A Study on the Distributed Energy of the CFA6470 Hybrid Electric Vehicle Based on the Method of the MATLAB

Deng Yuanwang  Wang Yaonan  Chen Jieping
College of the electric and information engineering, Hunan University, Changsha, Hunan, China, 410082
Email: yuanwang_deng@yahoo.com

Abstract—The paper presents an investigation of the distributed energy problem in the CFA6470 hybrid electric vehicle (CFA6470HEV). The parallel hybrid drivelines are introduced in the CFA6470HEV. The universal characteristics of the engine are achieved with the neural network model, based on the engine experiment. The optimal operating state of the engine is obtained by assuming one value of the specific fuel consumption. The power and torque of the vehicle is also calculated using four continuous ECE-15 cycles and one EUDC cycle. Thus the operation rule of the electric motor can be achieved. The state of charge of the battery pack has been evaluated by using the energy conservation between the electric motor and battery pack. The results show that the method is feasible. Both of the operating state of the vehicle and the state of charge of the battery pack can be controlled correctly.

Keywords—Hybrid electric vehicle, the neural network toolbox, the universal characteristics of the engine, the state of charge of the battery pack.

I. INTRODUCTION

In a world where environment pollution and energy crisis are growing concerns, the development of electric vehicles (EVs) has been paid highly attention in many countries. With the broad definition in mind, EVs may include battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and fuel-cell electric vehicles (FCEVs) [1]. As the energy density of the battery is lower than that of the fuel, BEV is mainly suitable for the short-range low-speed community transportation. The technology of FCEV is still in the development stage for its cost and refueling system are the major concerns. HEV utilizes two propulsion systems, an internal combustion engine and an electric motor powered by the battery pack, combined together to provide the drivelines in which the two elements act independently or as is more usual, complementary to each other. Since the two elements can operate in the optimal state, HEV presents better performance than that of the traditional vehicle, but it is more complex and has higher cost. The paper studies the distributed energy problem in the CFA6470HEV, based on the method of the MATLAB.

II. THE CONFIGURATION OF THE CFA6470HEV

CFA6470HEV is an off-road parallel hybrid electric vehicle, converted from CFA6470G. The configuration of its propulsion systems is demonstrated in figure 1 [2]. In the drivelines, the engine drives the rear wheels independently, and the electric motor drives the front wheels independently. There has no transfer case in the drivelines. When the power needed by the vehicle is too big or too small, the electric motor will assist the engine to operate in the optimal state, thus the vehicle have the optimal performance.

III. THE METHOD BASED ON THE MATLAB SOFT

The engine of HEV operates in the optimal state. It is the one reason why the performance of HEV is better than that of the internal combustion engine vehicle [3]. Since the engine performance is very complexity with high nonlinear, the MATLAB toolbox is introduced to study the engine performance so as to simplify the model
design.

A. Neural network toolbox

Whereas the universal approximation capabilities of the multilayer perceptron make it a popular choice for modeling nonlinear systems, it has been proved that the method was successful to simulate the engine performance in the past work [4]. When the neural network toolbox is used to design a model, there are usually three steps [5]. Firstly, the network must be initialized with the function of initff. It is suitable for the network that has not more than three hide layers. When the network has one hide layer, it can be showed as follows:

$$[w, b] = \text{initff}\left(X_k, S, f\right)$$  \hspace{1cm} (1)

In the formula, $w$ and $b$ is the weight and bias vector of the network respectively, $X_k$ is the input vector, $S$ is the neuron number, and $f$ presents the active function. A suitable weight and bias vector can be achieved with the formula.

Secondly, after the network has been initialized, it will be trained with the function of train by utilizing the sample data. It is also suitable for the network that has not more than three hide layers. There are several functions that can be used to train the network. When the network has one hide layer, they can be showed as follows:

$$[w, b, te, tr] = \text{trainbp}(w, b, f, X_k, D_k, tp)$$  \hspace{1cm} (2)

$$[w, b, te, tr] = \text{trainbpx}(w, b, f, X_k, D_k, tp)$$  \hspace{1cm} (2)

$$[w, b, te, tr] = \text{trainlm}(w, b, f, X_k, D_k, tp)$$  \hspace{1cm} (2)

In the formula, $te$ shows the actual training number, $tr$ shows the row vector of the sum squared error, $D_k$ is the goal vector corresponding to the input vector, $tp$ is a parameter set selected by the investigator. A good network can be achieved by adjusting the parameter values of $tp$.

Finally, the simulating results can be obtained with the function of simuff in the network by utilizing the predicting samples. In the same way, it can be showed as follows:

$$Y_k = \text{simuff}\left(X_k, w, b, f\right)$$  \hspace{1cm} (3)

In the formula, $Y_k$ presents the actual simulating result vector.

B. Statistics and spline toolbox

In the data processing, both of the curve fitting and spline are available. In order to obtain the optimal operating state of the engine with the best specific fuel consumption and minimum emissions, the universal characteristics of the engine are processed with the polynomial fitting function and spline function in the statistics and spline toolbox, based on the above work. A polynomial can be found with the function of polyfit to fit the known data. It can be showed as follows [6]:

$$p = \text{polyfit}(x, y, n)$$  \hspace{1cm} (4)

In the formula, $x$ and $y$ are the known data, $n$ is the scale of the polynomial.

