Research on the hybrid energy system of electric vehicle

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Abstract. In order to solve the negative problems of environment and energy caused by fuel vehicles, the application of new energy sources in the field of automobiles has gradually become the focus of attention. A hybrid energy system of electric vehicle was studied, which is composed of ultracapacitors (UCs), solar panel (namely PV) and lead-acid battery set. Through the research, it was found that the maximum power tracker can track the maximum power point of the solar panel, and the ultracapacitors with high power density and the battery with high energy density can be complementary by each other, shorten the discharge time of high current and improve the dynamic performance of the vehicle.

1. Introduction

The rapid depletion of fossil fuel and increasing environmental concern due to global warming motivates the researchers to develop cleaner and efficient drive systems [1]. The progress of vehicle technology is always accompanied by the pursuit of improving energy efficiency and promoting social sustainable development [2]. Modern electric vehicle (EV) is close to traditional fuel vehicle in terms of technical performance.

So far, a lot of research on hybrid system of solar electric vehicle (SEV) has been done by experts and scholars at home and abroad. The characteristics and model of photovoltaic power generation system applied in hybrid electric vehicle was studied by Egiziano, and compared the prototype of hybrid electric vehicle with the nonlinear numerical model [3]. After a large number of investigations, Hammad formulated the power basis for the design of solar vehicles [4]. Craparo compiled the code of "solar electric vehicle simulation" on the framework provided by TRNSYS (transient system) [5], and the team of South Bank University in London designed a series of “mad dog” SEVs, which were successful in projects such as the World Solar Challenge [6-8]. There are several problems in the use of SEVs, such as energy storage, high initial investment, battery and so on. However, these literatures show that many researches on SEV mainly focus on the design, model and application of solar power generation system. A relatively little research effort has been spent in order to track the maximum power point (MPPT) of PV panel for a SEV. The energy utilization strategy of the UC-battery hybrid energy system is shown in Figure 1. In this system, the UC meets the demand of the peak power of the vehicle, and the battery bat provides the relatively small power requirement when the vehicle is traveling at a low demand power.
Here, the hybrid energy system is designed for EV has very important practical significance: First of all, increasing the driving range of EVs effectively, not only using PV panel and battery set in parallel, effectively prolonging the driving range of the EV, but also using the characteristics of high power density of UCs, high charging current and high charge and discharge efficiency, can effectively absorb the energy of PV panel, and use UCs as auxiliary energy source when accelerating and climbing, so that the driving range of the EV can be effectively improved; Secondly, to improve the acceleration, climbing and starting performance of the vehicle, UCs can release the stored PV energy to assist battery set and be used as peak power generator in the acceleration and climbing process; Finally, the energy conversion technology and the MPPT technology of SEV design are very important for the development of new energy system such as PV power generation and wind power generation system.

![Figure 1. The energy utilization strategy of hybrid power system for SEV.](image)

2. Composition of hybrid energy system
The hybrid energy system of electric vehicle is mainly composed of solar panel module, maximum power tracker (MPPT), super capacitor, lead-acid battery pack, motor drive controller and motor. Its structure is shown in Figure 2.

![Figure 2. The hybrid energy system structure of electric vehicle.](image)

In this vehicle hybrid energy system, the main energy is provided by the battery set, and the instantaneous high power required in the process of starting, accelerating and climbing is provided by super capacitor. In this way, we can make full use of solar energy and avoid the battery working frequently in the state of high current discharge.

First of all, the vehicle for experiments was modified on the basis of a golf EV. The vehicle was provided by the Yiwei electric vehicle department of Guangzhou Dongfang Electric Appliance Co., Ltd., and the parameters before modification are shown in Table 1.
A series-excited DC motor was selected to obtain large torque at low speed. The parameters of the motor are shown in Table 2.

| Type       | EVG-222 |
|------------|---------|
| Length/mm  | 2325    |
| Width/mm   | 1210    |
| Height/mm  | 1780    |
| Total mass/kg | 300   |
| Upwind Area /m² | 0.6 |
| Coefficient of rolling resistance | 0.008 |
| Coefficient of air resistance | 0.315 |
| Brake power/ kw | 2 |
| Wheel diameter/mm | 340 |
| Transmission ratio | 6.3 |

