# Study on Battery Energy Management and Optimization Strategy for Electric Vehicles

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**Abstract:** Electric vehicles with the advantages of low noise, zero emission and energy saving are the development trend of automobile industry. But due to the influence of current battery technology, the driving range of electric vehicles is far from the level of fuel vehicles. Fortunately, excellent battery energy management control strategy can solve this bottleneck problem to a certain extent. HESS energy management strategy is widely used in electric vehicle. However, compared with the traditional EV with single power supply, the energy management strategy of electric vehicle with HESS is more complex, because it needs to allocate input / output power to each power supply according to the appropriate driving conditions. Therefore, this paper analyzes the working status of the HESS, summarizes the logic framework of the energy management strategy, and then analyzes and determines the appropriate logic threshold parameters from a reasonable perspective, and finally proposes an energy optimization management strategy.

## 1. Introduction

As a new vehicle, electric vehicle (EV) has the advantages of no exhaust emission, energy saving and environmental protection. Power battery is just like the heart of people, and it is the core component of EV. The research and development of battery energy management control has been a key factor affecting the industrialization of new energy vehicles. If there is no breakthrough in this field, it is difficult for electric vehicles to gain advantages in the competition with traditional fuel vehicles in terms of cost and service life. When the electric vehicle is running in the urban condition, it needs to start, accelerate, decelerate or brake frequently, which will form a high peak power. During braking and long downhill, most of the braking energy will be wasted, and the battery cannot bear the feedback pulse current during regenerative braking, and frequent pulse current will damage the internal structure of the battery and reduce its service life.

Ultra-capacitor is a kind of electrochemical capacitor with high energy density, which is hundreds to thousands times higher than the traditional electrolytic capacitor, and these characteristics can make up for the shortcomings of traditional batteries. Therefore, the traditional battery and ultra-capacitor are combined into a hybrid energy storage system (HESS), and be applied in EV. In HESS, ultra-capacitor can provide high power in the process of car start and acceleration, and avoid the impact of peak power on the battery during charging and discharging; and it can absorb energy when the electric vehicle decelerates, brakes or goes downhill for a long distance, so as to prolong the service life of the battery and reduce the energy loss of the system. However, the road information under urban conditions is usually unknown and changeable, and different from the initial driving conditions, so traditional HESS energy management optimization schemes are difficult to adapt to dynamic changes in working conditions, and it often cannot guarantee that HESS can achieve optimal EV performance in energy allocation. Therefore, to overcome these shortcomings, this paper proposes an improved scheme based on dynamic programming algorithm, and develops an optimized HESS energy management control strategy.

## 2. Traditional Electric Vehicle Battery Energy Management Solution

Traditional electric vehicles mostly use a single power battery as an energy storage component, but the power battery has the disadvantages of low power density and short cycle life, and it is

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difficult to meet the energy and power requirements of frequent starting, acceleration and braking in urban road conditions. Ultra-capacitor (UC) has the advantages of high power density, fast charging and discharging speed, long cycle life and wide working temperature range, which can form HESS with lithium-ion battery, as vehicle power source of EV. HESS uses lithium-ion battery as the main power source to provide average power, and ultra-capacitor as auxiliary energy to provide peak power. Therefore, HESS energy management strategy is widely used in electric vehicle. However, compared with the traditional EV with single power supply, the energy management strategy of electric vehicle with HESS is more complex, because it needs to allocate input / output power to each power supply according to the appropriate driving conditions.

