Analysis of power and energy management system for new energy dining car

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Abstract: Mobile dining car is very popular in Europe and USA because of its advantages of convenient and fast. However, most of dining cars still use traditional power and energy systems, which is not good for the environment. In recent years, the mobile dining car is developing towards light, convenient, and multi-functional. In large and medium-sized cities where business is concentrated, it is worth studying how to make the dining car cleaner and lower carbon, and make it a kind of green and healthy diet culture. In this paper, the green energy is introduced into the dining car power system and cooperated with the flywheel to realize the effective use of photovoltaic cells, achieve zero emission of the dining car, and put an end to the environmental pollution from the source. The social value and the actual effect will be great. Based on the analysis of the actual operating conditions of the dining car, the key parameters such as electrical equipment and motor load of the dining car are obtained, and then the matching calculation of the power system of the new energy dining car is carried out, including the power generation of photovoltaic cells and the storage capacity of flywheel batteries. Then, according to the unique working mode of the dining car, the energy distribution strategy and control system are analysed. Finally, a mathematical model is established and simulated with MATLAB to verify the effectiveness of the design. The results show that the system can complete the day work of the dining car.

1. New energy dining car power system parameter matching

1.1. Photovoltaic cell matching calculation

According to the power consumption of the dining car and the power generated by photovoltaic cells, the number of photovoltaic panels can be calculated.

Set the series-parallel efficiency of the battery as 0.9, and set the number of solar cells required to meet the use of the vehicle at rated power as follows:

\[ n = \frac{P_a \cdot 1000}{0.9P_n} \]  

Calculate \( n = 31.8 \), value \( n = 32 \).

In this chapter, 32 photovoltaic cell modules with a total power of 6.91 kW were selected in the dining car. According to the illumination of Shanghai and other variable factors, the power of solar cells can be calculated \( [1] \). Assume that the dining car on the photovoltaic cell components fully expanded. According to the daily lighting hours, working ten hours per day, the average illumination intensity is one third of the maximum illumination intensity, which can be calculated as, photovoltaic
cell modules receive an average of 3 hours of light per day, according to the formula to calculate power $Q = P_s \times t$.

According to the calculation, the daily output of photovoltaic cell modules $Q = 20.7$ kWh, far exceeding the normal energy consumption. Therefore, in order to match the power generation of the photovoltaic cell, a set of flywheel cells should be added.

1.2. Flywheel battery matching calculation

In this paper, the battery is designed according to the power parameters of the dining car. In the case of batteries as the only power supply, at this time, the battery should satisfy the dining car to travel 40km at a speed of 50km/h, and ensure that the highest 7kw electrical appliances work normally for 2 hours.

It is known from the analysis of working conditions that the dining car consumes 15.97 kWh of energy per day. However, considering that the self-discharge of the carbon-cellulose flywheel battery in the latest study is 5% in a day, and the energy conversion efficiency is about 95%, and the specific energy of the existing flywheel battery is not higher than 200 W·h/kg, the flywheel batteries need to store energy more than 200 W·h/kg, so the overall weight of the flywheel battery is at least 88.7 kg.

According to the formula, the mass, radius size and angular velocity of the flywheel battery can be calculated. Because the flywheel battery is a mechanical battery, its energy is calculated according to the mechanical energy. But in actual use, there will be a certain loss. So the actual parameters are shown in the table below:

| Storage capacity | Maximum power | Quality of the battery | Maximum speed | Radius of the rotor | The rotor material | The quality of rotor |
|------------------|---------------|------------------------|---------------|-------------------|------------------|-------------------|
| 18 kW·h          | 150 kW        | 90 kg                  | 450 r/s       | 0.3 m             | Composite        | 60 kg             |

1.3. Flywheel - photovoltaic system analysis and wiring control

The flowchart of energy conversion of the flywheel - photovoltaic system composed of photovoltaic wing and flywheel is shown in figure 1:

Figure 1. Flow chart of flywheel photovoltaic wing.

In the design of the new energy dining car, the photovoltaic wing is combined by 16 in series and 2 in parallel. The photovoltaic wing is controlled by MPPT controller to track the maximum power point, and its power and output voltage is monitored in real time by the monitoring end of the electronic control system[2]. After the energy distribution device is fed into the flywheel to stabilize the voltage, it is provided to the electric equipment and motor in the car. In this period, inverter is needed for Dc to Ac conversion. Finally, for the sake of safety, Dc circuit breaker and lightning protection switch are installed in the system circuit to protect the safe operation of the system[3] (as shown in figure 2).
The energy storage effect of the flywheel is quite strong. After charging in the daytime, there is no problem for the power system of the cooker to work in the evening. Therefore, it will not affect the use of the flywheel because the energy will be transformed into new energy dominated by solar energy[4].