Similarly, a spline function can be achieved with the given data. It also can be showed as follows [6]:

$$p = \text{spline}(x, y)$$  \hspace{1cm} (5)

In the formula, $x$ and $y$ are the known data.

IV. STUDYING THE ENGINE PERFORMANCE AND ITS OPTIMAL OPERATING STATE

Once the size and type of the engine is chosen, its optimal performance can be determined. In development of the CFA6470HEV, some experiments for the engine were done in the condition of every defined speed, such as the torque, specific fuel consumption, throttle opening angle of the engine had been measured in the experiments. The results presenting the relationship between the torque and specific fuel consumption are showed in figure 2. The x-coordinate shows the torque. The y-coordinate shows the specific fuel consumption. The legend 1 to 10 presents the engine speeds from 1000rpm to 5500rpm.

According to the formula (1), (2) and (3), in order to study the engine performance, the neural network model of the engine is built by selecting the speed and torque as the inputs of the network, the specific fuel consumption as the output of the network. Therefore, the universal characteristics of the engine have been obtained with the model using the experiment results in figure 2, and showed in figure 3. The x-coordinate shows the engine speed. The y-coordinate shows the engine torque. The contours show the specific fuel consumption ($\text{g/(kW}\cdot\text{h})$). Assuming that when the engine operates in the optimal state, its maximum specific fuel consumption is equal to $275\text{g/(kW}\cdot\text{h})$. According to the universal characteristics of the engine showed in figure 3, the engine optimal operating range has been presented with the close curve.

![Fig.2. Results of the torque and specific fuel consumption](image-url)
in figure 4. Its coordinates are the same as those in figure 3. The real line is the optimal operating line of the engine achieved with the formula (4). The dashed is also the optimal operating line of the engine achieved with the formula (5). In hybrid drivelines, the engine will be controlled to operate on the optimal line [7]. Since the emissions of the engine were not measured in the experiment, the optimal operating line of the engine presents the optimal fuel economy line.

V. STUDYING THE DISTRIBUTED ENERGY OF THE VEHICLE

In the light of the ECE-EUDC cycles, the simulation has been done for the CFA6470HEV. The power of the vehicle can be calculated with the following formula [8]:

\[ P = \frac{1}{\eta_T} \left( \frac{GfV_a}{3600} + \frac{G_i V_a}{3600} + \frac{C_D A V_a^3}{76140} + \frac{\Delta G V_a \, dV}{3600 \, g \, dt} \right) \] (6)

In the formula, \( P \) presents the power of the vehicle, kW; \( \eta_T \) presents the efficiency of the transmissions; \( G \) presents the vehicle weight, N; \( f \) presents the coefficient of rolling friction; \( V_a \) presents the speed without wind, \( km/h \); \( i = \tan \alpha \), \( \alpha \) presents the road gradient; \( C_D \) presents the coefficient of the air resistance; \( A \) is the area of the windward, \( m^2 \); \( \delta \) presents the conversion coefficients of the operating mass, \( (\delta > 1) \); \( g \) presents the gravity acceleration \( g = 9.8 \, m/s^2 \); \( \frac{dV}{dt} \) presents the vehicle acceleration, \( m/s^2 \).

The power of the vehicle has been calculated and showed in the figure 5. The torque on the wheel can also be calculated by utilizing the following formula, and showed in Figure 6.

\[ T_t = F_r r = 3600 \times \frac{P}{V_a} \] (7)

In the formula, \( r \) presents the wheel radius. According to figure 4, when the engine operates in the optimal state, both of the power and torque provided by the engine is known. Since the power of the vehicle is provided by both of the engine and motor, therefore, both of the power and torque of the motor can be calculated. They are showed in the figure 7 and 8 respectively.

For the motor operating state is decided by the state of the charge of the battery pack, when it drives the vehicle, the battery pack provide the electric energy to the motor, the state of the charge of the battery pack will be decreased. On the contrary, the motor provides electric energy to the battery pack, and the state of the charge of the battery pack will be increased. Assuming that the initial value of the state of charge of the battery pack is known, on the basis of the conservation of the energy between the engine and battery, the state of the charge of the battery pack has been achieved and showed in the figure 9.
Since the neural network model is based on the engine experiment, the engine performance should be perfectly presented with the experiment data. When initializing the network, one suitable value for the weights and biases should be selected according to the error between the simulating results and the experiment data. The parameters of $tp$ that influence the convergence time and precision of the network are also selected in the light of the training results for the network. It is obvious that the parameters of the model is not only, there are some differences for different user. But the results obtained with the model are almost the same.

When studying the optimal state of the engine in HEV, since the specific fuel consumption of the engine is decided in advance by the user, it is a changeable variable. In the study, the engine emissions were not measured, thus the optimal economy line is considered as the optimal operating line.

The motor operating modes are relative to the SOC of the battery pack. Thus the SOC of the battery pack must be estimated continuously when the vehicle operates. The SOC of the battery pack must be in a rational range so as to make it have a long life [9].

VII. CONCLUSIONS

The universal characteristics of the engine and its the optimal operating state have been achieved with the method of the MATLAB. It is proved that the method is feasible.

According to the ECE-EUDC cycles, the distributed energy between the engine and motor has been obtained, based on the optimal operating state of the engine. The SOC of the battery pack has also been estimated in the cycles. Thus the vehicle can operate in term of the given states, and has the optimal performance.

REFERENCE