Simulink Lab Report of PV-Battery System

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ABSTRACT

This report briefly introduces four kinds of rechargeable batteries and photovoltaic (PV) systems. The model used to study the dynamic behavior of a Li-ion battery coupled with the power generation of a photovoltaic system and a house load demand. The system can charge the battery when the electricity production is higher than the consumption and the battery delivers energy to the house load when the demand is higher. According to the assignment's requirements, dedicated battery parameters and simulation input data are created. The system is run for a whole day in MATLAB, and the terminal voltage, circuit current, and SOC curves of the battery are analyzed in both charging and discharging modes. The model is proposed to accurately depict the dynamic characteristics of the battery based on the power divide between home load demand and PV generation. By analyzing and explaining the change of the curve to do the sensitivity analyses to assess the effect of the system specifications (PV production, user demand, battery capacity and battery nominal voltage). In order to improve the feasibility of the scheme, the report make suggestions on the modification of the initial data in the end.

1. INTRODUCTION

There are four primary types of rechargeable batteries: Lead-acid, Nickel-Metal Hydride (NiMH), Nickel-Cadmium (NiCd) and Lithium-ion (Li-ion).

Lead-acid batteries

In 1859, the French scientist Gaston Planté invented lead-acid battery [1], which has experienced nearly 150 years of development. In terms of theoretical research, lead-acid battery has made great progress in product types and varieties, electrical performance and other aspects, no matter in transportation, communication, electric power, military, navigation, aviation and other economic fields, Lead acid batteries have played an indispensable role. The reaction during the discharge phase is as follows：

Positive reaction: $PbO_2+4H^++SO_4^{2-}+2e^-\rightarrow PbSO_4+2H_2O$

Negative reaction: $Pb+SO_4^{2-}-2e^-\rightarrow PbSO_4$

Complete reaction: $PbO_2+2H_2SO_4+Pb\rightarrow 2PbSO_4+2H_2O$

Nickel-Cadmium (NiCd) batteries

Nickel cadmium battery is a kind of direct current power supply battery. It can charge and discharge more than 500 times [2], which is economical and durable. Its internal resistance is small, it can charge quickly, and it can provide large current for the load, and the voltage change is very small when discharging, so it is a very ideal DC power supply battery. The reaction during the discharge phase is as follows：

Positive reaction: $NiO(OH)+e^-+H_20\rightarrow Ni(OH)_2+OH^-$

Negative reaction: $Cd-2e^-\rightarrow Cd+2OH^-$

Complete reaction: $2NiO(OH)+Cd+2H_2O\rightarrow Cd(OH)_2$

Nickel-Metal Hydride (NiMH) batteries

In recent years, more and more attention has been paid to the development and utilization of hydrogen energy due to the fact that fossil fuels are less and less developed and utilized on a large scale. As an important direction of hydrogen energy application, NiMH battery has attracted more and more attention. NiMH battery is divided into high voltage battery and low voltage battery [2]. The positive active material of is $Ni(OH)_2$ (called NiO electrode), the negative active material is metal hydride, also called hydrogen storage alloy, and the electrolyte is 6mol/L potassium hydroxide solution. The reaction during the discharge phase is as follows：

Positive reaction: $NiO(OH)+e^-+H_20 \rightarrow Ni(OH)_2+OH^-$

Negative reaction: $OH^-+XH \rightarrow H_2O+X+e^-$

Complete reaction: $XH+NiO(OH) \rightarrow Ni(OH)+X$

Lithium-ion (Li-ion) batteries

Of all metals available for battery chemistry, lithium is considered to be the most promising. Apart of being widely available and non-toxic, it is very light and electropositive. This fundamental advantage over other chemistries allows lithium-based batteries to have higher potential for energy storage. Today lithium and LIBs represent about 37% of the rechargeable battery world market and their use is increasing. Particularly demand for small rechargeable cells for the four sectors such as cellular, computers, video cameras and cordless are constantly growing. Batteries consume 39% of total lithium [3]. The reaction during the discharge phase is as follows：

Positive reaction: $Li(1-x)MO_2+xLi^++xe^- \rightarrow LiMO_2$

Negative reaction: $C_6Li-xe^- \rightarrow C_6Li_{(1-x)}+xLi^+$

Complete reaction: $XH+NiO(OH) \rightarrow Ni(OH)+X$

Within the family of Li-ion battery, there are six different chemistries available in the market for now: Lithium Cobalt Oxide (LCO), Lithium Manganese Oxide (LMO), Lithium Iron Phosphate (LFP), Lithium Nickel Cobalt Aluminum Oxide (NCA), Lithium Nickel Manganese Cobalt Oxide (NMC), and Lithium Titanite (LTO) [4]. The main differences among them mainly lie on the material of cathodes, while the anodes of most of them are made of graphite except LTO [4].

