Research on SOC estimation of battery based on BP neural network

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Abstract. State of charge (SOC) estimation is the core function of the battery management system of new energy vehicles. In this paper, BP neural network algorithm is used to estimate the real-time SOC value of the battery according to the working voltage, current, temperature, internal resistance and SOC of the previous moment. In order to improve the estimation accuracy, the initial weights and thresholds of BP neural network are optimized by genetic algorithm. The test results show that the estimation error of the optimized neural network is significantly reduced.

1. Research background of SOC estimation
SOC (state of charge) is the ratio of the remaining capacity of the battery to the rated capacity. The accurate estimation of SOC is helpful to make the most of the storage capacity of the battery while avoiding the overcharge and discharge of the battery, so as to improve the utilization efficiency and cycle life of the battery.

Therefore, the realization of SOC estimation function is the core problem to be solved in the design of new energy vehicle battery management system. Since SOC can't be measured directly, it can only be obtained indirectly through the external characteristic parameters of battery (such as internal resistance, voltage, current, temperature, battery self discharge, aging degree, etc.). Although researchers have made a lot of hard work for a long time, the accuracy of SOC estimation is not ideal. This is mainly because there are many parameters that affect SOC, and each parameter is highly nonlinear with SOC, so it is difficult to get accurate estimation results through a single parameter.

This paper attempts to use neural network algorithm to estimate SOC. Neural network is a complex nonlinear system formed by a large number of simple processing units (neurons), which can simulate the reaction process of biological neural system to the outside world. It does not need any prior formula, it can automatically summarize and sort out the existing data, and obtain the internal law [1].

2. Analysis and simulation tools
This paper uses MATLAB neural network toolbox to estimate SOC of battery. Matlab integrates matrix operation, numerical analysis, graphic display and signal processing to build a user-friendly, convenient and practical environment. Users can call functions related to network design and training in neural network toolbox according to their needs, without tedious programming [2].

The data used in the training and testing of the neural network in this paper are obtained through the Advanced Vehicle Simulator (Advisor). Advisor is an electric vehicle simulation platform developed by
National Renewable Energy Laboratory in the environment of MATLAB / Simulink software. It is one of the most widely used simulation software at present. The software can quickly analyze the power performance, fuel economy and emission performance of specific traditional vehicles, pure electric vehicles and hybrid vehicles by modifying vehicle parameters, component models or control strategies, so as to realize the optimization calculation of specific vehicle models.

In this paper, the hybrid vehicle model of hydrogen oxygen fuel cell and battery is configured in Advisor, and the power battery group adopts ESS_L17_TEMP lithium-ion battery. The model block diagram is shown in Figure 1.

![Model block diagram of hybrid fuel cell and battery](image)

**Figure 1. Model block diagram of hybrid fuel cell and battery**

### 3. Estimation of SOC using neural network

Considering the difficulty of obtaining SOC related parameters, this paper uses the working voltage, current, temperature, internal resistance of the battery and the SOC at the last moment as the input of the neural network, and the SOC at the moment as the output of the neural network. The function relationship is:

$$SOC_t = f(U_t, I_t, T_t, R, SOC_{t-1})$$

In the parameters of input layer, the working voltage, current and temperature of battery are easy to collect. However, since the formula is recursive, we need to give the initial value of SOC. For the initial state of the battery, there is no previous SOC data available. According to the research of some literatures, under the condition of high SOC of battery, the relationship between the open circuit voltage and SOC of battery can be approximately regarded as a linear relationship, so the initial value of SOC can be obtained according to the open circuit voltage before the battery starts to work.

In addition, the internal resistance of battery is an important parameter related to SOC. Although electrochemical impedance spectroscopy can obtain more accurate internal resistance value, but the electrochemical impedance equipment is complex and expensive, which is not easy to achieve in the car. Considering the practicability of the system, the approximate value of internal resistance calculated by high current discharge method is used as the reference of neural network prediction, that is, the difference between the corresponding open circuit voltage and the current working voltage of the battery under the current state of charge is divided by the current working current of the battery, which is the internal resistance of the battery. However, the open circuit voltage corresponding to the battery at the current state of charge is not a fixed parameter and needs to be updated and collected in real time.

