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Design and Implementation of PV Maximum Power Point Tracking Control

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Abstract: Photovoltaic Power generation system is an important renewable energy generation mode, in order to maximize the power generation efficiency of photovoltaic system, it is necessary to use Maximum Power Point Tracking (MPPT) technology. MPPT technology is designed to monitor the output voltage and current of the photovoltaic cell in real time, and adjust the operating point of the photovoltaic cell to make it work at the maximum power point. In this paper, the traditional disturbance observation method and variable step conductance increment method used in MPPT technology are modeled and compared, and it is concluded that the variable step conductance increment algorithm has high control accuracy, fast response speed and higher power generation efficiency in photovoltaic power generation. Secondly, based on the Arduino control chip, the hardware and software of the photovoltaic maximum power point tracking control circuit are designed, the hardware experiment platform of the photovoltaic power generation system is built, and the control algorithm of variable step length conductance increment method is realized in combination with programming. Finally, the performance of the variable step conductance increment algorithm in real environment is verified and evaluated. The test results are consistent with the simulation results, which further proves the superiority of variable step conductance increment method in practical application.

Keywords: PV; MPPT tracking; Perturb and Observe method; Incremental Conductance method.

1. Introduction

Energy is an important material basis for the survival and progress of human society. The sustainable development of human society cannot be separated from a compatible energy system[1]. Traditional non-renewable energy sources such as coal, oil and natural gas are the mainstay of the world's energy sources at present. Once fossil energy is consumed in large quantities, it will be exhausted one day [2]. Therefore, focusing on the development of clean and renewable energy is the direction of future development. Solar power is favoured as a clean, noiseless and green renewable energy source. Vigorously promoting solar power generation is of great practical significance for alleviating the status quo of energy shortage, improving the ecological environment, and promoting social and economic development[3].

The current research direction of MPPT technology in China mainly focuses on algorithm improvement, control strategy optimisation and system performance enhancement [4]-[5]. In terms of algorithm research, researchers have proposed a variety of MPPT algorithms, such as P&O algorithm, Incremental Conductance algorithm, fuzzy control algorithm, etc., for different light conditions and environmental changes, and have carried out simulation analysis and experimental validation of them. Currently the conventional methods used for uniform light intensity, such as the conductance incremental method (Incremental Conductance, abbreviated as INC), account for a large proportion of practical applications, but the traditional INC algorithm has a slow tracking speed and low tracking accuracy, and the output waveform oscillation amplitude is large, which has gradually failed to satisfy the application requirements of the actual engineering [6].To address the above problems, literature [7] combines the short-circuit current method with the variable step-size INC algorithm, the short-circuit current method makes the system able to quickly track to the MPP when the external conditions change, and the variable step-size INC algorithm is able to improve the tracking accuracy: Literature [8] adopts a combined algorithm of the INC and perturbation and observation method (P&O) combined algorithm to replace the DC/DC converter topology of the MPPT with a Z-source boost converter in order to improve the tracking accuracy and conversion efficiency; Literature [9] proposes a gradient-based variable-step-length INC algorithm to coordinate the tracking speed of the algorithm with the steady state accuracy. On the control strategy research, in order to improve the stability and response speed of the MPPT system, researchers proposed improved control strategies, such as model predictive control and adaptive control, to achieve more accurate maximum power tracking. On the system optimisation part of the research, the domestic research also focuses on the overall optimisation of the PV system, including the optimal configuration of parallel battery packs, array layout optimisation and system performance evaluation.

Foreign MPPT technologies are studied in terms of algorithm innovation, hardware design and practical application verification. Today's most advanced solar charge controller is the maximum power point tracking (MPPT). MPPT controller is more complex and expensive. MPPT controllers are more complex and expensive. It has several advantages over earlier charge controllers. It is 30% to 40% more efficient at low temperatures. The maximum power point tracker (MPPT) circuit is based on a synchronous buck converter circuit. It reduces the higher solar panel voltage to the charging voltage of the battery. At present, foreign scholars propose such as artificial intelligence-based algorithms, fuzzy logic control algorithms, artificial neural network algorithm and so on to improve the MPPT algorithm in order to improve the stability and tracking accuracy of the system. Literature [10] INC algorithm is combined with particle swarm optimisation (PSO) algorithm, which constantly adjusts the weight value of individual particles according to the distance of particles from the global MPP, in order to reduce the oscillation of the system in the vicinity of the MPP. Literature [11] introduces moth-flame optimisation (MFO) algorithm in INC algorithm, INC algorithm is used under normal lighting conditions, and MFO is used when irradiance changes abruptly in order to carry out a global search. The above studies are able to track the MPP effectively.

The above MPPT algorithms are reflected in the application of many control parameters, tracking accuracy and speed are inversely proportional, as well as higher hardware requirements. For example, in order to improve the performance and response speed of the system, the hardware design and implementation of MPPT controllers use high-efficiency energy converters, microcontrollers, and DSP chips, etc[12]. However, in the actual photovoltaic power station, the large-scale use of MPPT technology requires the application validation and practical performance evaluation of its hardware and software, and the further analysis of the MPPT technology in terms of improving the power generation efficiency and reducing the energy loss of the Effectiveness of MPPT Technology in Improving Power Generation Efficiency and Reducing Energy Losses[13].