2. METHODS

The inputs of the model parameters in this project are calculated as follows:

Name: Qifan, by which means β=17; Surname: Zhu, by which means γ=26.

Thus,

$$\alpha = \beta + \gamma = 43$$

$$Battery\ nominal\ capacity = 650 + 5\alpha = 865\text{Ah};$$

$$Charging\ nominal\ voltage = 12 + 0.2\beta = 15.4\text{V};$$

$$PV = PV_0 \left(0.9 + \frac{\gamma}{10}\right) = 3.5PV_0$$

$$House = House_0 \left(0.9 + \frac{\beta}{10}\right) = 2.6House_0$$

At first, the change of PV power generation and House load demand over times can be obtained as Fig.1.

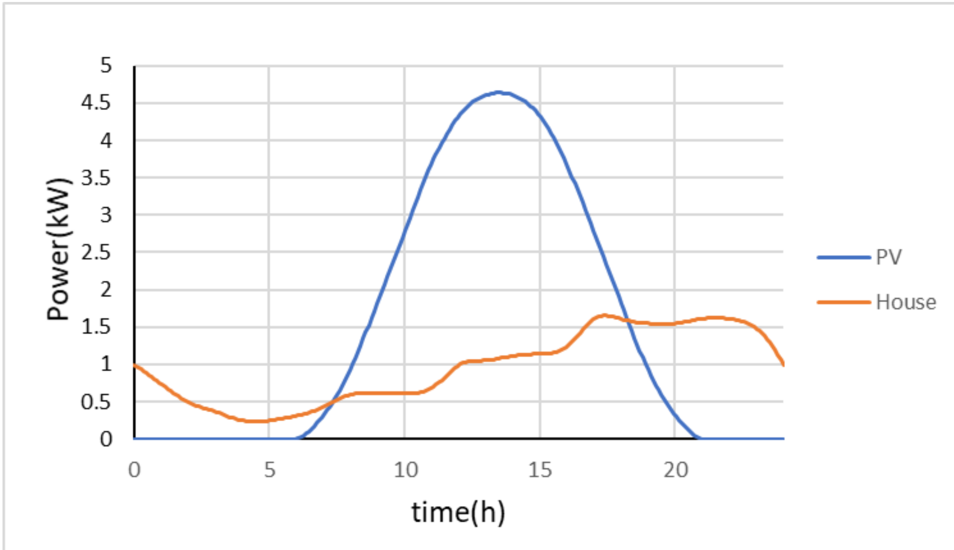


Fig. 1. Initial data.

Then we need to bring the data into the model shown in the fig.2.