2. Work mode and control strategy analysis

2.1. Analysis of dining car working mode
Control strategy of this paper is mainly according to the different working condition of concrete analysis, improve the service life and battery life of the dining car effectively, to put it simply, energy distribution consists of five modes: photovoltaic battery powered separately, flywheel battery powered separately, photovoltaic battery powered for load and charging for flywheel battery ,photovoltaic flywheel battery powered mixed and charging for flywheel battery . Under different conditions, how to use the five kinds of mode, is the focus of energy distribution.

The core of the whole energy distribution system is the flywheel battery, when to charge the flywheel battery, when the flywheel battery discharge, control this one, you can properly deal with the problem of energy distribution. And the diners practical block 32 solar photovoltaic panels, tightening state when driving, as shown in figure 3, the power is small, cannot satisfy the drive motor, electrical appliances, and give the flywheel battery, may also need to the flywheel battery discharge in auxiliary drive, when diners in a fixed mode, all the solar photovoltaic panels as shown in figure 4, the output power depending on light intensity and temperature of the outside world will have different change, the overall power is can satisfy a used electrical appliances and for flywheel battery.

Now the power distribution of the whole vehicle is listed as an equation:

\[ P_{me} + P_{fe} = P_{se} + P_{be} \]  

(2)

According to the above situation, the following two aspects should be considered when formulating the energy control and distribution strategy of solar energy dining car:

- To consider the SOC value of a flywheel battery, you need to put it between \( \text{SOC}_{\text{Low}} \) and \( \text{SOC}_{\text{Top}} \). That is the best operating range of the flywheel battery, which can maintain its...
service life and stable output. To do this, reserve a SOC*, which is the highest value that must be charged and the lowest value that can be charged into the flywheel battery.

- The output power of solar photovoltaic panel, because its output power varies greatly with the external environment, so even when the photovoltaic panel alone to power, also need to be in the working state of the battery. According to the different proportions of batteries, the working conditions are divided into the following four types:

  When the solar energy is supplied separately without charging the battery:
  \[ P_{me} + P_{fe} = P_{se} \]  
  (3)

  When the solar energy is supplied separately and the battery needs to be charged:
  \[ P_{me} + P_{fe} = P_{se} - P_{be} \]  
  (4)

  When no light, battery independent power supply:
  \[ P_{me} + P_{fe} = P_{be} \]  
  (5)

  When the dining car braking, there is surplus electricity:
  \[ P_{me} = P_{be} \]  
  (6)

3. Simulation

3.1. Power source engineering model of new energy dining car

The above solar cell model is to model the principle of solar power generation under ideal conditions, mainly to analyze its characteristic curve, and the research results can better match the calculation of the battery. According to the solar cells are commonly used several important parameters, such as the short circuit current \( I_{sc} \), open circuit voltage \( V_{oc} \), when the most high power voltage of maximum power point of current \( I_{m} \), \( V_{m} \), maximum power \( P_{m} \), these are available according to the battery factory, on this basis, can be simulated under certain precision solar diners a day's work, the first step first according to the principle of photovoltaic cell model established engineering practice[5]. The model is as follows:

\[
I = I_{sc}(1 - C_1) \left[ \exp \left( \frac{V}{C_2 V_{oc}} \right) - 1 \right]
\]  
(7)

At \( P_{m}, V=V_{m}, I=I_{m} \), so:

\[
I_m = I_{sc}(1 - C_1) \left[ \exp \left( \frac{V_m}{C_2 V_{oc}} \right) - 1 \right]
\]  
(8)

Because at normal temperature, \( \exp \left( \frac{V_m}{C_2 V_{oc}} \right) \gg 1 \), So the"-1" term can be ignored, work out \( C_1 \):

\[
C_1 = (1 - \frac{I_m}{I_{oc}}) \exp \left( - \frac{V_m}{C_2 V_{oc}} \right)
\]  
(9)

In the open circuit, when \( I=0, \ V=V_{OC} \), because \( \exp \left( \frac{1}{C_2} \right) \gg 1 \). Therefore, the term "-1" can also be ignored, and \( C_2 \) can be solved as:

\[
C_2 = \left( \frac{V_m}{V_{oc}} - 1 \right) \left[ \ln \left( 1 - \frac{I_m}{I_{oc}} \right) \right]^{-1}
\]  
(10)

However, this model is still to idealistic. In the practical application of the dining car, the influence of external environmental factors on the model should also be considered. For this reason, more accurate simulation should be carried out according to the changes of the external environment.