**Table 2. Motor parameters.**

| Capacity/W | 3000 |
| Voltage/V  | 48   |
| Current/A  | 80   |
| Character of service/hour | 1 |
| Insulation/class | F |
| Magnetic excitation mode | Series excitation |
| Rotation rate/rpm | 2000 |
| Over speed/rpm, min | 6500, 2 |
| Winding resistance to housing/Ω | 500M |
| Resistance between windings/Ω | 500M |
| Series magnet coil/Ω | 0.0175 |
| Armature coil/Ω | 0.0235 |
| Speed deviation | 5% |
| Withstand voltage/V | 550 |

The lead-acid battery set is used, which has low specific energy, low price, mature manufacturing technology, and superior reliability and safety. Moreover, due to the high voltage of its single cell (the voltage of the single cell is 2.0 V, the alkaline battery is 1.2 V; the zinc-silver battery is 1.1~1.65 V), the number of batteries connected in series is less and the specific power is larger, so the acceleration performance of automobile climbing is better. A lead-acid battery set consists of six independent cells in series. The battery parameters are shown in Table 3.

| Battery type          | Battery cell voltage/V | Battery cell charge voltage/V | Voltage for battery cell charging(After cooling)/V | Number of independent batteries | Independent cell voltage/V | Independent battery capacity/Ah |
|-----------------------|------------------------|-------------------------------|-----------------------------------------------|---------------------------------|---------------------------|-------------------------------|
| Lead-acid battery     | 2                      | 2.75                          | 2.25                                         | 6                               | 8                         | 145                           |

Through calculation, the rated voltage of battery set is 48V, the capacity is 145 Ah, the recommended charging current is 15A. At present, the charging current of our charger is 25A. The PV panel used in this hybrid energy EV are not standard components purchased from manufacturers. In order to obtain the characteristics of the panel used, the characteristics experiment was carried out. Test conditions: One day in January in Guangzhou, sunny to cloudy. Detection of solar intensity using TBQ-2 total radiometer. The instrument was used primarily to detect total solar radiation of 0.3~3.2 micrometers. The fitted PV panel characteristic curve according to the experimental results is shown in Figure 3. Where Figure 3(a) is the current-voltage characteristic curve of PV panel and Figure 3(b) is the power-voltage characteristic curve of PV panel. According to the experimental results, the maximum power point of PV panel is about 84% of the open circuit voltage. According to the experimental results, boost circuit was selected.

In Figure 4, a boost circuit was used as an MPPT. The output voltage of the boost circuit was higher than the input voltage. For MPPT boost converter, the duty cycle of IGBT was directly controlled by the algorithm.

A UC group consists of 21 independent cells in series. The UC parameters are shown in Table 4.
Figure 3. Characteristics of PV panel
(a) I-V characteristic curve; (b) P-V characteristic curve.

Table 4. The UC parameters.

| UC manufacturers | Rated voltage /V | Capacity /F | Efficiency/% | DC resistanceteries/mΩ | Price/yuan |
|------------------|------------------|-------------|--------------|-------------------------|-----------|
| BEN NA           | 2.7              | 1200        | 0.78         | 0.58                    | 596       |

Figure 4. The MPPT circuit. Figure 5. The principle of subsection adaptive hill climbing method.

3. MPPT design

Many control algorithms were used to track the maximum power point of photovoltaic panels. In particular, open circuit voltage control algorithm and adaptive hill climbing control algorithm were focused on. In order to quickly respond to the rapidly changing atmospheric environment, i.e. temperature and radiation, and quickly track MPP, an improved adaptive hill climbing control method was proposed, which was mainly to quickly respond to the atmospheric environment, such as temperature and solar radiation intensity, and quickly track the maximum power point of solar panels. In this algorithm, the characteristic curve P-V of solar panel was divided into three sections, namely, the large step approaching section, the adaptive climbing section and the maximum power section (as shown in Figure 5). The flow chart of segmented adaptive hill climbing control algorithm is shown in Figure 6.