The structure of this paper is arranged as follows:Section 1 introduces the principle of the MPPT algorithm; Section 2 gives the overall scheme design flow, including simulation, and the hardware design of the MPPT circuits; the software design part of Section 3 compares and analyses the performances of the different control algorithms in the form of a block diagram of the logic program; Section 4 experiments to verify the correctness of the circuit design, and at the same time statistically analyses the results of the experimental tests; finally, Section 5 gives the conclusion.

2. Principles of Photovoltaic Power Generation and Principles of MPPT Algorithm

2.1. Principles of Photovoltaic Power Generation

A photovoltaic cell is an energy converter that directly converts light energy into electrical energy, and its principle of operation is based on the photovoltaic effect that occurs when the semiconductor P-N junction receives light from the sun[14]. The output voltage of each photovoltaic cell is only about 0.5V. The output current of a PV cell is related to the intensity of the solar light, the temperature, the area of the PV cell and the form of parallel connection of the PV cells. PV cells in the project in order to output a sufficiently large electric power under the action of solar energy, many small photovoltaic cell units to be combined in series and parallel to form a photovoltaic array to use[15].

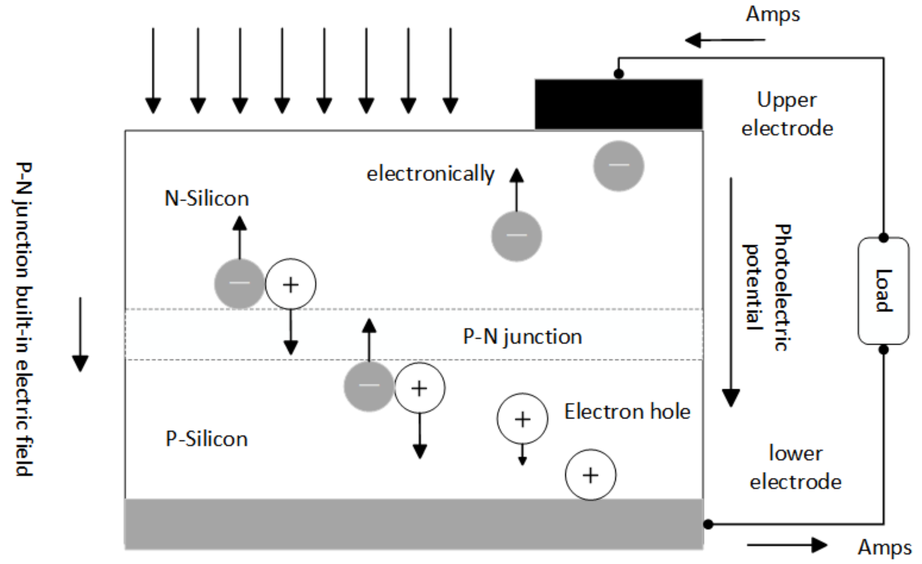

Figure 1. PV cell working principle diagram

Figure 1 shows the working principle of photovoltaic effect solar cell. The specific principle of photovoltaic power generation is the photoelectric effect of semiconductors. Photon irradiation to the metal, its energy can be absorbed by the metal in a certain electron all, the electron absorbed energy is large enough to overcome metal internal gravitational work, leaving the metal surface to escape, become photoelectrons. Silicon atoms have four outer electrons, if the pure silicon doped with five outer electrons of atoms such as phosphorus atoms, it becomes N-type semiconductor; if the pure silicon doped with three outer electrons of atoms such as boron atoms, the formation of P-type semiconductors[16]. When P-type and N-type combined together, the contact surface will form a potential difference, becoming a solar cell. Sunlight on the semiconductor p-n junction, the formation of new hole - electron pairs, in the p-n junction built-in electric field under the action of the hole from the n area flow to the p area, the electron from the p area flow to the n area, connected to the circuit on the formation of electric current[17].

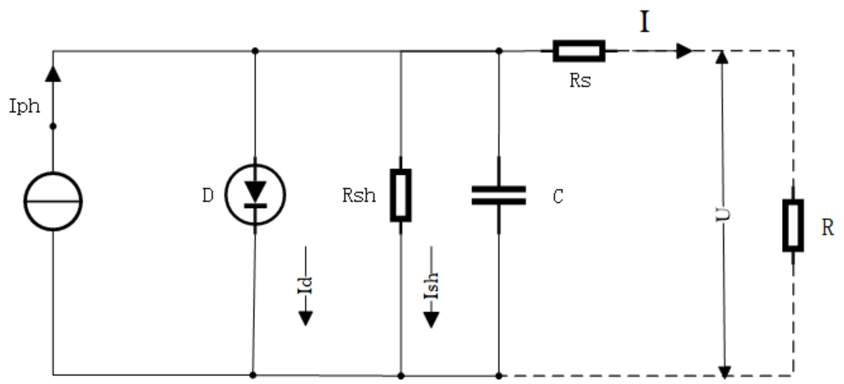

Figure 2. PV cell equivalent model

In the equivalent model of PV cell shown in Fig. 2, the value of the equivalent constant current source current of PV cell is I_{ph}.According to the principle of PV cells, it is known that the photovoltaic cell has a unidirectional conductivity inside the cell, so it can be equated to a diode D,At the same time, the capacitance C is equivalent to the characteristics of the photovoltaic cell.