Because most of the hybrid vehicles of fuel cell and battery are power hybrid energy configuration schemes, that is to say, fuel cell provides a large proportion of power, while battery is only used as auxiliary energy to make up for the lack of dynamic power output characteristics of fuel cell. Therefore, the open circuit voltage of the battery can be obtained under two kinds of vehicle operating conditions. In the first condition, at some time when the car is running, the car is powered by the fuel cell alone. If the car is not braked at this time, that is to say, the battery does not recover the braking energy at this time, then the battery is in an open circuit state, and the battery voltage collected at this time is the open circuit voltage of the battery; in the other case, during the actual operation of the car, especially in the case of urban road conditions, the car is often in the state of waiting for driving, the battery does not output electric energy, if the fuel cell does not charge the battery at this time, then the battery voltage is also the open circuit voltage of the battery. Although the accuracy of the internal resistance value obtained by using high current discharge method is not very high, at present, there is no perfect way to
measure the internal resistance on-line, so the internal resistance value obtained by this way is used as a reference value of neural network to estimate SOC.

3.1. Data collection and processing
The data is divided into training data and test data. The basic task of training neural network is to ensure that the trained network model has a good generalization ability for non training samples, that is, it can effectively approach the inherent law contained in the samples, not only fit the training samples. To analyze the generalization ability of the established network model to the inherent laws contained in the samples\cite{3}, non training sample error should be used to evaluate, so the total sample must be divided into two parts: training sample and test sample. In this paper, the training data and test data of the network are all from the Advisor. The data in the Advisor is used for the training and test of the neural network, which is not much different from the results generated by the real vehicle operation data.

![Figure 2. Vehicle operation condition of neural network learning and testing](image)

In order to make the trained neural network have a wider range of application, the battery data obtained in the mixed condition of 3UDDS + 1HWFET is used for neural network learning. UDDS is a kind of cycling condition developed by EPA to test various performances of vehicles on urban roads. The cycle time is 1370s, the total distance is 11.99km, the average speed is 31.51km/h, the maximum deceleration is -1.48m/s$^2$, the maximum acceleration is 1.48m/s$^2$, and the number of stops is 17. HWFET represents the operation condition of expressway. The test data uses the battery information obtained under the condition of INDIA_URBAN_SAMPLE. The total driving time under the condition of INDIA_URBAN_SAMPLE is 2689s, and the maximum speed is less than 40km/h, which represents the condition of frequent stop and start under the urban road condition. The specific speed time curve under the two working conditions is shown in Figure 2.
The voltage, current, working temperature, SOC and other information of the battery under different road conditions are obtained through simulation calculation. As the data of BP neural network learning and testing, the data obtained from simulation is shown in Figure 3 and Figure 4. In addition, in order to speed up the convergence of neural network and reduce the difficulty of calculation, data preprocessing is also needed, usually normalizing the data to [0,1], the normalized data is more convenient for neural network learning and training.

3.2. Using genetic algorithm to optimize neural network
In this paper, BP neural network is used to predict SOC. Because BP network is easy to fall into local minima, cause oscillation effect and slow convergence speed, which lead to the reduction of network
generalization ability\cite{5}, the initial weight and threshold value of the network are optimized by genetic algorithm\cite{6}, so that the optimized neural network can better predict the output.

Firstly, the fitness function is used to calculate the individual fitness value, and then the individual corresponding to the optimal fitness value is found by selection, crossover and mutation. Genetic algorithm optimizes the initial weight and threshold of BP neural network, and the trained network can predict the output of function more accurately.

3.3. Test of optimized neural network

When testing, if the error of non-training samples is very small, it can be considered that the established network model has effectively approximated the law contained in the training samples. If the difference is large, it means that the established network model does not effectively approximate the law contained in the training samples, but only reflects the error of the law contained in the training samples\cite{7}. For the trained network, the INDIA_URBAN_SAMPLE cycle condition provided in Advisor is selected for testing. Firstly, the battery data obtained under the condition of INDIA_URBAN_SAMPLE are imported into the neural network before and after the optimization of genetic algorithm for calculation, and then the final neural network prediction value is compared with the actual target output value, and the result is shown in Figure 5.

![Figure 5. SOC prediction value, actual value and estimation error](image)

The above figure (a) and (b) respectively show the predicted value and error of BP neural network before optimization, and the maximum error range is about 10%. Figure (c) and figure (d) show the prediction value and error of BP neural network after optimization respectively. The error can be controlled within 5%. Compared with that before optimization using genetic algorithm, the prediction error is significantly reduced.

4. conclusion

In this paper, BP neural network is used to estimate the real-time SOC value of the battery by taking the working voltage, current, temperature, internal resistance of the battery and SOC of the previous time as the input layer of the neural network. In order to improve the accuracy of estimation, the weight and threshold of neural network are optimized by genetic algorithm. The results show that the prediction error of the optimized neural network is significantly reduced. Using neural network to predict SOC can avoid the complex process of electrochemical reaction modeling inside the battery, and can achieve a relatively high estimation accuracy.
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