The energy management strategy based on rule control has the advantages of high efficiency, strong real-time, simple and intuitive. The design rules of this energy management strategy are as follows:

Firstly, HESS power demand objective function F(s) is expressed as Formula (1).

$$F(s) = \begin{cases} \dfrac{1}{\tau_{bat}^{s+l}} & (P_m^* \geq 0, \text{Discharge}) \\ \dfrac{1}{\tau_{us}^{s+l}} & (P_m^* \geq 0, \text{Rescharge}) \end{cases}$$

In the formula, $P_m^*$ represents the demand power from the EV; $P_a$ represents the average value of power required for a given driving cycle; $P_{bat}^*$ represents the working power of the lithium-ion battery pack; $P_{uc}$ represents the working power of the ultra-capacitor; $P_{b\max}$ and $P_{b\min}$ respectively represent the maximum discharge power and minimum charge power allowed by the battery pack; $SOC_{ucH}$ and $SOC_{ucL}$ respectively represent the upper and lower limits of the SOC of the ultra-capacitor bank; $SOC_{batH}$ and $SOC_{batL}$ respectively represent the upper and lower limits of the battery pack SOC; $\tau_{bat}$ and $\tau_{uc}$ respectively represent the dynamic response time constants of lithium-ion battery packs and ultra-capacitors.

In the HESS energy management strategy process, according to the power demand from the EV and the working status of the battery pack and ultra-capacitor, it is divided into the following five situations:

a) Li-ion battery pack does not work. When $SOC_{uc}$ is greater than $SOC_{ucL}$, EV demand power $P_m^*$ is provided by ultra-capacitor, otherwise, HESS will not provide energy for the EV.

b) The power required by the system is less than zero ($P_m^*$<0). In this case, the EV braking energy will be absorbed by the ultra-capacitor firstly; When $SOC_{uc}$ is greater than $SOC_{ucH}$, the braking energy will be absorbed by the battery pack according to $P_{b\min}$.

c) The power required by the system is less than the average power (0≤$P_m^* < P_a$). When $SOC_{bat}$ is greater than $SOC_{batL}$, total power is provided by battery pack; otherwise when $SOC_{uc}$ is greater than $SOC_{ucL}$, Ultra-capacitors provide motor demand power.

d) The power required by the system is less than the maximum discharge power ($P_a \leq P_m^* < P_{b\max}$). The battery pack provides the required average power, and the ultra-capacitor provides peak power and absorbs braking energy. Therefore, the required power of electric vehicles should be divided into two parts: the average power is provided by the battery pack, and the remaining power is provided by the ultra-capacitor.

e) The power required by the system is greater than the maximum discharge power ($P_m^* \geq P_{b\max}$). In this situation, if $SOC_{uc}$ is greater than $SOC_{ucL}$, then the battery pack provides the maximum discharge power $P_{b\max}$, and ultra-capacitor provides the remaining required power.

## 3. Battery Energy Optimization Scheme with the Introduction of Ultra-Capacitor

Through adding ultra-capacitor to a single lithium battery to form a HESS, the input and output of energy storage system power will become more flexible. The power demand of the whole vehicle is not only borne by lithium battery, but also shared by lithium battery and ultra-capacitor. The reasonable distribution of power and energy between them is the basis of stable and efficient operation of the HESS.

The energy management strategy of hybrid energy storage system focuses on the specific distribution of power and energy in the system, which can be divided into logic threshold-based energy management strategy and optimization-based energy management strategy. The former often uses non real-time algorithms such as dynamic programming to achieve the optimal solution of energy management strategy, but it is relatively complex; while the latter is relatively simple and effective, which is convenient for practical application and testing. Therefore, this paper designs an energy management strategy of HESS based on logic threshold.

### 3.1 Working State

In the hybrid energy storage system, the function of energy management strategy is to reasonably distribute the power between the lithium battery and the ultra-capacitor according to the working state of the vehicle, and realize the complementary energy and power characteristics of lithium battery and ultra-capacitor. The development of energy management strategy should be based on the working mode of HESS. When formulating the energy management strategy, the actual working state of each component in the system should be comprehensively considered, and the specific power distribution mode should be determined according to the vehicle power demand.

According to the positive and negative power demand of the vehicle, the working state of the HESS can be divided into two categories: driving state and braking energy recovery state, which correspond to the driving condition and braking energy recovery condition respectively. The driving state can be subdivided into lithium battery separate drive state and cooperative driving state; the braking energy recovery state can be subdivided into normal recovery state and fast charging state.

