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Dynamic Control Based Photovoltaic Illuminating System

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Abstract. Smart LED illumination system can use the power from whether the photovoltaic cell or the power grid automatically based on the SOC (State Of Charge) of the photovoltaic cell. This paper proposes a feedback control of the photovoltaic cells and a dynamic control strategy for the Energy system. The dynamic control strategy is used to determine the switching state of the photovoltaic cell based on the illumination load in the past one hour and the battery capacity. These controls are manifested by experimental prototype that the control scheme is correct and effective.

1 Introduction

With the development of the economy, China's environmental problems have become increasingly serious. At present, the use of new energy is regarded as one of the major developing projects in many countries. And, it is studied that the lighting load will occupy 20% of total electric load approximately. The fast growth of electricity for lighting not only spends much funds, but will also produce environmental pollution. So, it's considerable to combine the photovoltaic cell and illuminating system.

Nowadays the combination of the photovoltaic cell [1] and illuminating system has been developed a lot. The traditional combined system determines a fixed switching SOC [2] of the photovoltaic cell. When the control system finds that the SOC of the cell is under a preset value, the system will cut out the photovoltaic cell and use the power from the power grid. When the control system finds that the SOC of the cell is above a preset value, the system will cut out the power grid and use the power from the photovoltaic cell[3].

However, this mode of the combination of the photovoltaic cell and illuminating system is rigescent. A fixed switching state of the photovoltaic cell can't reflect the conditions of the system. In the traditional combined system [4], although the cell can still power the lower-load illuminating system for several hours, It's common that the cell has to be cut out because its SOC is under the preset value.

This paper proposes a feedback control of the photovoltaic cells and a dynamic control strategy for the Energy system [5]. When the system is under the dynamic control strategy, it can be avoided that the cell has to be cut out for its SOC is under the preset value when the cell can still power the lower-load illuminating system for several hours.

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2 Traditional Mode of The Combination of The Photovoltaic Cell And Illuminating System

The voltage of the storage cell can reflect the SOC of the storage cell [6]. The traditional combined system sets the rated voltage of the illuminating system as the switching voltage of the system. When the system finds that the voltage of the discharging cell is under the switching voltage [7], it'll cut out the photovoltaic cell and input the power grid. Also the traditional system sets the working voltage of the system. The working voltage of the system [8] means that, after being input to power the system, the voltage of the no-load cell is at the state that the cell can achieve the switching voltage.

Although this method of the combination of the photovoltaic cell and illuminating system can make the energy system stable and practical, the system with this combination can't make the most of the solar energy and lack the control of the photovoltaic cells' charging . As for these questions, this paper proposes a feedback control of the photovoltaic cells and a dynamic control strategy for the energy system to ease them.

3 Dynamic Mode of the Combination Of The Photovoltaic Cell And Illuminating System

3.1 Feedback Control of the Photovoltaic Cells

To make the most of the solar energy, this dynamic control based photovoltaic illuminating system uses two cells in the energy system [9]. The charging current of the photovoltaic is monitored by AD module whose measurement data is transferred to the SCM. Once the SCM finds that the charging current is greater than the rated charging current of the cell, it'll output a signal to control the relay switch to put one more cell in the charging circuit. Also, when two cells have been put into the charging circuit, if the SCM finds that the charging circuit is half of the rated charging current of a single cell, then, it'll output a signal to control the relay switch cutting one cell out of the charging circuit. Through this feedback control of the photovoltaic cells, the dynamic control based photovoltaic illuminating system can make the most of the solar energy and increase battery lifespan. Furthermore, this feedback control is easy to be brought into life and costs little. **Figure 1** Shows the Feedback control based Energy system. **Figure 2** Shows the control flow chart of the feedback control [10].(I=the charging current of the photovoltaic; I_N=rated short circuit current)

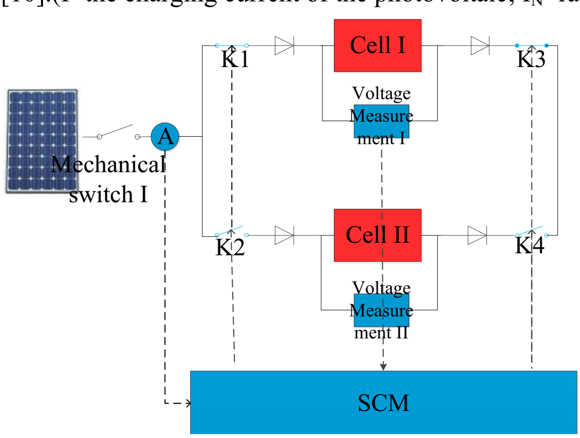

Figure 1. Feedback control based Energy system

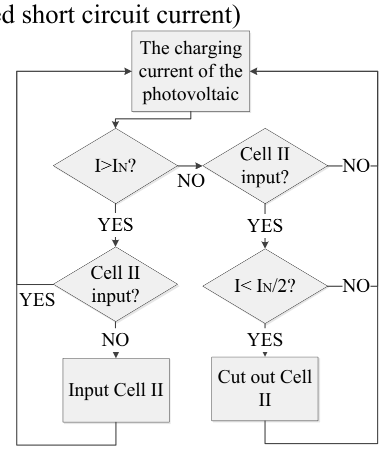

Figure 2. The control flow chart of the feedback control

3.2 Dynamic Control Strategy of The Combination

It is shown that the relationship between the SOC of the cell and the voltage of the cell is about linear by actual experiment. According to the charging and discharging curve of the cell and Battery parameters, the cell's discharging function can be calculated out approximately(This function is nearly a liner function).