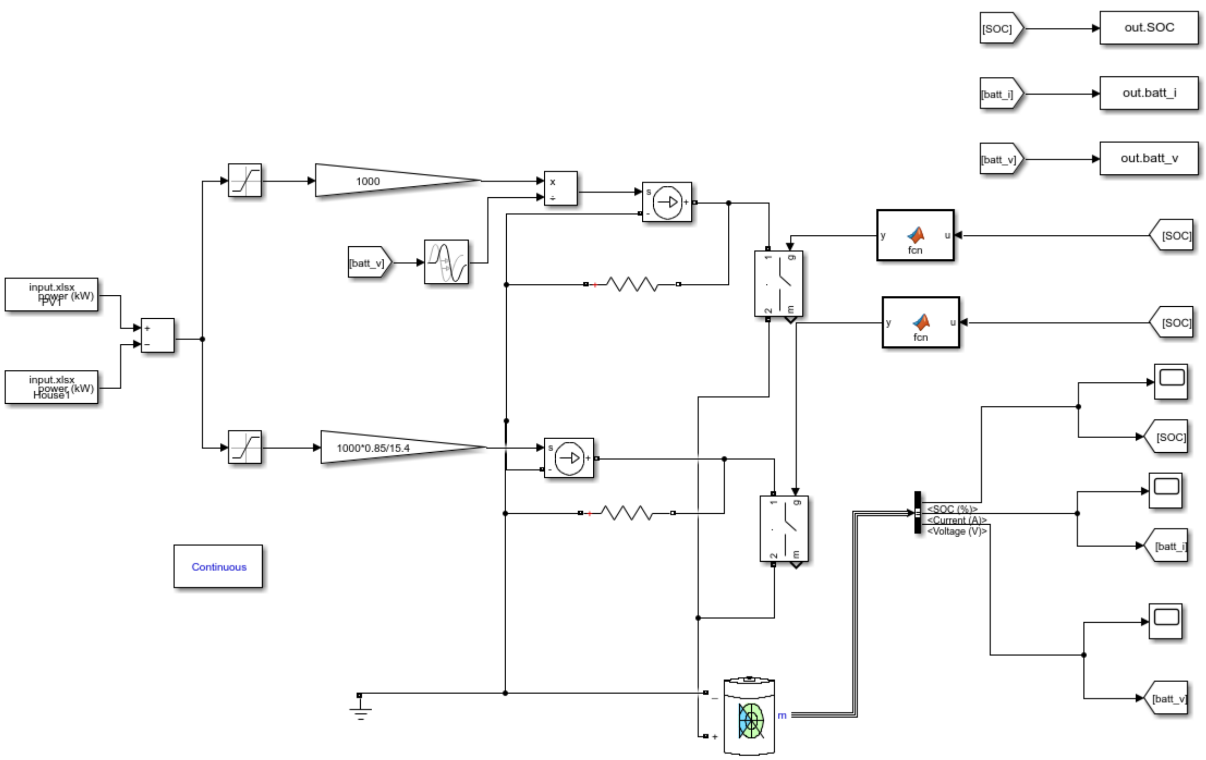


Fig. 2. System model in Simulink.

For this system, the two from spreadsheets on the left are used as our original data input points, which are the data shown in Fig. 1. The middle part is the charging and discharging circuit of the system. The upper part is the discharge circuit, and the lower part is the charging circuit. In the circuit, saturation and gain are in turn. Discharge current to meet the power demand, voltage imposed by the battery. Charge current from the surplus power. Current delivered at constant voltage imposed by a DC-DC converter with an efficiency of 0.85。

The charging current is calculated as:

$$I_{charge}=(P_{PV}-P_{USER})\times\eta_{converter}/U_{nominal\text{-}battery}$$

The discharging current is calculated as:

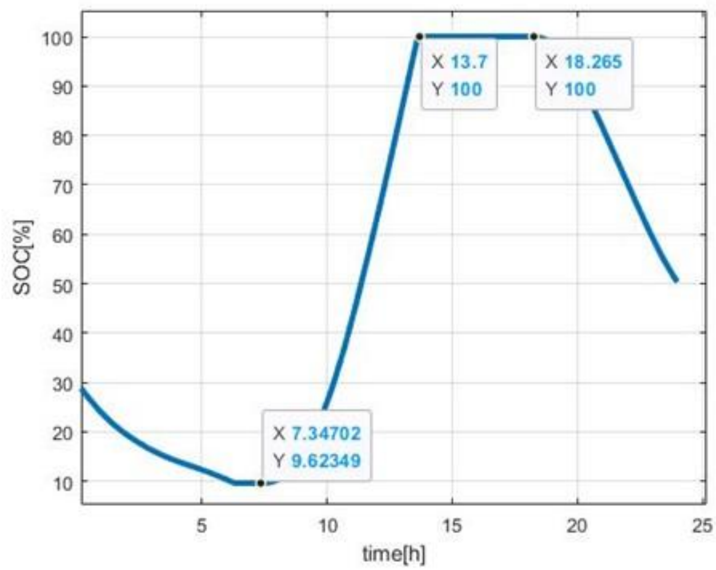
$$I_{discharge}=(P_{USER}-P_{PV})/U_{nominal\text{-}battery}$$

Current source can't be in an open circuit, so we put RLC branches as Dummy Load and ideal switch to state of charge control. Finally, the current, voltage and SOC of the battery are derived through bus selector and draw to pictures from different scopes.