In driving conditions, when the vehicle's demand for power is low, the two-way DC/DC does not work, the lithium battery will provide all the driving power of the vehicle and its output power will follow the change of the demand power. It belongs to a kind of lithium battery separate drive state. The schematic diagram of the energy flow of the HESS under lithium battery separate drive state is shown in Figure 1.

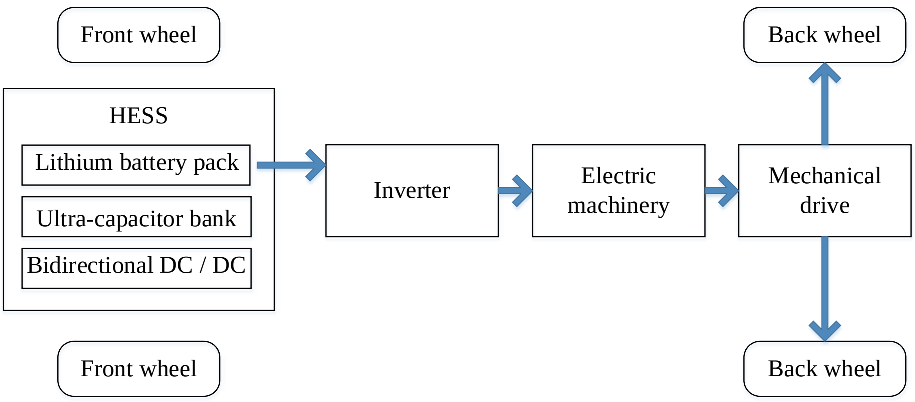


Figure 1. Energy flow of the HESS under lithium battery separate drive state

In driving conditions, when the vehicle requires high power and the ultra-capacitor's state of charge permits, the lithium battery and the ultra-capacitor will drive the vehicle together. Therefore, this working state is called a lithium battery/supercapacitor cooperative driving state. The schematic diagram of the energy flow of the HESS under lithium battery/supercapacitor cooperative driving state is shown in Figure 2.

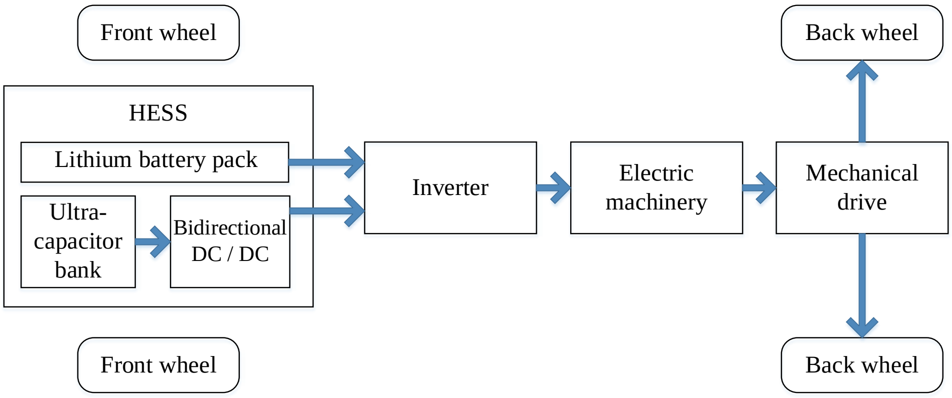


Figure 2. Energy flow of the HESS under cooperative driving state

Under the braking energy recovery condition, when the state of charge of the ultra-capacitor allows, the ultra-capacitor will be used preferentially to recover all the regenerative energy generated by the motor, so as to reduce the impact of the braking regeneration current on the lithium battery. This working state is called normal recycling state. The schematic diagram of the energy flow of the HESS under normal recycling state is shown in Figure 3.