Parameter $c_1$ is a constant, while $m_1, m_2$ are two variables determined by the control requirements of MPPT system. When the MPPT system is working, if the absolute value of power changes namely $\Delta P = |P(k) - P(k-1)|$, when the absolute value of the power change is less than the threshold value, then it can be considered that the photovoltaic system has run to the maximum power point, and the program will proceed to the next cycle. On the contrary, it is considered that the photovoltaic system does not work at the maximum power point, then the output voltage $V(k)$ of the photovoltaic system is compared with the reference voltage $V_l$ and $V_u$, respectively $V_4$, shown in Figure 5. Assuming $V_l < V(k) < V_u$, the PV system works near the maximum power point, the adaptive hill climbing control
algorithm is used to track the maximum power point. However, if $V(k) < V_i$ or $V(k) > V_s$, the large step size approximation method is used to approximate the adaptive hill climbing part.

![Flow chart of segmented adaptive hill climbing control algorithm](image)

**Figure 6.** The flow chart of segmented adaptive hill climbing control algorithm.

### 4. Experimental research

On the platform of MATLAB / Simulink, the simulation model of boost circuit was established, as shown in Figure 7. The four input variables of the simulation model are input current $I_L$, current through diode $I_D$, current through IGBT $I_C$ and output voltage $V_o$.

The used parameters are:
- Input voltage $V_{in}$: 40V
- Duty cycle $D$: 0.4
- Load $R_L$: 50Ω
- Capacitor $C$: 3 μF

It can be seen from the simulation results in Figure 8 that the adjustment time, current ripple coefficient and voltage ripple coefficient of the system are less than 0.005 s, about 13% and less than 3%, respectively.

Experimental objective: In order to verify the change of starting performance of electric vehicle before and after adding UCs, an experimental study on starting performance of electric vehicle was carried out.
A physical diagram of 10 samples selected at different climatic conditions to compare the output power of PV with MPPT and without it, shown in Figure 9. The solar radiation intensity and temperature values of the 10 samples are shown in Table 5. Where a power resistance box with a load of 400 Ω is used, and its resistance value is much greater than the internal resistance of the PV panel. As is shown Figure 9, the output power of the PV panel is obviously increased relative to the output power without MPPT.

Table 5. Solar radiation intensity $S$ and temperature $T$ at 10 samples.

| Samples | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---------|---|---|---|---|---|---|---|---|---|----|
| $S$ (W/m$^2$) | 60 | 130 | 180 | 180 | 260 | 340 | 340 | 480 | 620 | 1100 |
| $T$ (°C) | 27 | 26 | 26 | 26 | 27 | 32 | 28 | 28 | 30 |    |

As is shown in Figure 9, the MPPT can effectively track the maximum output power of PV panel in various cases.

Experimental conditions; cloudy to cloudy weather, temperature 22°C, PV panel were paralleled to the DC bus. Two groups of experiments were carried out before and after the UCs were added to detect the change of discharge voltage and current of the main battery set before and after starting the vehicle

The experimental results show that before the system was added to the UCs, the voltage at the end of the battery set has obvious voltage drop when the vehicle starts, and about 2.5 s table is close to
45V. With the addition of UCs, the battery set terminal voltage was stable at 47 V, which was very close to the rated operating voltage of the battery 48 v. Before adding UCs, the battery set was in the state of high current discharge (more than 140 A) for more than 2 s when starting vehicle, and the maximum current reaches 180 A. Figure 10 shows the starting acceleration characteristic of a "pure" electric vehicle without PV panel and UCs, where the required energy is provided by the batteries. Figure 11 shows the characteristic of starting acceleration using hybrid energy when the PV panel is disconnected.

![Figure 10](image1.png) ![Figure 11](image2.png)

**Figure 10.** The characteristic of starting acceleration only using battery set.  **Figure 11.** The characteristic of starting acceleration using hybrid energy.

From the results, we can see that this short time and high current discharge is very unfavorable to the life and capacity of the batteries. After the UCs was added, the UCs started to be discharged when the battery set current is more than 80A and the battery set was kept the discharge current within 140 A. Because less power was supplied by the solar panel when the vehicle was started, the efficient MPPT is needed to maximize the storage of the solar energy converted from the PV panel into the UCs.

5. **Conclusions**

In order to make the best use of the energy, a composite energy system is proposed and designed according to the working characteristics of the vehicle. In this system, the solar energy has been fully utilized, and it can avoid the harm of high current discharge to lead-acid batteries. The economy and practicability of the vehicle equipped with the composite energy system has been greatly improved.

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