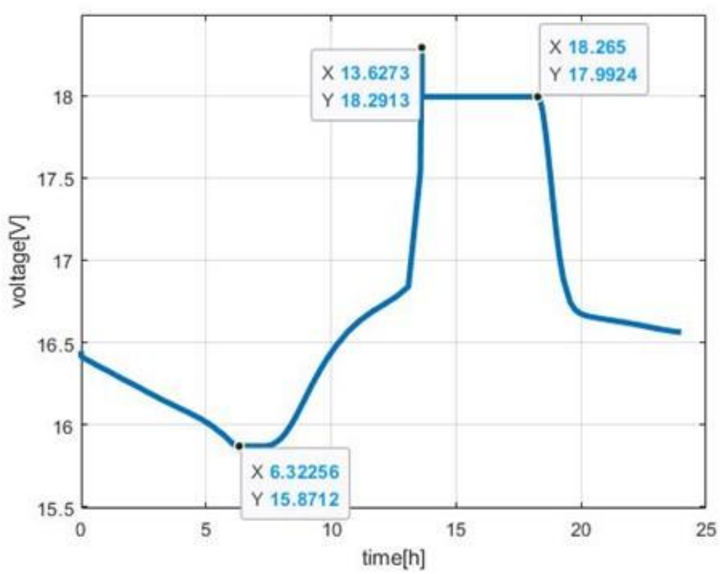
Generally speaking, in one typical day, the PV power generation would reach it peak value at the noon after sunrise and fall to zero at the sunset. On the contrary, the household power demand usually increases dramatically in the evening. During the period that power generation is larger than load demand, the surplus output from PV could be stored by charging the battery through a DC-DC converter, which could provide a constant output voltage for the battery. Vice versa, when there is not sufficient output from PV, the battery could compensate the demand in discharging mode. Since both overcharge and over discharge will cause great harm to the integrity of the battery, a simplified battery management system (BMS) is applied to open the charging circuit when the state of charge (SOC) has reached 99% and open the discharging circuit when the SOC has dropped at 10%.

3. RESULTS

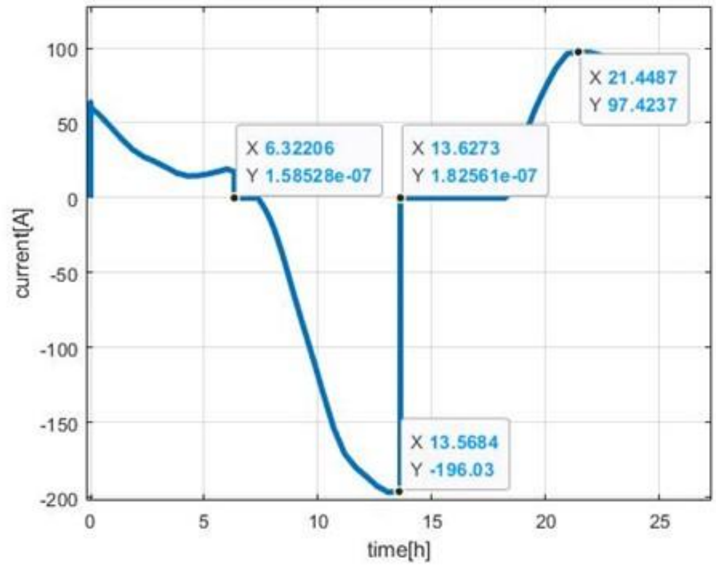
The simulated results are as follows:



(a) Battery SOC[%]-t[h] curve



(b) Battery terminal voltage[V]-t[h] curve



(c) Battery circuit current[A]-t[h] curve

Fig. 3. SOC curve of battery nominal capacity expansion attempt.

As can be seen from the three pictures in Fig.3 combine with Fig.1, there is not PV generation until 21860s (i.e., 6.07h in the day), the battery is discharging to supply the loads. The terminal voltage keeps decreasing during this process, while the circuit current varies with the net power mismatch. Though SOC of the battery falls, the lowest point is still around 10%. At the same time, the current and the voltage are decreasing.

According to the supply and demand curve, it is about 7.34h, PV power generation and house load demand are equal. Before that point, SOC, current and voltage all tends to be flat.

Between hour 7.23 and hour 13.7, the PV generation surpasses the power demand, the battery is charged. During this process, the terminal voltage of the battery and circuit current has been restored, while the negative value of the current suggests that the battery is being charged. The SOC rise to 100% dramatically. At this moment, due to the protection scheme of BMS, the charging process is stopped, which leads to a transient fluctuation of the voltage here. Then the terminal voltage of battery maintains constant and the circuit current turns to zero until 18.265h. The number of PV power generation and house load demand are equal again.

From this 18.265h to about 21h, PV generation gradually decreased to 0kWh. The battery begins to discharge again. SOC began to decline gradually, and voltage dropped rapidly. The discharging current varies following the net power demand change in the system. After that, all the data began to fall.

4. CONCLUSIONS

For this system, it can basically meet the requirements of house load demand. But there are still some problems with this system. To be specific, it can be found that during the discharge phase, the SOC value falls to under 10% as minimum, slightly lower the circuit open threshold value and battery cannot deliver the power requested by the user since it is discharged. And when the time comes from 13.7h to 18.265h, the SOC comes to 100% and the battery cannot be charged anymore. It can be inferred that full battery leads to a waste of the PV energy. Therefore, the battery is undersized for the system.

