Holtek Solar Panel MPPT Algorithm Application

D/N: AN0617EN

Introduction

Solar panel output power is mainly affected by factors such as illumination intensity, temperature and humidity. Therefore, any environmental changes will always cause output power changes in actual applications. MPPT, namely the Maximum Power Point Tracking, is a way to obtain maximum solar panel power to improve charging efficiency and maximise solar energy utilisation.

This application note will introduce the principles and instructions of how to use the Holtek solar panel MPPT algorithm library in detail, which will assist users to develop MPPT solar charging related products.

Operating Principles

Holtek's solar panel MPPT algorithm library adopts a perturbation and observation method in the MPPT algorithm as its basic principles. Its tracking accuracy ideally has no relation to the voltage/current accuracy and the tracking efficiency can be up to more than 99%. It can be used in solar MPPT charging products.

The solar panel output voltage/current characteristics are determined by the manufacturing process and the I-V characteristic curves are determined by the manufacturer. The corresponding P-V characteristic curves, shown in Figure 1b and Figure 2b, can be drawn according to the I-V characteristic curves, shown in Figure 1a and Figure 2a. Under different illumination intensities and temperatures, the solar panel I-V and P-V characteristic curves will change and specifically a maximum power point offset will occur.

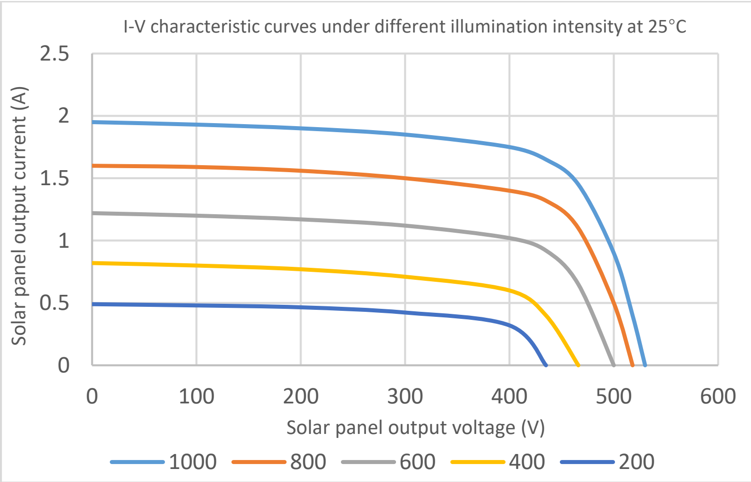


Figure 1a. I-V Characteristic Curves under Different Illumination Intensity

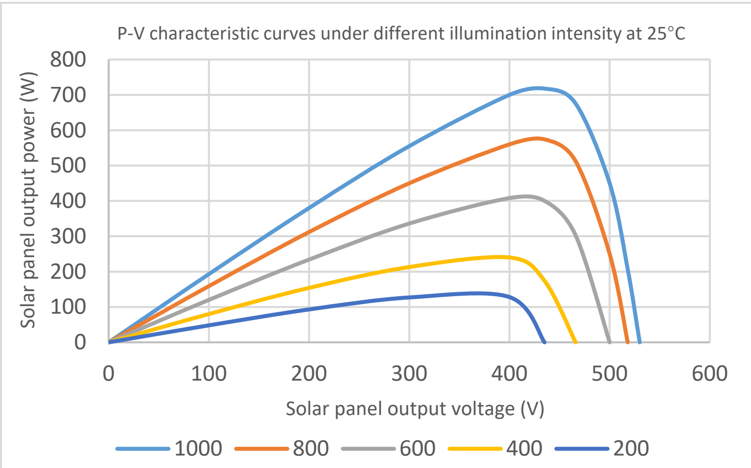


Figure 1b. P-V Characteristic Curves under Different Illumination Intensity

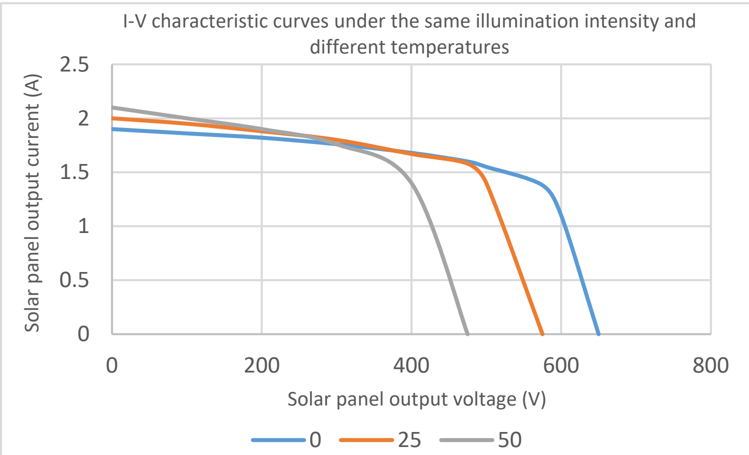


Figure 2a. I-V Characteristic Curves at Different Temperatures

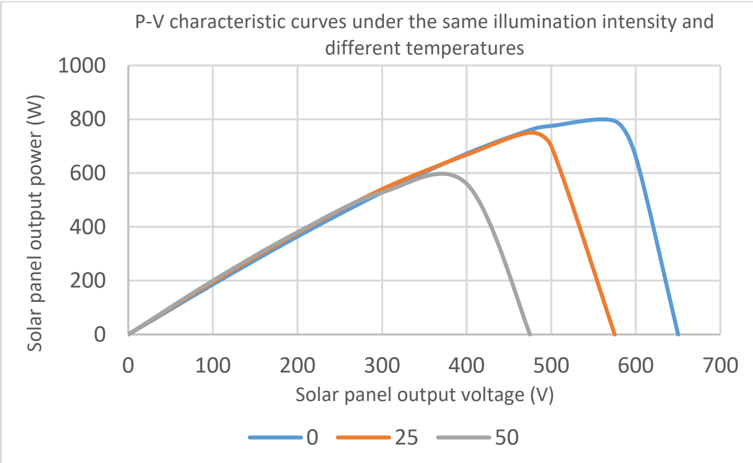


Figure 2b. P-V Characteristic Curves at Different Temperatures