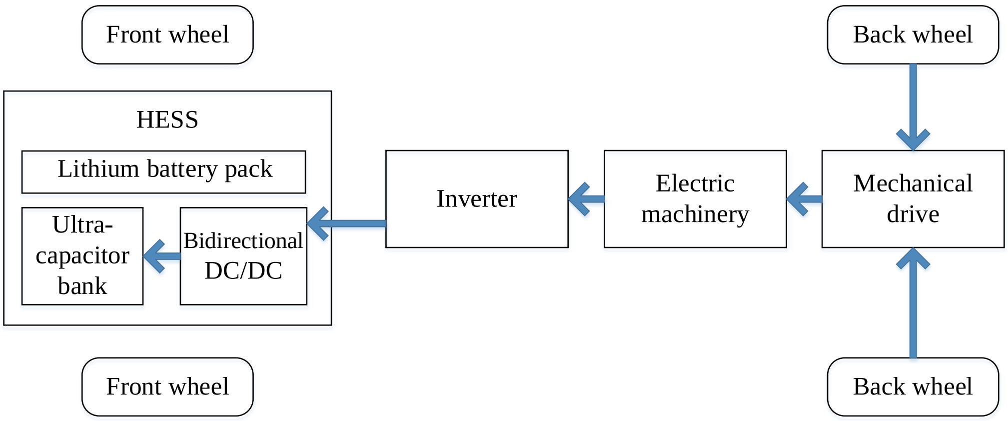


Figure 3. Energy flow of the HESS under normal recycling state

When the state of charge of the ultra-capacitor group is low and the braking power is small, the recovery speed of the ultra-capacitor group will be usually slower only by the energy recovered by braking. In addition, when the required power of the vehicle frequently jumps in the positive and negative states, the working mode of the HESS will be frequently switched between the normal recovery state and the constant power output state, which will cause frequent fluctuations in the output current of the battery. Therefore, on the one hand, in order to increase the recovery speed of the ultra-capacitor, on the other hand, in order to reduce the fluctuation of the battery output current, the rapid charging state inherited from the constant power output state is added. This state refers to the use of ultra-capacitors to recover all the braking energy when the state of charge of the ultra-capacitor is low under braking energy recovery conditions. Meanwhile, the battery also charges the ultra-capacitor with a constant power, which can greatly speed up the power recovery speed of the ultra-capacitor and reduce the current pulsation of the lithium battery when the working state is switched. The schematic diagram of the energy flow of the HESS under fast charging state is shown in Figure 4.

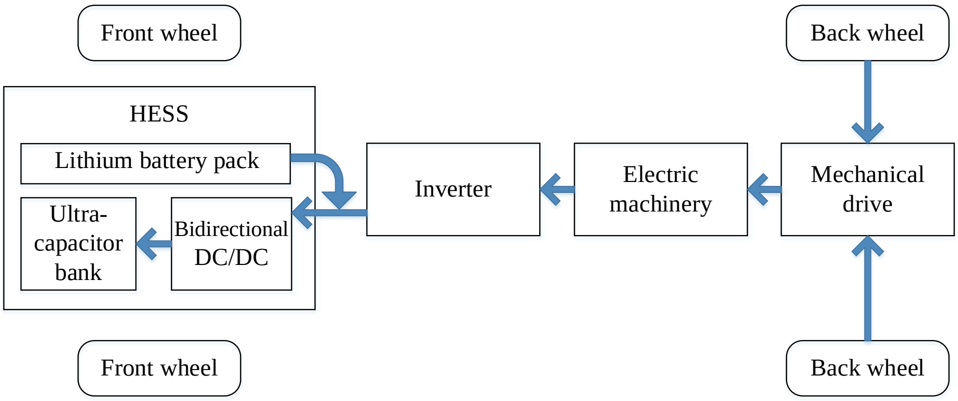


Figure 4. Energy flow of the HESS under fast charging state

In this paper, when analyzing the working state of the HESS, under driving conditions, when the vehicle power demand is low, only the ultra-capacitor driven by the ultra-capacitor alone drives the working state. At the same time, the ultra-capacitor will not charge the lithium battery pack under any working conditions. This is because the energy density of the ultra-capacitor is very low compared with that of the lithium battery. Even if the ultra-capacitor is full, all its power is recharged by the lithium battery, and the state of charge of the lithium battery is almost unchanged. In this process, the efficiency loss of the bidirectional DC / DC should be considered to further increase the energy loss.