Since the materials used to make PV cells are less than ideal therefore a certain circuit loss occurs during the operation of the PV cell, for this reason it is necessary to connect a resistor R_s in series in the equivalent circuit to represent the circuit loss that occurs[18].If R_s is too large it means that too much energy is lost when the current passes through the photovoltaic cell, but the effect can be ignored when analysing the mathematical model of the solar cell because in general R_s is only a few ohms maximum.At the same time the photovoltaic cells can also crack and leak, this is due to the manufacturing process, so it is necessary to connect in parallel on the equivalent resistance R_{sh}, generally R_{sh} will be more than 1000 ohms[19].

$$I = I_{ph} - I_d - I_{sh} \tag{1}$$

The current-voltage relationship for the barrier region (P-N junction) is expressed in equation (2).

$$I_d = I_o \left[e^{\frac{q(U+IR_s)}{AKT}} - 1 \right] \tag{2}$$

From Kirchhoff's voltage law, as follows:

$$I_{sh} = \frac{U+IR_s}{R_{sh}} \tag{3}$$

The sum of equations (1), (2) and (3) .as follows:

$$I = I_{ph} - I_o \left[e^{\frac{q(U+IR_s)}{AKT}} - 1 \right] - \frac{U+IR_s}{R_{sh}} \tag{4}$$

Table 1. Specific meaning of each parameter

Number	Parametric	Connotation
1	I	PV Cell Output Current
2	U	PV Cell Output Voltage
3	I_o	PN-junction reverse saturation current
4	I_{ph}	light-generated current (electricity)
5	I_d	Current flowing through diode
6	I_{sh}	Current through shunt resistor
7	q	electric charge(1.6×10^{-19}C)
8	R_s	Series Resistors
9	R_{sh}	Parallel resistance
10	K	Boltzmann constant (1.38×10^{-23}J/K)
11	A	Diode Ideal Factors
12	T	Absolute temperature of photovoltaic cells

Although equation (4) is derived from the equivalent circuit of the photovoltaic cell physical expressions, but in the practical application and the establishment of mathematical models are not commonly used, because the parameters of the formulaI_{ph},R_{sh},A,R_s,$I_o$follow the environment is particularly sensitive to changes, so it is impossible to determine the value of these parameters, making the establishment of mathematical models of photovoltaic cells is more difficult, for this reason, usually in the photovoltaic cell mathematical modeling will be simplified, today there are a lot of ways to simplify the simplification of the simplification, but after simplification of the effect of the difference is not very big, this paper is only one of the simplification of the choice of simplification, as follows:

According to the previous section the resistance$R_{sh}$is larger, the current flowing is smaller and the resistance R_s is smaller, so ignoring it in the calculations has very little effect on the final result, so it can be ignored ($U + IR_s$)/ R_{sh} . Let I_{ph}=I_{sc},According to the literature [20] the above equation can be simplified as:

$$I = I_{sc} \left[1 - C \left(e^{\frac{U}{DU_{oc}}} - 1 \right) \right] \tag{5}$$

In the open circuit state, let the equivalent circuit satisfyI=0,

$U=U_{oc}$. At the point of maximum power the equivalent circuit satisfies $I=I_m$, $U=U_m$. If the PV cell operates at the MPP, according to the above conditions and equation (5) we can get:

$$I_m = I_{sc}\left[1 - C\left(e^{\frac{U_m}{DU_{oc}}} - 1\right)\right] \quad (6)$$

Since at room temperature, $e^{\frac{U_m}{DU_{oc}}} > 1$, it follows from equation (6) ,as follows:

$$C=\left(1 - \frac{I_m}{I_{sc}}\right) e^{-\frac{U_m}{DU_{oc}}} \quad (7)$$

Combining the above conditions for the open circuit state and substituting Eq. (7) into Eq. (5) yields.as follows:

$$0 = I_{sc}\left[1 - \left(1 - \frac{I_m}{I_{sc}}\right) e^{-\frac{U_m}{DU_{oc}}}\left(e^{\frac{1}{D}} - 1\right)\right] \quad (8)$$

Since $e^{\frac{1}{D}} - 1$ is much greater than 0, this follows from equation (8):

$$D = \left(\frac{U_m}{U_{oc}} - 1\right)\left[\ln\left(1 - \frac{I_m}{I_{sc}}\right)\right]^{-1} \quad (9)$$

As the environmental factor is subject to constant change in engineering applications, it is not possible to use a definitive value to represent it. Changes in the environment affect the parameters of the PV cell, so corrections to the environmental factor are necessary[21]. These corrections are made as follows:

$$\Delta T = T - T_{ref} \quad (10)$$

$$\Delta S = \frac{S}{S_{ref}} - 1 \quad (11)$$

$$I'_{sc} = I_{sc}\left(\frac{S}{S_{ref}}\right)(1 + \alpha\Delta T) \quad (12)$$

$$U'_{oc} = U_{oc}(1 - c\Delta T)\ln(e + b\Delta S) \quad (13)$$

$$I'_m = I_m\left(\frac{S}{S_{ref}}\right)(1 + \alpha\Delta T) \quad (14)$$

$$U'_m = U_m(1 - c\Delta T)\ln(e + b\Delta S) \quad (15)$$

Standard ambient temperature T_{ref} and standard illuminance S_{ref} are used to determine the calibration parameters α,b and c.

Table 2. Meaning and value of parameters

Number	**Parametric**	**Meaning**	**Values**
1	T_{ref}	Standard ambient temperature	25°C
2	S_{ref}	Standard illuminance	1000W/㎡
3	α	Calibration parameters	0.0025/°C
4	b	Calibration parameters	0.5
5	c	Calibration parameters	0.00288/°C

The mathematical model resulting from the derivation and simplification above contains only four unknown quantities: I_{sc} , U_{oc} , I_m and U_m .And in non-standard experimental conditions I'_{sc} , U'_{oc} , I'_m and U'_m are the parameters after correction.None of these unknowns are affected by the environment, greatly simplifying the mathematical modelling process[22]. The manufacturer provides these four unknowns, making it easy to build simulation models that accurately reflect the actual situation.