Figures 1 and 2 show the influence of different irradiance on the panel voltage, current and power. It can be seen from the characteristic curves that the temperature mainly changes the voltage point at maximum power and the irradiance mainly changes the panel operating current.

We can see the location of the maximum power point in the P-V characteristic curves, which have corresponding voltage/current values. The maximum power tracking is to make the system operate at its maximum power point. This means finding the operating voltage at the maximum power point.

Perturbation and Observation Method Principles

The P&O method is a commonly used MPPT algorithm. The algorithm introduces a perturbation in the panel operating voltage and then modifies the panel voltage by changing the converter duty cycle. How this is implemented is important for some converter topologies.

It can be seen from the P-V characteristic curve that on the right side of the maximum power point, reducing the output voltage can increase the power. On the left side of the maximum power point, increasing the output voltage can increase the power. This is the main idea behind the P&O method. This means that when the panel operating voltage increases, the algorithm will compare the current power reading with the previous power reading. If the power increases, then maintain the same direction to increase the voltage, otherwise change the direction to reduce the voltage. This process will be repeated at each MPP tracking step until the MPP is reached. When the MPP has been reached, the algorithm will oscillate around the correct value.

The basic algorithm uses a fixed step size to increase or reduce the voltage. The step size determines the error between the MPP and the current value oscillating near the MPP. Small steps helps reduce oscillation but reduces the tracking speed. Large steps can speed up the tracking speed to reach the MPP quicker but increases power consumption during oscillation. Measuring the panel voltage and current are required for applications to implement the P&O MPPT function.