When the cell is under the rated voltage of the illuminating system, we set the cell's discharging function as

$$U(t) = \mathrm{A}t+\mathrm{B} \tag{1}$$

U(t)= the voltage of the cell

t= the discharging time

A,B=the cell's discharging parameters

Furthermore, the voltage of the cell is used to reflect the SOC of the cell in this paper.

$$\mathrm{SOC} = \frac{U' - U_{\mathrm{MIN}}}{U_{MAX} - U_{\mathrm{MIN}}} \tag{2}$$

U'=the real-time voltage of the cell

U_{MAX}=the maximum voltage of the cell during the discharging phase

U_{MIN}=the minimum voltage of the cell during the discharging phase

The system uses a dynamic control strategy to make the combined system more flexible. The SCM keeps receiving the metrical data from the Voltage Measurement. Meanwhile the SCM calculate out the average load of the illuminating system in the coming one hour —Wav.

$$A' = \frac{U' - U''}{1} \tag{3}$$

$$t^* = \frac{U' - A' - B}{A'} \tag{4}$$

$$W_{av} = \int_{t^*}^{1+t^*} \frac{(A't+B)^2}{R} tdt \tag{5}$$

A'=the modified gradient of the discharging curve based on the past one –hour change of the voltage

U'=the real-time voltage of the cell

U''=the voltage of the cell one hour ago

t*=the starting prediction moment of the one-hour discharging phase

R= the rated resistance of the illuminating system

The dynamic control strategy is based on the prediction model of the coming one-hour. An auxiliary parameter is set to predict the consumption of the illuminating system in the coming one hour.

$$G_{load} = \frac{W_{av}}{Q} \tag{6}$$

Q=the whole battery power

$$V_X = \left(\frac{U' - U_{\mathrm{MIN}}}{U_{MAX} - U_{\mathrm{MIN}}} - G_{load}\right)(U_{MAX} - U_{\mathrm{MIN}}) + U_{\mathrm{MIN}} \tag{7}$$

Once the dynamic control is taken by the combined system, the SCM will keep calculating the Vx of the system[11]. After the calculation of the Vx , the SCM will judge whether the Cell I is in the power system or not. If the SCM finds that the voltage of the working cell is smaller than the Vx or the voltage of the non-working cell is smaller than 11.4V(which is the working voltage of the lowest level), the SCM will then check whether the voltage of the non-working cell II is greater than 11.4V. If it does be greater than 11.4V, the system will output a signal to control the relay switch to bring the cell II into the power system and cut the cell I out of the power system. Else it won't bring Cell I & Cell II in until the voltage of cell I can be greater than 11.4V. **Figure 3** shows the control flow chart of the dynamic model.

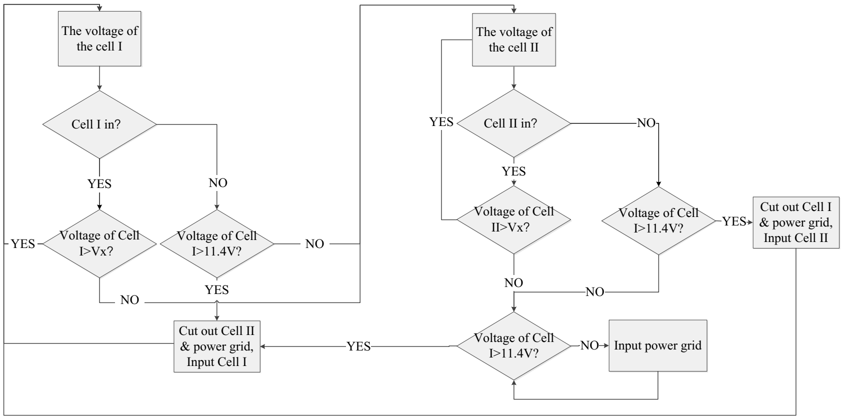

Figure 3. The control flow chart of the dynamic model

4 Experimental Check

To validate the effectiveness of the proposed algorithm, a simulation environment is established, as is shown in **Figure 4**. This model simulated the characteristics of the traditional combined systems including the inefficient use of the solar energy. Under the inefficient use of the solar energy working condition, the proposed dynamic control is used to make the good use of the solar energy.

4.1 Feedback Control of The Photovoltaic Cells

The simulation environment adopts 12v lead-acid batteries. The rated storage of this battery is 5A.h, the rated charging current of which is 0.5A. The feedback control is taken into use.

The SCM controls the amount of the charging cell automatically. Once the charging current is greater than 0.5A, two cells will be put into the charging system. Once the charging current is lower than 0.25A, only one cell will stay in the charging circuit. It's manifested by experimental prototype that the control scheme is correct and effective and the experimental data is shown in the **Table 1**, the Experimental Environment is shown in the **Figure 4**.

