Design of portable intelligent photovoltaic system

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Abstract. For current photovoltaic devices, the portability is poor, the intelligence of device is low, and the stability of the system and the power conversion efficiency are not high. This design uses the photovoltaic panel as the input. By setting up the battery mathematical model and simulation, the maximum power MPPT is tracked to extend the service life of the photovoltaic cell system. The constant current charging and constant voltage discharge of the battery should be as high as possible to achieve efficient conversion control. The output of the battery is boosted to a stable value through the BOOST circuit, and the DC-DC and DC-AC systems are built separately. DC-DC and DC-AC perform linear regression using the SVM training parameters for the voltage and set values of the BUCK circuit and the inverter. By adjusting the fitting parameters offline, the PWM and SPWM of the BUCK circuit and the inverter circuit are respectively adjusted to meet the use of low-power AC-DC devices. The design of the control section is based on the MSP430F149. When the CPU is idle, it enters a low-power mode to meet the low-power requirements of the PV system. The device realizes the portability of the photovoltaic system and the intelligent voltage output, and the system has a stable conversion efficiency.

1. Introduction

With the continuous development of solar energy technology, social production requires efficient and reliable photovoltaic equipment [1-2]. Small-scale community lighting, smart homes and outdoor activities, as well as military rescue, highway power systems and aerospace can all use solar energy technology [3-4]. Due to the instability of solar energy, there is a non-linear factor in battery charging. When the system is connected to solar energy, there is fluctuation of electric energy, causing overvoltage and undervoltage to the subsequent circuit. Therefore, high-precision and controllable energy conversion circuits are particularly important [5-6]. Then, the maximum power tracking at the input of the system and the setting of the voltage at the output of the system need to be monitored in real time in order to prevent system instability and low conversion efficiency[7].

The system first controls the output through least squares regression and realizes the functions of intelligence and modularization. However, the voltage output error of the system is relatively large, in which the conversion efficiency of the electrical energy is only about 90%, and the voltage value and the set value can be more than 95% using the SVM training parameters for linear regression conversion [8, 9]. Therefore, using the SVM algorithm for regression analysis, a system design study for a portable smart photovoltaic device was conducted [10].
2. **Device hardware structure**

The main circuit part adopts BOOST step-up circuit and BUCK step-down circuit, and is designed to modulate the pulse width to convert DC-DC and DC-AC. The current and voltage output from the photovoltaic cell are collected through the feedback circuit, the collected data is output according to a set value through regression fitting, and the closed loop control is used to adjust the voltage and current of the system. Ultimately, the system's maximum power tracking and system load output are regulated by the feedback voltage of the battery management system and the load.

![Figure 1. Hardware Structure](image1)

As shown in Figure 1, this system is mainly divided into the following seven modules: Photovoltaic modules, MPPT and battery charge management module, battery module, BOOST step-up circuit module, BUCK DC Buck Module, Inverter module, Main control board and information acquisition circuit module [11-12]. The DC-DC, DC-AC system can be constructed to meet the working requirements of different low-power devices.

3. **Device algorithm processing**

The system collects the voltage array of the BUCK and the inverter by collecting the voltage array, comparing with the system setting voltage value. The CPU adjusts the CCR1 and CCR2 registers to control the pulse width ratio of the PWM and SPWM waves. The output value is fitted to the set value. The result of the logical prediction returns a new fitting parameter to the MCU to adjust the absolute error of the system. As shown in Figure 2.

![Figure 2. Algorithm flow](image2)
The output voltage is between the setting voltage 0–24, by comparing the least squares fitting linear regression and SVM linear regression, the degree of fitting of the two algorithms to the set value. The SVM linear regression has better output characteristics, which makes the system output voltage control within 0.01V accuracy.

3.1. Least square fitting regression
The traditional data processing method is a least-squares linear fitting method. The system adjusts the output voltage in real time through the feedback of the load. The target voltage is compared with the output voltage, and the data collected by the host computer is extracted to find the absolute error value of the system, as shown in Table 1.

| No. | Set voltage (V) | The output voltage (V) | Absolute error (V) |
|-----|-----------------|------------------------|--------------------|
| 1   | 3.10            | 2.90                   | 0.20               |
| 2   | 3.40            | 3.24                   | 0.16               |
| 3   | 5.00            | 4.89                   | 0.11               |
| 4   | 7.20            | 7.13                   | 0.07               |
| 5   | 9.00            | 9.23                   | 0.23               |
| 6   | 10.50           | 10.30                  | 0.20               |
| 7   | 12.00           | 12.04                  | 0.04               |
| 8   | 15.00           | 15.05                  | 0.05               |
| 9   | 17.30           | 17.40                  | 0.10               |
| 10  | 24.00           | 23.77                  | 0.23               |