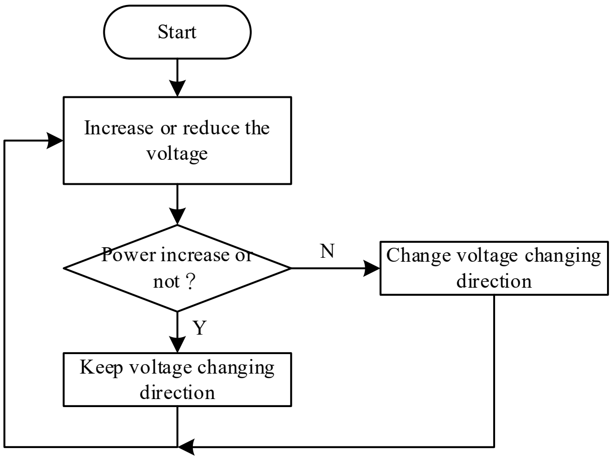


Figure 3

Library Description

This library is mainly used to process the solar panel MPPT part and provides both HT8 and HT32 versions. The resource occupancy and other specifications are shown in the following table.

Resource Item	HT8	HT32
ROM Size	671 Words	1416 Bytes
RAM Size	59 Bytes	56 Bytes
ADC Resolution	12-bit	12-bit
Current Accuracy	8-bit	12-bit
Voltage Accuracy	12-bit	12-bit

Table 1

- Regarding the selection of an HT8 master MCU, it is recommended that the RAM BANK 0 capacity is 256-bytes or above. If the variables are defined in BANK1 due to insufficient RAM capacity, it will increase the ROM capacity and affect the program running speed.
- If the product requires displaying or has other functions that may occupy a significant amount of ROM, it is recommended that the ROM capacity is greater than 4KB.

File Structure and Description

File Name	Description
HT8_Solar_MPPT.obj	HT8-MPPT library
HT8_Solar_MPPT.h	HT8-MPPT variables and function declarations in library functions
HT32_Solar_MPPT.obj	HT32-MPPT library
HT32_Solar_MPPT.h	HT32-MPPT variables and function declarations in library functions

Table 2

Description of Important Parameters

The parameters in the structure HT8_v_MPPT_PNO in the HT8 version library and the structure HT32_v_MPPT_PNO in the HT32 version library are described as follows:

State	Global Variable	Type	Description	Unit
R/W	MPPT_Duty_sum	CHAR	Total number of PWM duty levels	–
R/W	MPPT_Duty_min	CHAR	PWM duty minimum	–
R/W	MPPT_Duty_max	CHAR	PWM duty maximum	–
R/W	Dutysize	CHAR	Duty adjustment step size	–
R	Duty	CHAR	PWM duty value	–
R	BAT_I_max_Duty	CHAR	Duty value corresponding to the maximum charging current	–
R/W	MPPT_CHG_BATV_Max	INT	Maximum battery charging voltage	10mV
R/W	MPPT_CHG_BATV_MaxAdjust	INT	Maximum battery charging voltage adjustment value	10mV
R/W	MPPT_CHG_BATI_Min	CHAR	Minimum battery charging current	10mA
R/W	MPPT_CHG_BATI_Max	INT	Maximum battery charging current	10mA
R/W	MPPT_CHG_BATI_MaxAdjust	INT	Maximum battery charging current adjustment value	10mA
R/W	MPPT_CHG_DeltaBat_Imin	CHAR	Minimum battery current variation	10mA
R/W	MPPT_PV_V_min	INT	Minimum solar panel voltage value	10mV
R/W	MPPT_PNO_Time	CHAR	Timing for re-perturbation	Library calling cycle
R/W	Mppt_process	CHAR	MPPT process	–

Table 3. HT8 Parameter Description

State	Global Variable	Type	Description	Unit
R/W	Duty_sum	SHORT	Total number of PWM duty levels	–
R/W	Duty_min	SHORT	PWM duty minimum	–
R/W	Duty_max	SHORT	PWM duty maximum	–
R/W	Dutysize	CHAR	Duty adjustment step size	–
R	Duty	SHORT	PWM duty value	–
R	Bat_max_I_duty	SHORT	Duty value corresponding to the maximum charging current	–
R/W	MPPT_CHG_CC_BATVMAX	SHORT	Maximum battery constant- current charging voltage	10mV
R/W	MPPT_CHG_CV_BATVMAX	SHORT	Maximum battery constant-voltage charging voltage	10mV
R/W	MPPT_CHG_BATVMAXRipple	SHORT	Maximum battery charging voltage adjustment value	10mV
R/W	MPPT_CHG_BATIMIN	SHORT	Minimum battery charging current	10mA
R/W	MPPT_CHG_BATIMAX	SHORT	Maximum battery charging current	10mA
R/W	MPPT_CHG_BATIMAXRipple	SHORT	Maximum battery charging current adjustment value	10mA
R/W	MPPT_CHG_DeltaBat_Imin	SHORT	Minimum battery current variation	10mA
R/W	MPPT_PV_V_min	SHORT	Minimum solar panel voltage value	10mV
R/W	Time_Debounce	SHORT	Timing for re-perturbation	Library calling cycle
R/W	Mppt_process	CHAR	MPPT process	–