3.2. The engineering model when the external environmental conditions change

According to the above research on the \( I-V \) characteristic curve of solar cells, it shows that solar power and current are related to solar intensity and battery temperature. According to the environment of the
dining car, the change range of solar intensity on the ground in Shanghai area is 0 ~ 1000 W/m², and it is the strongest at noon. And the temperature change of the solar cell is bigger, so the change of the design range is 10 ~ 70 °C. The characteristic curve of solar photovoltaic panel is simulated [6]. When the sunshine intensity and the battery temperature are inconsistent with the standard conditions, the influence of external environmental conditions on the characteristics of solar cells must be considered. Therefore, G is set as any light intensity, and T is set as the solar cell temperature under any ambient temperature T_{air}. According to the experimental data and some data searched, the following formula is proved to be of sufficient accuracy in engineering sense [7]:

\[ T = T_{air} + K + G \]  \hspace{1cm} (11)

In the formula above, K is determined by the slope of the line T (s), According to the common characteristics of the panel as well as access to some information, \( K = 0.03 \, ^{\circ}C \cdot m^2/W \).

According to the derivation of the model and the change of the characteristic curve, two models can be selected as the actual operation of the solar power model of the dining car.

According to the I-V characteristic curve of reference sunshine intensity and reference battery temperature, the change curvature of any point \((V, I)\) can be obtained, and the movement of any point \((V', I')\) on the i-v characteristic curve under the new battery temperature. The specific algorithm is as follows [8]:

\[ I' = I + \Delta I \]  \hspace{1cm} (12)

\[ V' = V + \Delta V \]  \hspace{1cm} (13)

\[ \Delta T = T - T_{ref} \]  \hspace{1cm} (14)

\[ \Delta = -\beta \times \Delta T - R_{sc} \times \Delta I \]  \hspace{1cm} (15)

\[ \Delta I = \alpha \frac{G}{G_{ref}} \times \Delta T + I_{sc} \left(\frac{G}{G_{ref}} - 1\right) \]  \hspace{1cm} (16)

For monocrystalline and polycrystalline silicon solar cells, the test values are:

\[ \alpha = 0.0012 \]  \hspace{1cm} (17)

\[ \beta = 0.005V_{oc} \]  \hspace{1cm} (18)

Thus, the engineering model of solar panels under changing external conditions is as follows:

\[ V' = V + \Delta V \]  \hspace{1cm} (19)

\[ I' = I_{sc} \left(1 - C_1 \left[\exp \left(\frac{V-V'}{C_2 V_{oc}}\right) - 1\right] + \Delta I\right) \]  \hspace{1cm} (20)

3.3. Simulation of photovoltaic cell under actual operation condition of dining car

Since the key values of this model are all calculated above, and the main influencing factors are the input light intensity and temperature, MATLAB software is used to simulate several key input values, which can be substituted into the model to obtain relatively accurate simulation results.
All the coefficients calculated above (open circuit voltage $V_{oc}$, peak voltage $V_m$, short circuit current $I_{soc}$, peak current $I_m$) and the variables (the change of simulated voltage, light intensity, temperature changes) simulated are substituted into the model, the simulation results of output current and power are shown in figure 7:

According to the comparison between the solar power generated by the simulation and the load power obtained from the experiment above, the energy change balance of the new energy dining car studied can continue to cycle. The power of the dining car is all below the power of the power generation, and there are only three wave peaks. The remaining electricity is underestimated. The photovoltaic cell can power the flywheel battery to ensure the power supply when the light is weak. According to the comparison of figure 6 and 7, in this paper, the design of photovoltaic panels slightly larger, because its simulation model is based on light intensity at the time of the theoretical value, therefore should be performed according to the actual climate situation photovoltaic panels and battery matching calculation, different regions, different latitude and longitude of the dining cars, it should be personalized customization, in order to ensure maximum use of energy.

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