2.2. Principles of Photovoltaic Power Generation

2.2.1. PV array P-U curve

Figure 3 shows the P-U curve for the output power characteristic of the PV array. The figure indicates that the maximum power point, where the output power P is at its highest[23], occurs when the operating voltage of the PV array is U_{pmax}.

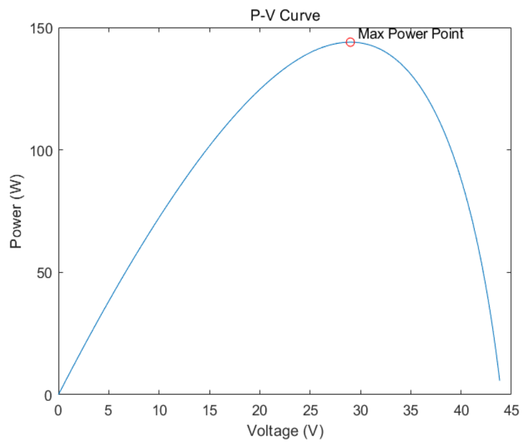

Figure 3. PV Array P-U Curve Output Power Characteristics

2.2.2. P&O

The Perturb and Observe (P&O) algorithm is a commonly used method for Maximum Power Point Tracking (MPPT) in photovoltaic systems. It works by periodically adjusting the operating point of the PV battery bank and observing the resulting change in output power to determine the maximum power point. The algorithm begins by selecting an initial operating point, which is typically either the open circuit voltage of the PV cell bank or the current operating point.The perturbation process alters the operating point of the PV battery bank by incrementally adjusting the voltage or current. If the voltage is perturbed, the algorithm will modify the voltage value while maintaining a constant current. If the current is perturbed, the algorithm will adjust the current value while keeping the voltage constant[24]. After each perturbation, observe whether the output power of the PV battery bank increases or decreases. An increase in output power indicates that the perturbation is in the direction towards the maximum power point, and the algorithm will continue to perturb in the same direction. Conversely, a decrease in output power indicates that the perturbation is in the direction away from the maximum power point, and the algorithm will change direction and continue to perturb. It is important to note that the algorithm should only continue to perturb in the same direction if the output power increases.To enhance the response speed and stability of the algorithm, the P&O algorithm dynamically adjusts the perturbation step size[25]. If consecutive perturbations result in a power increase, the algorithm gradually reduces the perturbation step. Conversely, if consecutive perturbations lead to a power decrease, the algorithm increases the perturbation step to hasten the approach to the maximum power point. The Perturbation & Observation (P&O) algorithm gradually approaches the maximum power point of the PV cell bank by constantly repeating the process of perturbation and observation. Once the algorithm observes a reversal in the power trend, indicating a decrease in power, it determines the maximum power point and stops the perturbation to maintain the battery bank's operation at that point. Figure 4 shows the flowchart of the P&O algorithm.

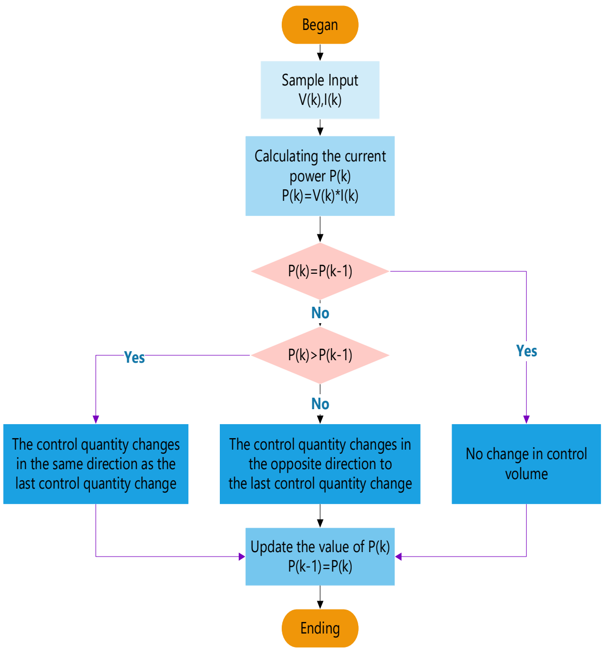

Figure 4. P&O Algorithm Flowchart

Explanation of the flowchart: if dP=0, the battery operates at the maximum power point and the voltage does not need to be changed;

If dP>0, dU>0, the battery operates to the left of the maximum power point and the output voltage must be increased;

If dP>0, dU<0, the battery operates to the right of the maximum power point and the output voltage must be reduced;

If dP<0, dU>0, the battery is operating to the right of the maximum power point and the output voltage must be reduced;

If dP<0, dU<0, the battery operates to the left of the maximum power point and the output voltage must be increased.

The perturbation observation method is a popular technique in PV systems due to its concise algorithmic structure, ease of implementation, and efficient tracking capability. It is also independent of the electrical characteristic parameters of the PV array. When using the perturbation observation method with a fixed step size, a smaller step size results in a smaller oscillation amplitude of the PV system near the maximum power point, thereby reducing energy loss. However, increasing the number of perturbations required to reach the maximum power point also increases the tracking time. On the other hand, a larger step size accelerates the tracking speed but results in increased energy loss due to the amplitude of the oscillation near the maximum power point. Therefore, achieving both speed and steady state accuracy in maximum power point tracking of PV systems is challenging. A compromise can only be made in terms of the perturbation step size to achieve acceptable dynamic and steady-state performance.