Figure 3. Absolute error
As shown in Figure 3, the output fitting equations for different constructions of fitting parameters are also different. Different parameters are judged in the MCU to achieve different control effects. The fitting equation (1) is transplanted to the MCU, and an absolute error map can be obtained by comparing the set voltage values.

\[ 0.997X[0]-0.0012X[0]+1.4502 \geq \frac{Y[0]}{4095.0} \]  

(1)

3.2. SVM regression fitting
In the SVM regression analysis, as with the least squares linear fit regression analysis, the return of the fitting parameters is required. By fitting with the set voltage and combining the returned parameters with the actual output data, the regression parameters can be transplanted into the single-chip microcomputer and the regression analysis of the two methods can be performed. The SVM has the best degree of fit to the output and input, and the system has the smallest absolute error.
In the training set and test set, the goal is to find a linear function, such as formula (2):

$$f(x) = w^T x + b$$  \hspace{1cm} (2)

The data collected by the host computer is the set voltage value and output voltage value. If the data has a $\pm \varepsilon$ deviation from the regression function, i.e., equations (3), (4), this belongs to the constraints within the accuracy range.

$$|f_{x_i} - w^T x - b| < \varepsilon$$  \hspace{1cm} (3)

$$|w^T x - b - f_{x_i}| < \varepsilon$$  \hspace{1cm} (4)

However, in the actual collection, there will still be some data scattered in the $\pm \varepsilon$, you need to introduce relaxation factors, soft boundary methods, such as constraint equation (5);

$$\zeta_i, \zeta_i^* \geq 0$$  \hspace{1cm} (5)

So there will be constraints like equation (6):

$$\begin{cases} |f_{x_i} - w^T x - b| < \varepsilon + \zeta_i \\ s.t. \quad |w^T x - b - f_{x_i}| < \varepsilon + \zeta_i^* \\ \zeta_i + \zeta_i^* \geq 0 \end{cases}$$  \hspace{1cm} (6)

Comparison of training set forecast results

$$mse = 0.00048351 \quad R^2 = 0.99907$$

![Figure 4. SVM training set](image-url)
The sample is divided into a test set and a training set, which are respectively set with 0-24V set values (tag values), and parameters c, g are used for training and the parameters with the least errors in the optimal classification surface are obtained. The accuracy of the output is maximized using the data fitted to the MCU in the parameters.

4. AC circuit control section
The drive module of the inverter module selects IR2104, the MOS FET uses IR540, and the inductor low-pass filter uses 150uH. Among them, the variable pulse width modulation technology uses SPWM modulation technology and is a commonly used sine wave pulse width modulation technology. The output waveform is a series of rectangular pulse waveforms of equal width that are equivalent to sine waves. In principle, the area of each interval is equal. The output voltage is 0~12V AC adjustable, used for the role of low-power motor drive.

4.1. Bipolar SPWM simulation
As shown in Figure6, a bipolar SPWM is constructed through the establishment of a simulink simulation model, in which the width of the pulse width is consistent with the change of the sine wave. The object of the establishment of the simulation model is shown in the circuit of Figure8. The drive tube is a bridge type circuit, and the cross-over MOS tube is controlled by controlling the SPWM pulse width ratio. As shown in Figure7, the simulation result is that the fundamental frequency belongs to AC 50Hz. The emulated pulse width modulation can control the amplitude output of the output sine wave. The DC part of the modulating wave is to provide useful power to the load and the rest is useless. By increasing the carrier frequency, the conversion efficiency can be increased, making the output closer to a sine wave.
The simulink simulates the working principle of the inverter, in which the drive is protected by a dead zone and the modulating wave is a sine wave of frequency $f_s$.

$$u_s = U_{sm} \sin \omega_s t$$  \hspace{1cm} (7)

$$\omega_s = 2\pi f_s$$  \hspace{1cm} (8)

Carrier $u_s$ is a triangle wave with amplitude $U_{cm}$ and frequency $f_c$. The ratio of carrier signal frequency $f_c$ to modulation signal frequency $f$ is called the carrier ratio $\rho$, as shown in Equation 9:

$$\rho = f_c / f_s$$  \hspace{1cm} (9)