Table 4. HT32 Parameter Description

The above parameters should be set up according to the product specifications. It is noted that the setting values of some parameters are limited. Refer to HT8_Solar_MPPT.h and HT32_Solar_MPPT.h files for a detailed parameter description.

Taking the total number of duty levels as an example, the relationship between the duty levels, the system frequency f_h and topology switching frequency f is $f_h = f \times \text{Duty}$. The switching frequency f is generated by the timer, therefore it is constrained by the number of register bits.

Descriptions of Other Variables

Global Variable	Type	Description	Unit
pv_I	unsigned int	Solar panel current	10mA
pv_V	unsigned int	Solar panel voltage, MPPT library input parameter	10mV
Bat_I	unsigned int	Battery current, MPPT library input parameter	10mA
Bat_V	unsigned int	Battery voltage, MPPT library input parameter	10mV

Table 5

The MPPT library does not provide the above variables, which should be used as parameters in a decimal form for MPPT library functions.

Subroutine Description

The MPPT library contains two subroutines which can be called during battery charging. The following is the subroutine description, including the HT8 and HT32 versions subroutine description.

Function Name	void fun_HT8_mppt_chg_Config(void)
Function	MPPT algorithm initialisation library function (HT8 version)
Input	NULL
Output	NULL
Description	First configure the parameters such as PWM duty range, adjustment step size, solar panel voltage and maximum battery charging voltage/current before MPPT charging

Table 6

Function Name	Void Fun_MPPT_PNO_F_init (&gv_MPPT_PNO_LED)
Function	MPPT algorithm initialisation library function (HT32 version)
Input	NULL
Output	NULL
Description	First configure the parameters such as PWM duty range, adjustment step size, solar panel voltage and maximum battery charging voltage/current before MPPT charging

Table 7

Function Name	unsigned char Fun_MPPT_PNO_F_FUNC (u8 Chgmode)
Function	MPPT algorithm tracking library function (HT8 version)

Input	pv_V; //Real-time sampling of solar panel voltage
	Bat_I; //Real-time sampling of battery current
	Bat_V; //Real-time sampling of battery voltage
	Chgmode: 0x00: disable 0x01: enable

Output	0x00: error, stop PWM charging or restart tracking charging 0x01: normal mode, duty adjustable 0x80: BAT I OCP or BAT V OVP, stop PWM charging or restart tracking charging

Table 8

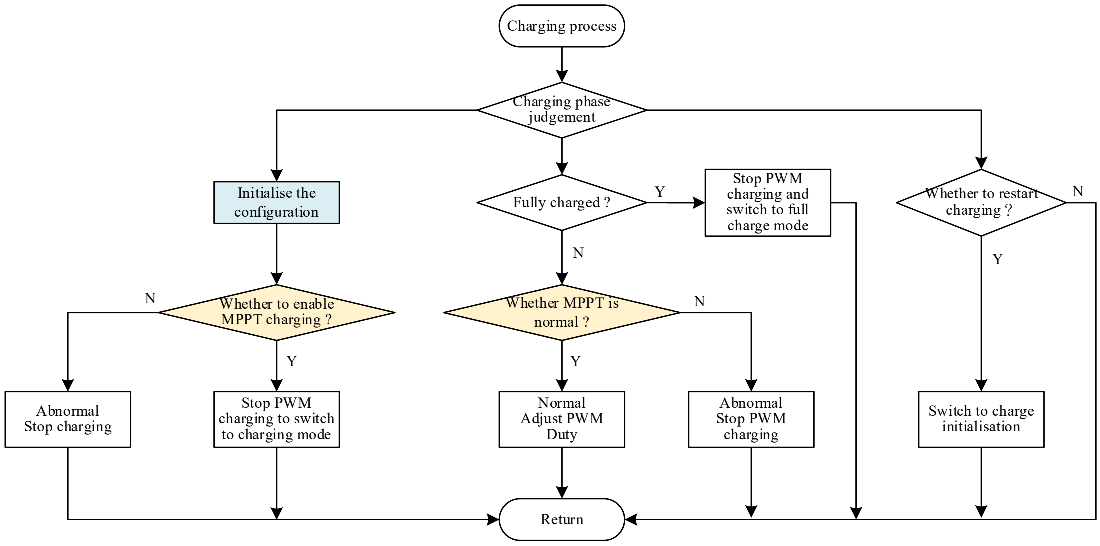
Function Name	unsigned char Fun_MPPT_PNO_F_FUNC(&gv_MPPT_PNO_LED,u8 Chgmode)
Function	MPPT algorithm tracking library function (HT32 version)