2.2.3. INC

The Incremental Conductance (INC) method is utilised to determine the direction of reference voltage change by comparing the amount of change in output conductance with the magnitude of the instantaneous conductance value. It can be observed from the P-U curve of the photovoltaic cell that dP/dU=0 at the maximum power point (i.e., dI/dU=I/U). When dP/dU>0, U is less than the MPP, and when dP/dU<0, U is greater than the maximum power point voltage. By analysing the sign of I/U+dI/dU, it is possible to determine whether the PV array is operating at its maximum power point[26].

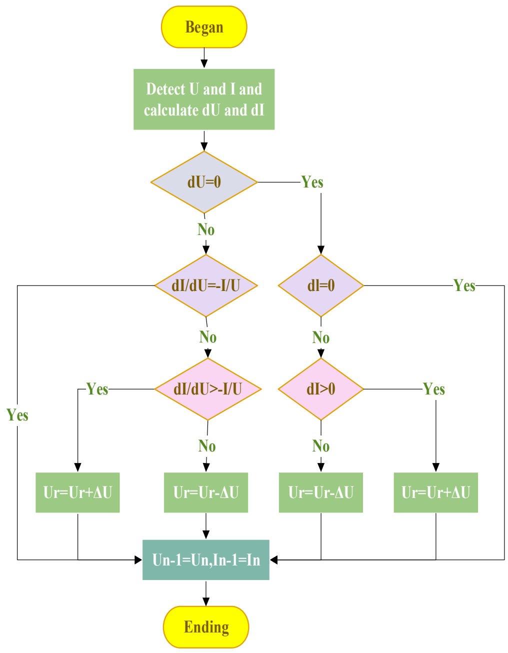

Figure 5.P&O Algorithm Flowchart

The flowchart of the algorithm is shown in Fig. 5 and explained below:

If the photovoltaic array operates to the left of the maximum power point, then dP/dU>0, i.e. I/U+dI/dU>0, indicates that the operating voltage should be changed in an increasing direction.

Similarly, if the PV array operates to the right of the maximum power point, there are two indicators that the operating voltage should decrease: dP/dU<0 and I/U+dI/dU<0.

If the operating point of the PV array is close to the maximum power point, then dP/dU=0,I/U+dI/dU=0, the operating voltage remains unchanged, i.e. the PV array is operating at the maximum power point.

The conductivity increment method has the advantage of allowing for smooth changes in output voltage when the external environment changes rapidly. This results in good control effect and high stability, unaffected by the power time curve or the previous moment's working voltage and power size. However, the method's disadvantage is its complex control algorithm, which requires a higher level of control system. Simultaneously, the selection of the voltage increment step size is also a delicate matter. If the step size is too large, the tracking error increases, whereas if it is too small, the tracking speed decreases[27].

3. Overall Program Design

This paper presents the construction of a solar MPPT charge controller using Arduino, as shown in Fig. 4. The controller includes an LCD display, LED indicators, and the ability to charge various USB devices. It is equipped with multiple protection features to safeguard the circuit from abnormal conditions. The controller employs an Arduino Nano micro controller and is designed for charging a 12V lead-acid battery using a 50W solar panel. The duty cycle is controlled by the Arduino to maximize the solar cell power input and keep the solar panel running at its maximum power point. Figure 6 shows the main frame diagram.

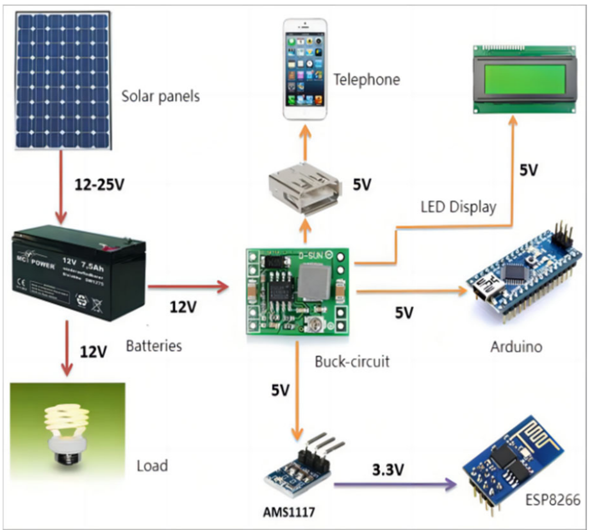

Figure 6. Main framework diagram

3.1. Hardware Circuitry Design

3.1.1. Design of the sampling module

The sampling voltage circuit and sampling current circuit comprise the sampling module. The sampling voltage circuit is a voltage divider circuit consisting of resistors R2, R3, and capacitor C1. As the Arduino module's analogue pins can only measure voltages up to 5V, a voltage divider is necessary to sample the output voltage of the PV cell, which has a maximum voltage of 20V due to its single crystal board. The AO port of the Arduino module is connected directly to the middle of R2 and R3 to achieve this purpose. The ACS712 chip is utilised for current sampling and can accurately measure currents up to 5A, as shown in Figure 7.