### 3.2 Formulation of Energy Optimization Strategy

At the beginning of configuration, the core idea of HESS is to use the good power characteristics of ultra-capacitor to realize two functions: compensation of driving peak power and efficient recovery of braking energy. At the same time, in order to ensure that the HESS can work reasonably and efficiently, the ultra-capacitor should always maintain a relatively reasonable energy state. Therefore, the energy management strategy should achieve the following objectives: on the one hand, should give full play to the good power characteristics of ultra-capacitor, so that reduce the impact of peak charge discharge current and alternating charge discharge cycle on the life of lithium battery; on the other hand, the energy management strategy can adjust the energy state of ultra-capacitor actively.

According to the working state of the HESS, the specific plan of the energy optimization strategy developed here is as follows:

(1) Under driving conditions

a) When the required power $P_{req}$ of the vehicle is less than the intervention power $P_{in}$ of the ultra-capacitor, the required power of the vehicle is all provided by the lithium battery; if the ultra-capacitor $SOC_c$ is lower than the target value $SOC_t$, the lithium battery will be discharged at a constant power $P_{st}$.

b) When the required power $P_{req}$ of the vehicle is greater than the intervention power $P_{in}$ of the ultra-capacitor, if the $SOC_c$ of the ultra-capacitor is higher than its discharge threshold lower limit $SOC_{c\min}$, the excess power is borne by the ultra-capacitor, and the battery is discharged at a constant power $P_{in}$.

(2) Under braking energy recovery conditions

a) When the $SOC_c$ of the ultra-capacitor is lower than its charge threshold lower limit $SOC_{c\max}$, ultra-capacitors will be used first to recover the regenerative energy generated by the motor, and battery energy is neither output nor input; if the ultra-capacitor $SOC_c$ is lower than the target value $SOC_t$, In order to speed up the recovery speed of the ultra-capacitor and reduce the battery current pulsation, the battery will be discharged with a constant power $P_{st}$. The charging power of the ultra-capacitor is the sum of the braking energy recovery power and the battery discharge power, corresponding to the fast charging state.

b) When the ultra-capacitor $SOC_c$ is higher than the upper limit of its charging threshold $SOC_{c\max}$, it shows that the ultra-capacitor is almost full and it is not suitable for continuing to recover braking energy.

### 3.3 Protection Strategy

The above are the normal working conditions of the system, but considering the need to realize the functions of the HESS, from a safety perspective, two protection strategies have been added as follow:

a) Under braking energy recovery conditions, since ultra-capacitors are preferred to recover regenerative braking energy, when the battery and ultra-capacitors are full, the energy storage system cannot continue to recover braking energy at this time, and the charging power of the entire system will be limited to Zero. Therefore, in real vehicle environment, this rule needs to be implemented with a motor controller and a mechanical brake system.

b) Under driving conditions, when the $SOC_b$ of the lithium battery is lower than a lower threshold $SOC_{blow}$, it indicates that the power of the lithium battery is low. From the perspective of protecting the lithium battery and ensuring the continuous driving of the vehicle as much as possible, the output power of the lithium battery will be limited, and the ultra-capacitor and two-way DC/DC will no longer participate in the driving of the vehicle. Therefore, in real vehicle applications, a motor controller is required to achieve this function.

It can be seen that the selection of logic rule threshold parameters has a great impact on the execution of energy management strategies. For the logic rules in this article, the parameters that need to be determined mainly include: the threshold at which the battery's low state of charge limits the output $SOC_{blow}$ and the corresponding battery output limit power $P_{b\lim}$; intervention power of supercapacitor $P_{in}$; target state of charge of supercapacitor $SOC_t$; the upper limit states $SOC_{c\max}$ and lower limit states $SOC_{c\min}$ of charge of supercapacitors; constant output power of lithium battery assisted supercapacitor charging $P_{st}$.