Table 1. The Experimental Data of the Feedback Control Tests.

Charging Current (A)	State of the Charging Circuit	Action	Switching Action Time (Second)	Charging Current after Actions(A)
0.60	One cell is in the charging circuit	One more cell is put into the charging circuit	10.16s	0.29
0.19	Two cells are in the charging circuit	One cell is cut out of the charging circuit	9.56s	0.41
0.41	One cell is in the charging circuit	No action		0.41

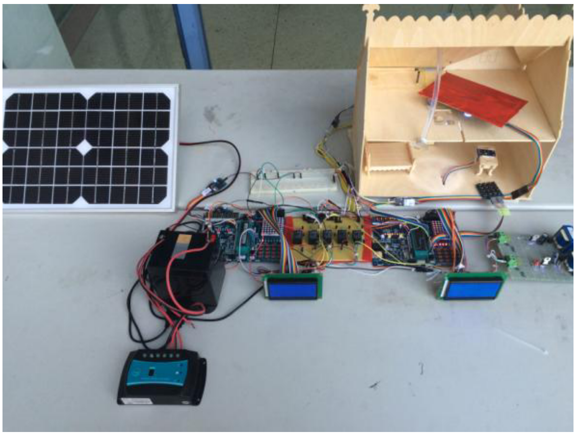

Figure 4. Experimental environment

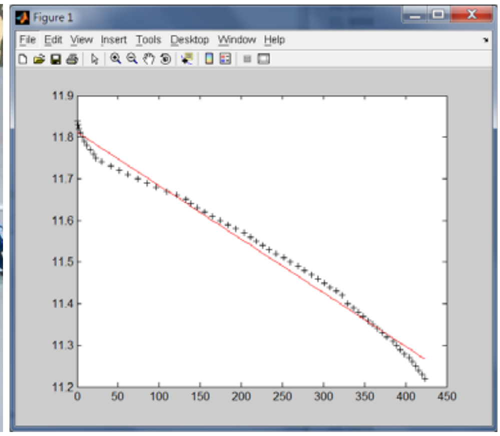

Figure 5. The discharging curve of the lead-acid battery under 1W load

4.2 Dynamic Control Strategy of the Combination

When the lead-acid battery is under 1W load, the discharging time and the voltage changes are recorded in the table. Figure 5 shows the discharging curve of the lead-acid battery under 1W load based on the experimental data.

It is shown in the Figure 5 that the relationship between the voltage of the lead-acid battery and discharging time is about linear by actual experiment .The relationship between those two is

$$y= 11.8123-0.0013t \tag{8}$$

y=the voltage of the lead-acid battery

t=the discharging time

So, through this experimental prototype, the A in formula (1) is -0.0013; The B in formula (1) is 11.8123; The SCM is set to achieve the goal of the dynamic control of the combined system. The experimental environment is shown in the Figure 4. First, the traditional control is adopted by the system. When its voltage comes to the rated voltage of the system, the cells are cut out of the power circuit, and the power grid begins to power the system. At that time, the voltage is the rated voltage of the state when the load is the maximum. Then, under the same condition, the dynamic control is adopted. When its voltage comes to the rated voltage of the system, the cells still power the system and the illuminating system can keep the same illuminating condition of the experimental environment for another 19.9min. The experimental data is shown in the Table 2.

Table 2. The Experimental Data of the Comparison Between the Traditional Control And the Dynamic Control.

Control strategy Adopted	Voltage of the system(V)	The cut-off voltage (V)	State of the illuminating system	Kind of the power energy	Time of the solar energy use(min)
Traditional control	11.56	11.5	One lamp on	Solar power	48.8
	11.5*	11.5	One lamp on	Power grid	0
Dynamic control	11.5	11.44	One lamp on	Solar energy	19.9

*11.5V is the switching voltage of the illuminating system

5 Conclusions

Based on the experimental data of the feedback control tests, the feedback control of the photovoltaic cells is capable to improve the charging efficiency of the photovoltaic cells and improve the battery lifespan. Meanwhile, based on the experimental data of the feedback control tests, the dynamic control strategy is capable to make the most of the solar energy. When the feedback control is not applied, the charging current can sometimes get greater than the rated charging current which will shorten the battery's lifespan. When the dynamic control is not applied, although the solar cell can still power the illuminating system, it is common that the cell has to be cut out of the power system because of the traditional fixed control.

After the feedback control of the photovoltaic cells is applied to the system, the charging circuit can be changed automatically based on the value of the charging current. Also, after the dynamic control strategy is applied to the system, the switching value is changed automatically based on the real-time voltage of the photovoltaic cell, the illumination load and the calculation of the dynamic model.

Unlike the traditional fixed control, the feedback control and dynamic control are more intelligent and efficient. In dynamic control based photovoltaic illuminating system, the control center controls the system based on the system load and the system power. In addition, by taking the new dynamic control, the system gets more stable and makes the collections and the use of the solar energy more efficient.

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