Input	pv_V; // Real-time sampling of solar panel voltage
	Bat_I; // Real-time sampling of battery current
	Bat_V; // Real-time sampling of battery voltage
	Chgmode: 0x00: disable 0x01: enable

Output	0x00: error, stop PWM charging or restart tracking charging 0x01: normal mode, duty adjustable 0x80: BAT I OCP or BAT V OVP, stop PWM charging or restart tracking charging

Table 9

Directions for Use



Charging initialisation function: void fun_HT8_mppt_chg_Config(void) or fun_HT32_mppt_chg_Config(&HT32_v_MPPT_PNO)

Judging conditions of MPPT normal charging state: Fun_MPPT_PNO_F_FUNC(1) == 0 ? or Fun_MPPT_PNO_F_FUNC(&HT32_v_MPPT_PNO, 1) == 0 ?

Figure 4

1. Before using the MPPT library, it is required to complete the basic initialisation settings, including the battery specification, the battery operating voltage/current range, the solar panel operating voltage/current range and other MPPT related settings, which is the most important step.
2. Real-time sampling of voltage, current and temperature data. The voltage and current data should be converted into decimal data for backup.
3. The battery charging state machine periodically calls the MPPT library function.
4. The MPPT library already contains multiple protections such as battery OCP, OVP and solar panel UVP. The remaining protection functions need to be implemented by methods other than the MPPT library.

Application Example

This section will introduce a practical application example in combination with an MPPT solar street light Demo board.

