surely, the more parameters are to be optimized, the more optimized the results are, and the more complex and time-consuming this process is.

The objective function chosen here is the overall fuel consumption; it is constituted by two parts: fuel consumption of the APU and SOC compensation.

The constraint is built according to the requirements of max velocity, max grade and acceleration time.

3 Details

Although the basic optimization procedure is introduced, but still lots of problems are waiting to be solved like how to deal with different vehicle configurations and what optimization algorithms should be chosen. So let's discuss this now.

3.1 Models

The vehicle models are very important for the optimization. It has to be adequate enough so the final optimization results can be meaningful. There are a few ways to build vehicle models:

- Build new vehicle models directly in the Matlab/Simulink environment. The vehicle models can be built totally as you designed in this way, but that's a huge work and the results are not so convincible. It's suitable if one only wants to build an easy model to test this method or want to save time.
- Call models from mature simulation tools such as PSAT or ADVISOR. These tools can run in a non-GUI environment. But the delivery of parameters is a little complex. And lots of time would be taken when models are adequate enough.

3.2 Vehicle Configurations

There are hundreds of vehicle configurations worldwide, one should construct the corresponding configurations before optimization. Different configurations should be treated differently during optimization while determine the degree of hybridization. Three basic kinds of vehicle types are discussed in this paper: serial (Fig. 1); parallel-coupling before transmission (Fig. 2); parallel-coupling after transmission (Fig. 3).

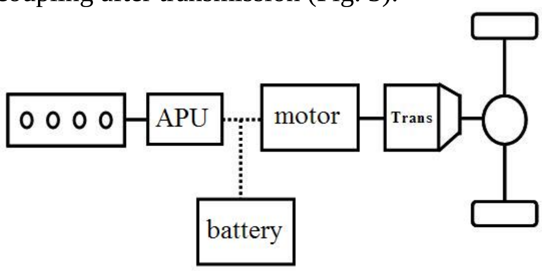

Figure1: Serial Configuration

In serial condition, all mechanical energy is output by the motor, the APU doesn't connect to the transmission directly. So the selection of motor is based on the maximum overall vehicle dynamic demand; power is allocated to the APU and the battery according to the control strategy. So the sizing of APU and the battery is important here.

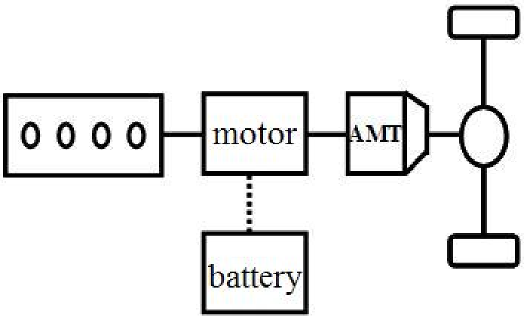

Figure2: parallel-coupling before transmission

In parallel-coupling before transmission type, in case of the optimization process be influenced by shifting methods and discontinuous transmission ratios, the transmission parameters should be fixed at first. Then the problem changes to sizing the APU and the motor. The parameters of the battery can be derived from the motor.

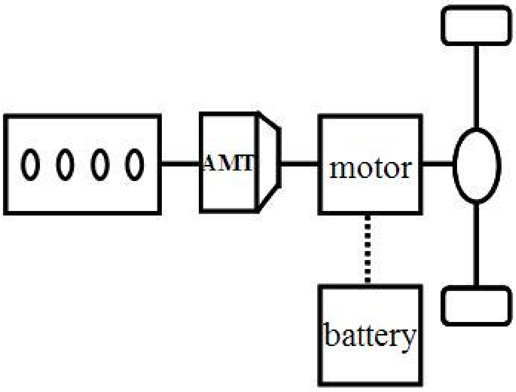

Figure3: parallel-coupling after transmission

In parallel-coupling after transmission type, the engine and the transmission shall be seemed as a whole at first, and this combination is considered as an ideal motor. Then the control strategy decides the power distribution between two motors. After that, parameters of the battery are derived from the real motor, and the engine and the transmission are optimized using traditional ways.

3.3 Control Strategies

For different configurations, different kinds of control strategies should be used. So it's better if control strategies can be chosen freely during the process.
Take serial HEV for an example, two basic control strategies can be used: Thermostatic strategy and Power Following strategy. The vehicle will operate by Thermostatic based on three rules: 1) The engine turns on when the battery reaches the SOC low limit; 2) The engine turns off when the battery reaches the SOC high limit; 3) The engine operates at the most efficient speed and torque level according to the feature of engine. In energy following strategy, the engine is always on, and the energy output is changed based on the energy requirement.

3.4 Optimization algorithms

Lots of algorithms are tested on vehicles recently. We choose the most common algorithms here: SQP and DIRECT.
SQP is a well-known local algorithm which uses derivative information to find the local minima and it does not search the entire design space; it is not proper enough to be used here because the system is enormous and noisy, derivative information can not always be found;[2] but because this algorithm is mature and widely used, we still list it here to contribute a compare.
In Keith Wipke's opinion, DIRECT is the best non-gradient based method to find the global optimum solution for HEV power control strategy, DIRECT moves towards the global optimum by trisecting the multi-dimension design space and selecting the optimal rectangles. It begins at the center point of the multi-dimensional design space in the searching process. It covers the entire design space in search of global optimum and it does not have tuning parameters. [3]
Some algorithms like Genetic Algorithm and Simulated Annealing are also recommended.

4 An example

A serial fuel cell electric vehicle is used as an example. Its configuration is the same with Figure 1. The vehicle parameters and dynamic targets are displayed in table1 and table2.

Table1: Vehicle Parameters

Parameters	Values
Fully loaded mass/kg	17000
Front face area A/m2	7.95
Air resistance coefficient CD	0.7
Rolling radius Rr/m	0.475
Transmission ratio	i_1=3.6,i_2=1.86
Main reduction ratio	i_0=6.2

Table2: Dynamic Parameters

Items	Target
Acceleration time(0~50km/h)/s	≤25
Maximum velocity/km • h-1	≥80
Maximum grade/%	≥20

Table 3:Optimized Results

algorithm		result	Fuel economy/kg
Thermostatic	SQP	FC:107KW Bat:32 modules, 384V	0.164
	DIRECT	FC:102KW Bat:34 modules, 408V	0.164
Power Following	SQP	FC:110.5KW Bat:32 modules, 384V	0.344
	DIRECT	FC:92.3KW Bat:39 modules,468V	0.346

The whole systems run smoothly, different algorithms and different control strategies have all be applied, Two kinds of control strategies are used here: Thermostatic and Power Following; The results are listed in Table 3: The fuel economy results are better than that of similar vehicles. This example proves that the whole process is practical and reliable. We can use this way to match components and reduce fuel consumptions, and different optimization algorithms or control strategies can be tested, compared and chosen.

5 Conclusions

Different control strategies may result in different outcomes, so control strategies should be carefully chosen, and more control strategies should be applied. More optimization algorithms are also needed. A user-friendly Graphical User Interface has already been developed to carry out the whole process automatically.

The next step is to find an optimization method to optimize control strategies and components. A simple vehicle model is used in this paper, more adequate models should be utilized in the future.

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