## 4. Conclusion

The traditional rule-based battery energy management strategy cannot achieve global optimal performance under complex conditions. This paper analyzes the working status of the HESS, summarizes the logic framework of the energy management strategy, and then analyzes and determines the appropriate logic threshold parameters from a reasonable perspective, and finally proposes an energy optimization management strategy.


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## References


[1] Abdelrazek, Sherif, A, et al. Integrated PV Capacity Firming and Energy Time Shift Battery Energy Storage Management Using Energy-Oriented Optimization.[J]. IEEE Transactions on Industry Applications, 2016, 3(001): 55-78.

[2] Kutaiba N , Monaaf A F , Duc N H , et al. Grey Wolf Optimization-Based Optimum Energy-Management and Battery-Sizing Method for Grid-Connected Microgrids[J]. Energies, 2018, 11(4):847.

[3] Yang Y , Ling S U , Datong Q , et al. Energy Management Strategy for Hybrid Electric Vehicle Based on System Efficiency and Battery Life Optimization[J]. Wuhan University Journal of Natural ences, 2014, 19(003):269-276.

[4] Rezk H , Al-Dhaifallah M , Hassan Y B , et al. Optimization and Energy Management of Hybrid Photovoltaic-Diesel-Battery System to Pump and Desalinate Water at Isolated Regions[J]. IEEE Access, 2020, PP(99):1-1.

[5] Yang Y , Su L , Qin D , et al. Energy management strategy for hybrid electric vehicle based on system efficiency and battery life optimization[J]. Wuhan University Journal of Natural Sciences, 2014, 15(2): 23-57.

[6] A S X , B X H , A Q Z , et al. Aging-aware co-optimization of battery size, depth of discharge, and energy management for plug-in hybrid electric vehicles[J]. Journal of Power Sources, 2019: 11-47.

[7] Amini M R , Sun J , Kolmanovsky I . Two-Layer Model Predictive Battery Thermal and Energy Management Optimization for Connected and Automated Electric Vehicles[J]. 2018, 54(5): 89-106.

[8] Xie SB, Xin ZK, Li HL, et al. A Study on Coordinated Optimization on Battery Capacity and Energy Management Strategy for a Plug-in Hybrid Electric Bus[J]. Automotive Engineering, 2018, 040(006):625-631,645.

[9] Melhem F Y , Grunder O , Hammoudan Z , et al. Optimization and Energy Management in Smart Home Considering Photovoltaic, Wind, and Battery Storage System With Integration of Electric Vehicles[J]. Canadian Journal of Electrical and Computer Engineering, 2017, 40(2):128-138.

[10] Liu Y , Jiang C , Wang X , et al. Energy management with stochastic constraint and multi-objective optimization algorithm for electric vehicle battery swap station[J]. Electric Power Automation Equipment, 2013, 33(8):59-63+69.

[11] Zeng X , Berti S . New optimization method based on energy management in microgrids based on energy storage systems and combined heat and power[J]. Computational Intelligence, 2019(3), 76-97.

[12] SUN Dongye, LIN Xinyou*, QIN Datong, et al. Power-balancing Instantaneous Optimization Energy Management for a Novel Series-parallel Hybrid Electric Bus[J]. Chinese Journal of Mechanical Engineering, 2012, 5(4): 18-38.

[13] Shankar, Ravi, Marco, et al. Energies, Vol. 5, Pages 4892-4923: The Novel Application of Optimization and Charge Blended Energy Management Control for Component Downsizing within a Plug-in Hybrid Electric Vehicle[J]. 2012, 6(2): 42-71.

[14] Moradi H , Esfahanian M , Abtahi A , et al. Optimization and energy management of a standalone hybrid microgrid in the presence of battery storage system[J]. Energy, 2018, 147(MAR.15):226-238.