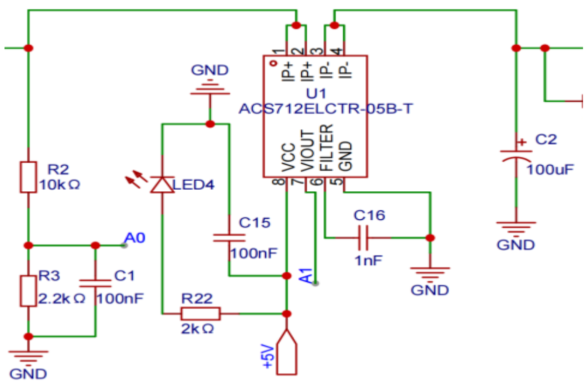

Figure 7. Sampling Module Circuit Diagram

3.1.2. Design of BUCK Step-Down Modules

The BUCK module (Figure 8) consists mainly of three MOSFET thyristors, where thyristor Q1 serves to prevent the nighttime battery current from flowing back into the PV cell, and the G poles of thyristors Q1 and Q2 are connected together so that Q1 and Q2 are both on and off at the same time.

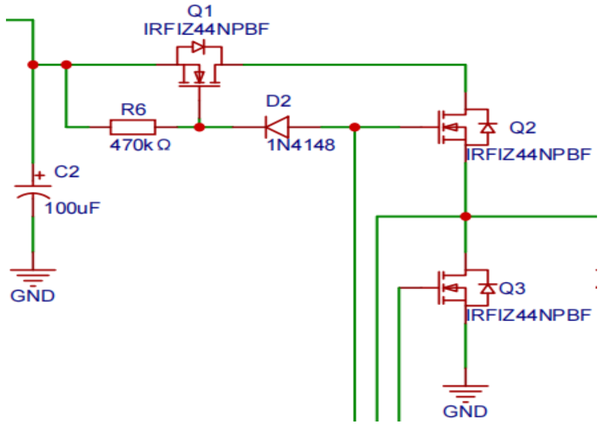

Figure 8. BUCK Step-Down Modules Diagram

3.1.3. Design of Half Bridge Driver Module

The IC IR2104 (U2 in Figure 9) functions as a half-bridge MOSFET gate driver, utilizing PWM signals from the Arduino (pin D9) to operate the high-side and low-side MOSFETs. The IN and SD ports of the IR2104 chip are connected to the D9 and D8 ports of the Arduino module to receive the PWM signals, and then output on/off signals to the thyristors Q1, Q2, and Q3 through the HO and LO, enabling the Buck module to perform the corresponding operation.

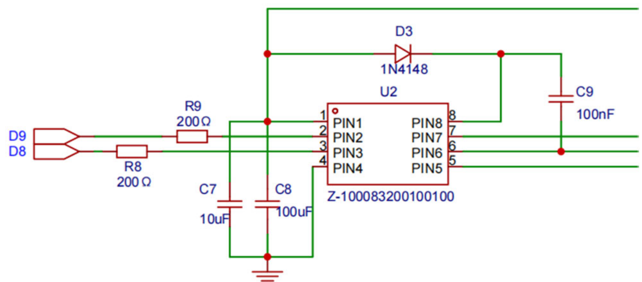

Figure 9. Half Bridge Driver Module Diagram

3.1.4. Design of Output Modules

The output module comprises a buffer circuit and an indication circuit. The buffer circuit, as shown in Fig. 7, primarily filters and smooths the current after the Buck circuit has been stepped down. The indication circuit, as shown in Fig. 10, is responsible for indicating the working status of the storage battery, with four possible states:

(1) Red light on, indicating that the energy storage battery is in the buck state and being tracked by the MPPT algorithm.

(2) The yellow light indicates that the storage battery is not charging.

(3) The green light indicates that the energy storage battery is charging.

(4) When all three lights are on, the energy storage battery is in a float charging state.

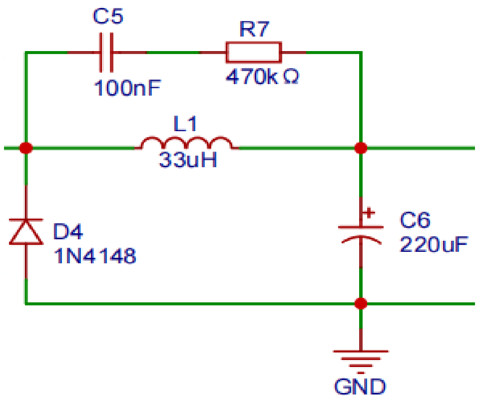

Figure 10. Buffer circuits Diagram

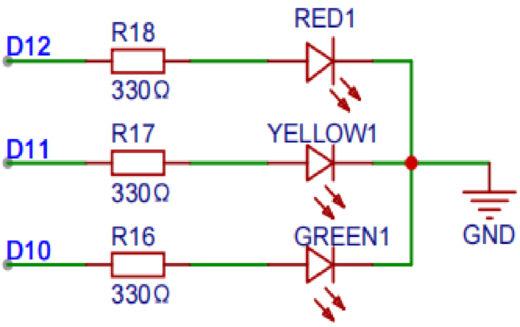

Figure 11. Sampling Module Circuit Diagram

3.1.5. Design of Power supply module

The power supply module is shown in the schematic diagram (Figure 12), and its main function is to provide 5V and 3.3V to the various components within the circuit for their normal operation.