Facing the problem, we try to expand the battery nominal capacity to 1500Ah, the curve of SOC can be shown in Fig.4.

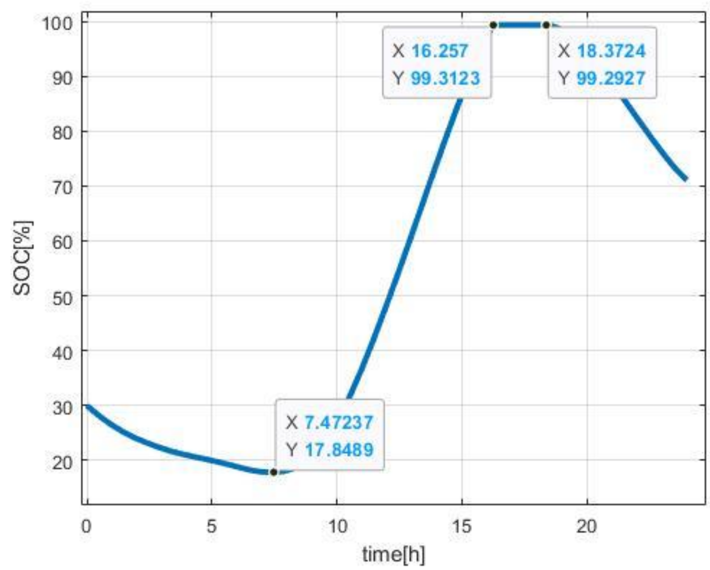


Fig. 4. SOC curve of battery nominal capacity expansion attempt.

When the capacity of the battery is expanded to 1500ah, the minimum value of SOC rises to 17.8328%. In the time from 16.25h to 18.27h, the battery is almost full, and PV generation is more used than before. At the end of the day, the final SOC increased from 50.88% to 71.04%. This shows that larger batteries can get better use of solar energy and more power reserves at the end of the day. However, the benefit relationship between the economy of large battery and energy storage and energy utilization capacity still needs to be considered.

When the charging nominal voltage is increased, the minimum value of SOC is increased, which meets the operation standard, and the charging speed is increased, and the battery saturation time is reduced. The following figure shows the change of SOC curve when charging nominal voltage rises to 20V.

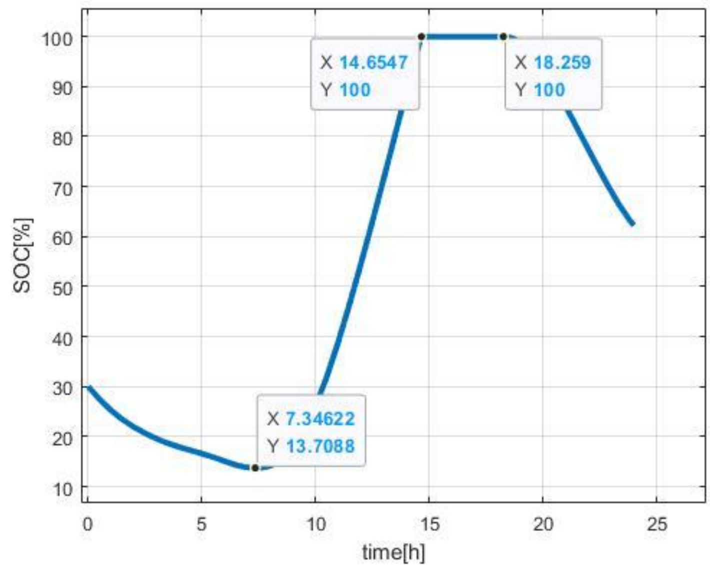


Fig. 5. SOC curve of charging nominal voltage risen attempt.

For PV power generation and house load demand, the analysis of Part 3 shows that higher the value PV and lower house load demand have a greater impact on the final remaining SOC. For this system, PV power generation is difficult to control. House load demand needs to match battery capacity and PV power generation to get higher revenue. For example, in this system, reducing the house load demand will lead to the increase of the final SOC value, but it will prolong the time of the battery in full charge, leading to PV energy waste.

To sum up, in order to achieve better results, we can appropriately increase battery nominal capacity and charging nominal voltage. If we can control house load demand, we can increase load when PV power generation value is high, such as noon in a day, and reduce the use at other times to save energy and maximize the use of renewable energy.

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