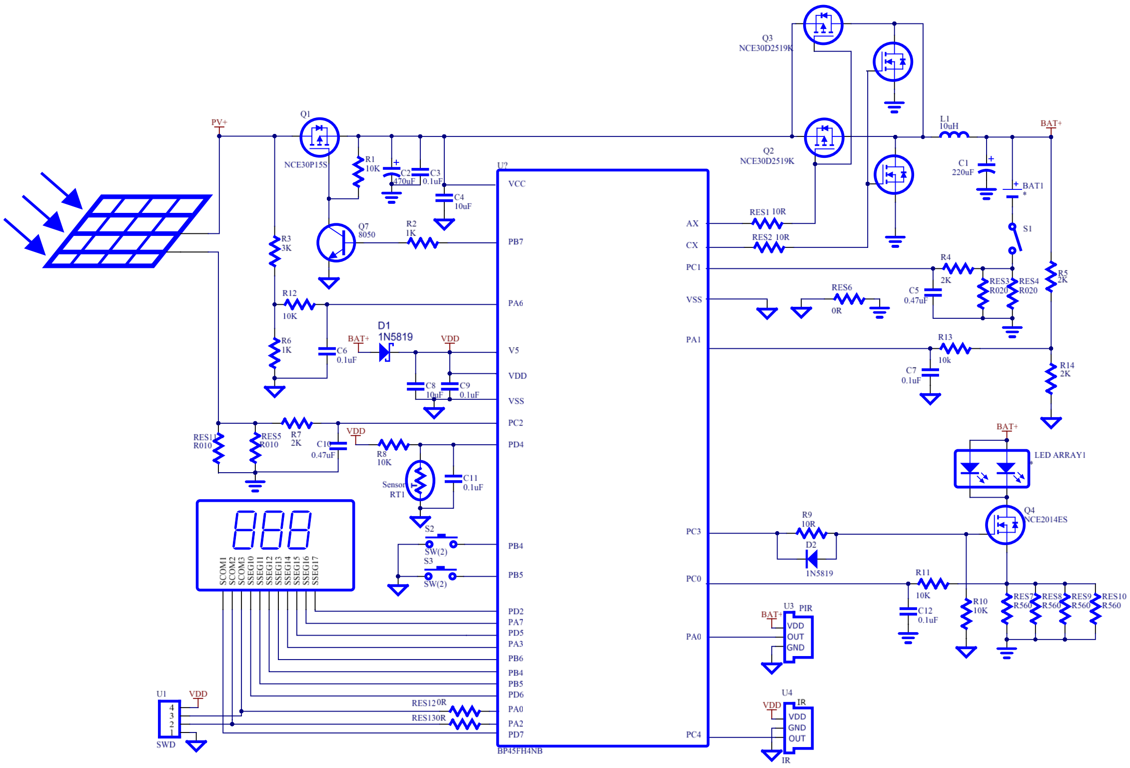


Figure 5

The MPPT solar street light Demo contains a DC-DC buck module, a voltage/current/temperature sampling module, a PIR human body sensing module, digital display, keys and other components.

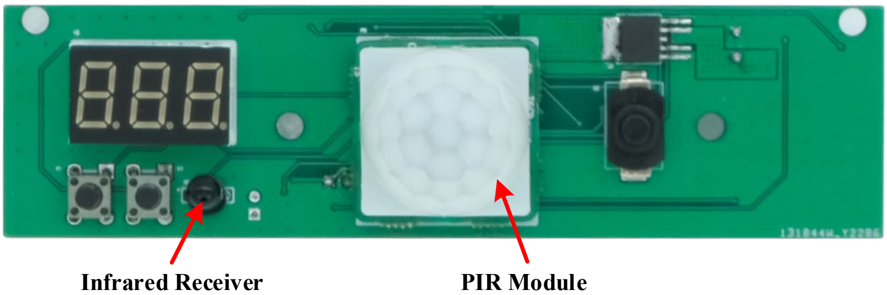


Figure 6-A

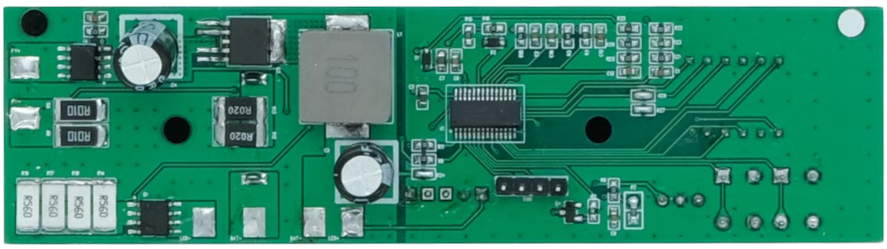


Figure 6-B

- Demo main specifications
  - Solar panel: 20W @ 6V/3.3A, open-circuit voltage of 7.2V, short-circuit current of 4A.
  - Battery: Lithium iron phosphate battery of 3.2V@20Ah, operating voltage ranging from 2.5V to 3.6V
- MPPT library parameter settings