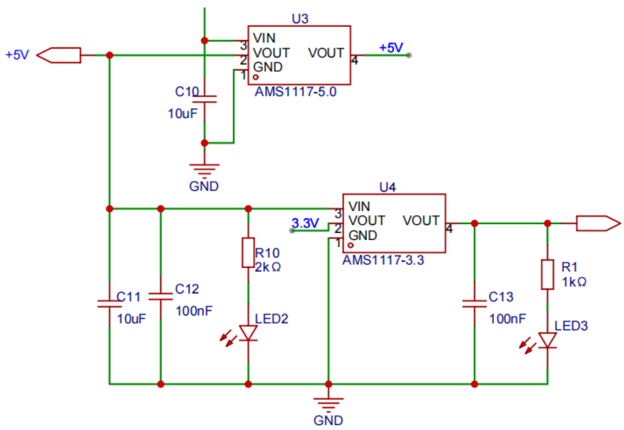

Figure 12. Power supply module Diagram

4. Software Design

As the chip utilises the Arduino nano module, the programming software used is the Arduino IDE programme. It mainly implements the following functions: reading data, adjusting the PWM duty cycle (MPPT algorithm), detecting the energy storage battery charging status, and displaying the display and backlight module. The flowchart of the programme is shown in Fig 13.

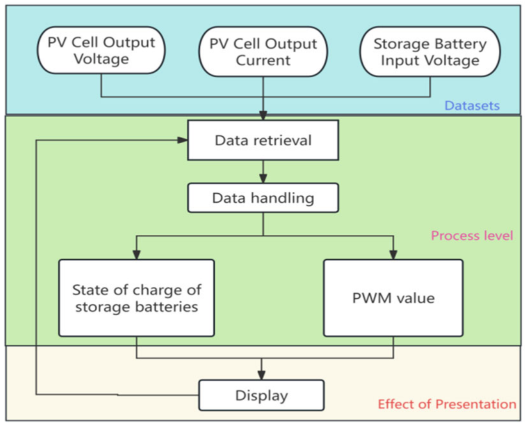

Figure 13. Procedure flowchart

Figure 13 shows the sampled output voltage and current of the PV battery and the input voltage of the storage battery being imported into the data processing and analysis module to determine the operating stage of both batteries and perform the corresponding operations. The display [28] shows the read data, state of charge of the storage battery, and PWM value.

4.1. Algorithm design for P&O

In addition, based on the flowchart of the perturbation observation method in Fig. 4, a simulation model of the perturbation observation method was constructed in Maltab/Simulink as shown in Fig. 14 as follows:

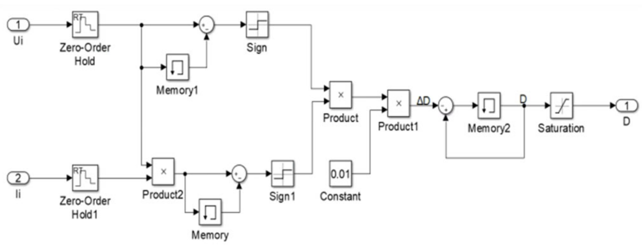

Figure 14. (P&O) simulation flowchart

The perturbation observation method is a technique used for system identification and control. To implement this algorithm on Arduino, it is necessary to consider the system's characteristics and the required observation/control strategy. The software design flow for the perturbation observation method is depicted in the block diagram below.

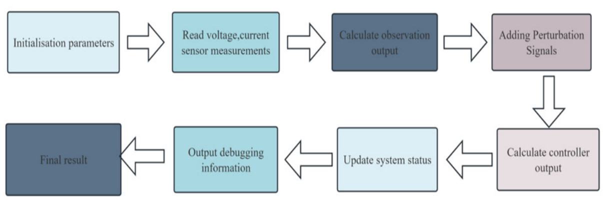

Figure 15. (P&O) software flowchart

4.2. Algorithm design for INC

Similarly, the simulation model of the conductivity increment method was built in Matlab/Simulink in this section, based on the flowchart in Fig. 5. The block diagram of the software flow is shown in Figs. 16 and 17.

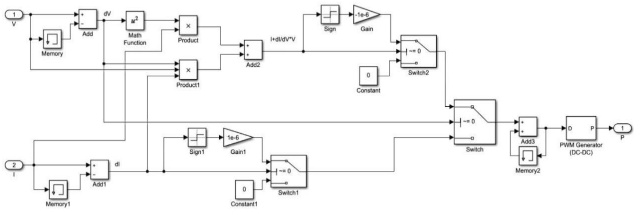

Figure 16. Simulation Model of the INC

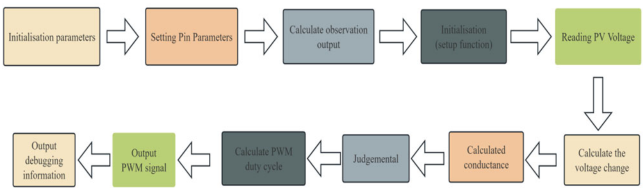

Figure 17. INC software design

5. Discussion

Matlab was used to compare the effectiveness of two control strategies: Variable Step-size Conductance Increment Method (VSCIM) and Perturbation Observation Method [29]-[30]. The simulation parameters, including the total simulation time and time step size, were set, and the state variables were initialised. The simulation process was run in a loop to calculate the control inputs using the VSCIM and perturbation observation method. The system state was updated at each time node. Plots were created to visually compare the control accuracy of the two strategies. This process allows for the evaluation and comparison of the performance of two control strategies in a specific system, enabling the selection of the most suitable control method for practical applications. As follows(The response of the two control methods under a unit step input signal.):