The modulation depth $m$ is determined by the mathematical relationship between the triangular carrier signal and the sine modulation signal.

$$m = U_{sm} / U_{cm}$$  \hspace{1cm} (10)

4.2. Inverter section
MCU can be output through the look-up table bipolar SPWM to reduce the harmonic content, and the SPWM drive power can be increased through the IR2104 drive circuit. SPWM cross conduction, control dead-zone delay effect. Alternating MOS transistors can be turned on to make the sine wave fundamental frequency and the square wave carrier frequency generated. Through LC low-pass filtering, stable AC power can be obtained, and the final AC output amplitude is regulated by the switching frequency of the switching circuit. The circuit is shown in Figure 8:
5. DC circuit control section
Since the output of the photovoltaic cell is a non-linear output, it is necessary to find the maximum power point to achieve the maximum conversion efficiency of the electric energy in order to fully utilize the solar energy.

5.1. Battery management circuit
CN3722 adopts switch buck mode, and the input voltage range meets the requirements of 0~24V. Through the DC-DC conversion method, the constant voltage method is used to achieve the maximum power point tracking function of the photovoltaic cell, which is very suitable for applications where the input voltage and the battery voltage are relatively large. Figure 9 shows MPPT and battery management modules.

5.2. BOOST circuit
BOOST circuit control chip selects TPS61175, input 5-20V, the output reaches 24V and the maximum drive current reaches 3A. The BOOST Circuit formed by the TPS61175 is available in a variety of standard switching regulator topologies, including boost, SEPIC and flyback configurations. The switching frequency of the PWM in the TPS61175 is determined by an external clock frequency or resistor, and the output frequency can reach 2.2 MHz. Figure 10 shows the boost module consisting of the TPS61175.
5.3. **BUCK step-down circuit**

BUCK DC step-down module selects H bridge drive circuit, input 80KHZ square wave signal in PWM port, the power supply voltage is 24V, can realize 0–24V adjustable output. The output terminal accesses the voltage acquisition circuit. When the output voltage is too large or too small, the output voltage can be dynamically adjusted by controlling the 430 control board’s CCR1 and CCR2 registers to adjust the duty cycle of the H-bridge PWM. Figure 11 shows the BUCK step-down circuit block.

![Figure 11. BUCK circuit](image)

6. **Experimental results**

Two solar charging boards charge 12V, 6800mA NiMH batteries. As shown in Figure 12, the MMPT management circuit consists of a CN3722 chip. Through the voltage acquisition circuit, the output voltages of the BUCK and BOOST circuits are collected and fed back to the microcontroller for output regulation. The system output voltage can be collected by the host computer.

As shown in Figure 13, the upper computer is programmed by LABVIEW, and the floating point number is acquired through section display. Through experiments, we can see that the device charge current is charged at 500mA constant current, the output voltage can be controlled at 0-24V change, the linear regression voltage error through the SVM can be controlled at 0.01V. The output error by least squares fitting is greater than 0.2V.

![Figure 12. System Hardware Circuit Physical](image)
Figure 13. Upper computer monitoring system

The upper computer communicates with the PC terminal through the serial port of the single-chip microcomputer, identifies different flag bits, and obtains the corresponding character string. The final conversion to floating point is displayed on the LABVIEW console. The upper computer mainly monitors the transmission voltage, current and power of the system in real time and stores the monitored data. By analyzing the collected data, the above two different algorithms can be used to fit different parameters. By continuously collecting data and learning offline, the system's output can be optimized.

7. Conclusion
The designed system can be divided into two parts: the lower computer and the upper computer. The data collected by the upper computer is compared with the voltage setting value in the lower computer to control the output voltage. The maximum output power is achieved through the battery management system, and the DC control of the voltage is achieved through a step-up and step-down circuit. The output of the AC is realized through the inverter. The host computer is responsible for collecting the output signals and fitting the acquired data to the SVM linear regression. The absolute value of the voltage output from the system is continuously optimized. The optimized parameters are the results of regression prediction, which constantly returns new fitting parameters to the control circuit to adjust the absolute error of the system. Until the system meets the error requirement, the adjustment of the system is stopped so that the output value and the set value are constrained within the accuracy range.

When the device is charged with constant current, it can autonomously control the output voltage between 0~24V. The data collected by the host computer is compared with least-squares fitting and SVM linear regression, and the two algorithms are used to fit the set values. By using the SVM for data fitting learning, the system output voltage can be controlled within the accuracy range of 0.01V.

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