  The MPPT library parameters should be setup according to the solar panel and the battery specifications. The above-mentioned solar light Demo uses an HT8 MCU as the master controller, therefore the HT8 version library will be taken as an example.
  - The only parameter related to the solar panel is MPPT_PV_V_min. Because the battery used is an LFP battery and the voltage is 2.8V when the battery capacity is low, the MPPT_PV_V_min can be set to 300 with parameter units of 10mV. When the solar panel voltage is lower than 3V, the solar panel will exit the MPPT charging process. The reference setting range of this parameter is 280~360.
  - The battery charging termination voltage is about 3.65V, therefore the MPPT_CHG_BATV_Max can be set to 360 with parameter units of 10mV and the MPPT_CHG_BATV_MaxAdjust can be set to 355 with parameter units of 10mV.
  - The battery capacity is 20Ah and the maximum current is 6A at 0.3C. The MPPT_CHG_BATI_Max can be set to 600 with parameter units of 10mA and the MPPT_CHG_BATI_MaxAdjust can be set to 580.
  - The MPPT_CHG_DeltaBat_Imin with parameter units of 10mA is the minimum battery current variation, which is a key basis for judging the photovoltaic panel operating voltage direction. This value should not be less than the current value corresponding to the 1-bit A/D value, but it should not be too large, otherwise the MPPT tracking efficiency will be reduced. If the solar panel current at maximum operating power point is 3.3A, it is 33mA calculated by 1%, and the battery current is estimated to be about 50~100mA, therefore the MPPT_CHG_DeltaBat_Imin can be in the range of 5~10.
  - The battery structure is four single-cell batteries connected in parallel. If the minimum current is calculated as 50mA per branch, the MPPT_CHG_BATI_Min will be set to 20 with parameter units of 10mA.
  - The topology switching frequency is determined by MPPT_Duty_sum, whose setting is limited by MCU register bits. For example, if the switching frequency f is set to 100K, then according to the conditions where MPPT_Duty_sum=f_h/f, f_h =30M and MPPT_Duty_sum=300, the MPPT_Duty_min and MPPT_Duty_max are the duty lower limit and upper limit. Obviously under the above conditions, the lower limit cannot be less than 0 and the upper limit cannot be more than 300.
  - Dutysize is the step size of the duty adjustment. Too small a step size will cause a low MPPT tracking speed and too large a step size will cause a low tracking accuracy and poor system stability. Dutysize can be selected either 1 or 2 in applications.

- The MPPT_PNO_Time is the MPPT perturbation time. When the duration for which the system is at the maximum power point exceeds this time, the system will start to change the duty value due to the perturbation. Too small a value will cause poor system stability. If the timing is too large, the tracking speed will be slow and will not be able to keep up with environmental changes. The timing can be set in the range of 5s to 10s.

Test Data

Voltage and current measurement point and test item description.

- Input voltage: photovoltaic panel positive terminal on the PCB board – PV+
- Input current: the sampling resistor at the photovoltaic panel negative terminal on the PCB board – PV-
- Output voltage: lithium battery positive terminal on the PCB board – BAT+
- Output current: the sampling resistor at the lithium battery negative terminal on the PCB board – BAT-
- The 1~4 items are short-duration test and the 5~6 items are long-duration tests. The system uses an LFP battery type 3.2V@20000mAh and the maximum charging current is set to 4A.

1. Charging power and efficiency - simulate a 20W@6V, 3.33A photovoltaic panel with a maximum output power of 10W

	Input Voltage (V)	Input Current (A)	Input Power (W)	Output Voltage (V)	Output Current (A)	Output Power (W)	Charging Efficiency (%)	Energy Utilisation (%)
MPPT Charging	6.0	1.65	9.9	3.348	2.75	9.2	92.9	98.05

Table 10

2. Charging power and efficiency - simulate a 20W@6V, 3.33A photovoltaic panel with a maximum output power of 20W

	Input Voltage (V)	Input Current (A)	Input Power (W)	Output Voltage (V)	Output Current (A)	Output Power (W)	Charging Efficiency (%)	Energy Utilisation (%)
MPPT Charging	6.0	3.3	19.8	3.4	5	17	85.85	99

Table 11

3. Charging power and efficiency - simulate a 10W@6V, 1.66A photovoltaic panel with a maximum output power of 5W

	Input Voltage (V)	Input Current (A)	Input Power (W)	Output Voltage (V)	Output Current (A)	Output Power (W)	Charging Efficiency (%)	Energy Utilisation (%)
MPPT Charging	6	0.82	4.92	3.29	1.4	4.606	93.6	98.4

Table 12

4. Charging power and efficiency - simulate a 10W@6V, 1.66A photovoltaic panel with a maximum output power of 10W

	Input Voltage (V)	Input Current (A)	Input Power (W)	Output Voltage (V)	Output Current (A)	Output Power (W)	Charging Efficiency (%)	Energy Utilisation (%)
MPPT Charging	6	1.647	9.882	3.345	2.75	9.198	93.08	98.82