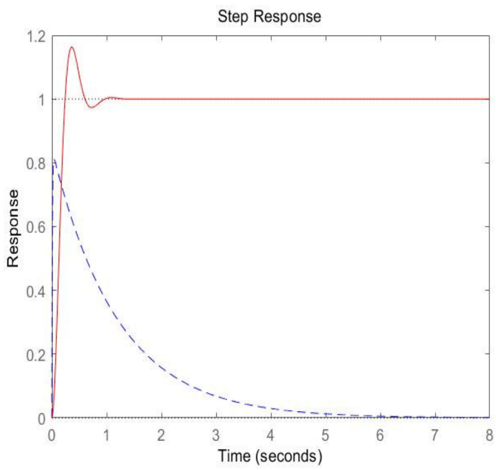

Figure 18. Control Precision Comparison Chart

The analysis focused on the time taken for the system to reach a steady state. We expect the system to reach steady state faster when using the variable step size conductance increment method, which is more effective. By comparing the time required for the two methods to reach steady state, we can assess the effectiveness of the variable step size conductance increment method over the perturbation observation method.

A graph comparing the response speed is presented, with the blue curve representing the response of the conductance increment method and the red curve representing the response of the perturbation observation method. This allows for a visual comparison of the response speeds of the two control strategies, verifying the hypothesis that the variable step size conductance increment method is more effective. As follows:

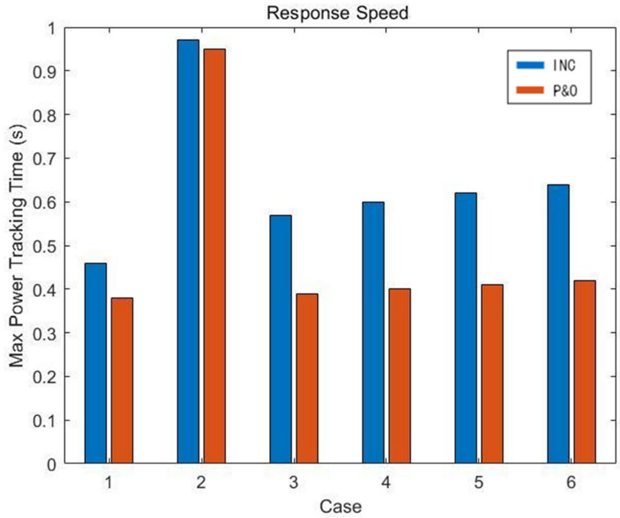

Figure 19. Response Speed Comparison Chart

In order to verify the advantages and disadvantages of the maximum power tracking control strategy for photovoltaic power generation based on Arduino solar MPPT charge controller perturbation observation method and improved conductivity incremental method, physical simulation is carried out to validate the strategy.

Table 3. Simulation Parameter List

Number	Parametric	Values
1	Environmental temperature	25°C
2	Solar panel power	20W
3	Rated Battery Voltage	12V
4	Maximum current	5A
5	Maximum load current	10A
6	Input Voltage	17 ~25V

Considering the light, the change in temperature will have an effect on the output power of the solar panel, for this reason, here the temperature is averaged, the room temperature of the test is constant, and the light intensity variable of a day is also used to compare the effect of the perturbation observation method and conductivity increment method on the charge controller. The comparison results are shown in the table below.

Table 4. Accuracy and Speed

Number	Max Power Tracking Time (s)		Input Voltage Fluctuation at Startup(V)	
	P&O	INC	P&O	INC
1	0.46	0.000	0.64	0.54
2	0.97	0.201	0.97	0.78
3	0.57	0.390	0.57	0.28
4	0.41	0.714	0.41	0.47
5	0.64	1.081	0.23	0.56
6	0.62	1.454	0.38	0.24

Table 5. Simulation results for variable light conditions

Number	Actual value(mm)	P&O	INC
1	T_1/s	0.46	0.38
2	$\Delta u_1/V$	0.97	0.95
3	$\Delta U_1/V$	0.025	0
4	T_2/s	0.41	0.33
5	$\Delta u_2/V$	0.64	0.52
6	$\Delta U_2/V$	0	0

The variables used in this study are: T_1/s, which represents the time required for maximum power tracking at startup; $\Delta u_1/V$, the range of input voltage fluctuation at startup; $\Delta U_1/V$, the range of input voltage fluctuation when the maximum power point is reached; T_2/s, the time required for maximum power tracking after the light intensity is varied; $\Delta u_2/V$, the range of input voltage fluctuation after the light intensity is varied; and $\Delta U_2/V$, the range of input voltage fluctuation after the light intensity is varied and the maximum power point is reached again.

The conductance increment method can effectively suppress the input voltage and improve the stability and accuracy of the maximum power output under varying light conditions.

6. Conclusion

The MPPT technique is important for improving the performance of photovoltaic power generation systems. This study compares and analyses the application of the traditional perturbation observation method and the variable step size conductance increment method in PV power generation systems. Compared to the traditional perturbation observation method, the variable step-size conductance incremental method demonstrates higher stability and accuracy under varying light conditions. It is also capable of quickly locating and locking onto the maximum power point, resulting in increased energy conversion efficiency and faster tracking of the maximum power point. A control hardware experimental platform for a photovoltaic power generation system was built using the Arduino chip. The control algorithm for the variable step conductivity increment method was implemented through programming and its performance was verified in a real environment. The study confirms the effectiveness of MPPT technology in PV power generation systems and proves the superiority of the variable step-size conductance increment method in practical applications. T he results obtained through testing and analysis are consistent with simulation. This study provides a useful reference for the optimal design and application of future PV power generation systems and promotes the development and application of renewable energy technologies.

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