Table 13

5. Charging curve - the battery is charged from 2.9V to full capacity with a maximum battery current of 4A.

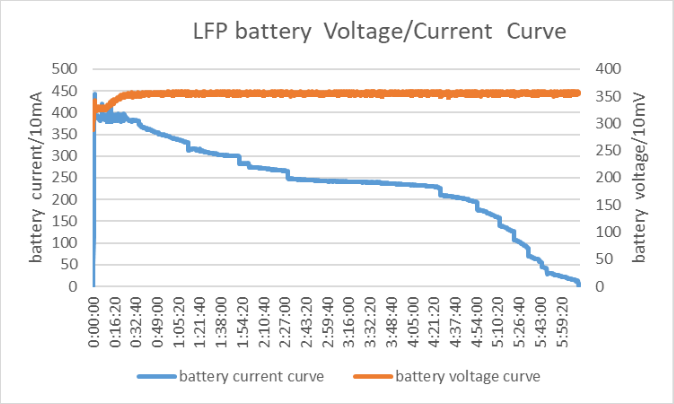


Figure 7

6. Charging curve - the battery is charged from 2.9V to full capacity with a maximum input power of 10W.

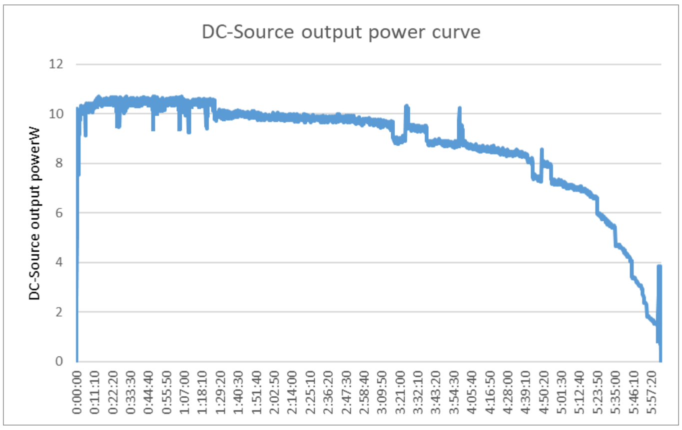


Figure 8

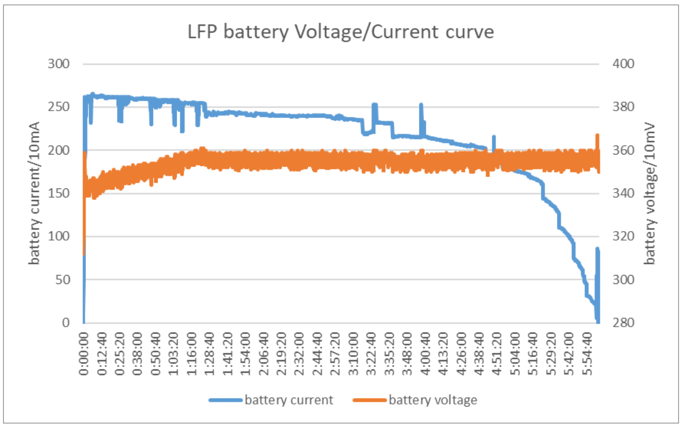


Figure 9

Conclusion

In this application note, the MPPT algorithm library is based on the perturbation and observation method principles. Here the battery voltage and current is detected during charging to determine the change direction of the solar panel output power and track its maximum power value. This improves the battery charging efficiency and makes full use of the solar panel output power for better performance. Users can modify the library parameters according to their actual application requirements and can use this in products with a variety of specifications to shorten the development time. Due to the different product requirements, users should verify and calibrate the product functions in detail in order to obtain the best effects from the library.

Reference File

Reference file: BP45FH4NB Datasheet.

For more information, consult the Holtek official website: www.holtek.com.

Revision and Modification Information

Date	Author	Issue	Modification Information
2022.05.05	譚林祥	V1.00	First Version

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