AN14856

MPPT Demo Based on MCX A346

Rev. 1.0 — 11 December 2025 Application note

Document information

Information	Content
Keywords	AN14856, MCX A346, Maximum Power Point Tracking (MPPT)
Abstract	This application note describes the Maximum Power Point Tracking (MPPT) demo based on MCX A346.

1 Introduction

Under the conditions of growing energy demand and continuously changing climate, the energy consumption structure is accelerating toward low-carbon development, and the proportion of renewable energy in the total energy is increasing. Solar energy is an excellent renewable energy source. Photovoltaic (PV) cells convert light energy into electrical energy and are popular in recent years. To use the energy from PV cells, the PV system must work at the Maximum Power Point (MPP). To achieve this goal, use the Maximum Power Point Tracking (MPPT) algorithm.

The MCX A346 is a 180 MHz mixed-signal microcontroller from the MCX A series. It is used as the controller in the MPPT demo. The following features are used in this demo:

- Flex Pulse Width Modulator (FlexPWM) is used for DC-DC control.
- Analog-to-Digital Converter (ADC) is used for voltage/current sampling.
- Low-Power Inter-Integrated Circuit (LPI2C) is used for communication with the fast charging chip and temperature acquisition.
- Low-Power Serial Peripheral Interface (LPSPI) is used for LCD display.
- Quadrature Decoder (eQDC) is used for knob (encoder) detection.
- Low-Power Universal Asynchronous Receiver-Transmitter (LPUART) is used for FreeMASTER communication and debugging.
- General-Purpose Input/Output (GPIO) is used for load switch control and key input.
- Serial Wire Debug (SWD) is used for downloading and debugging.

2 Basics

A PV cell, also known as a solar cell, is based on the PV effect. It converts light energy into electrical energy. The commonly used PV panels are made by combining individual PV cells.

2.1 PV cell model

The Silicon-based PV cells are the mainstream PV cell products in the market. The effective structure is the P-N junction. When sunlight irradiates the P-N junction, due to the PV effect, the photoelectron-hole pairs are generated. The built-in electric field in the P-N junction creates a photoelectric field, which changes light energy into electrical energy. According to the principle of PV cells, the model is simplified as follows:

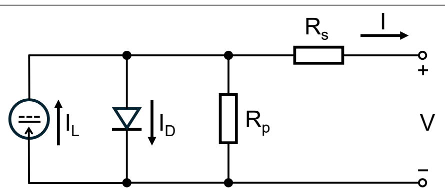

Figure 1. PV cell model

Figure 1 shows the details as follows:

- I_L: electric current generated by PV cells
- I_D: current flowing through the P-N junction
- R_p: equivalent parallel resistance of PV cells
- R_s: equivalent series resistance of PV cells

By analyzing the model of the PV cell, we can obtain the I-V characteristic curve and P-V characteristic curve of the PV panel, as shown in Figure 2:

Note: *Usually, PV cells are connected in series and parallel to form a PV panel with the required power. In Figure 2, a 100 W PV panel is used for analysis.*

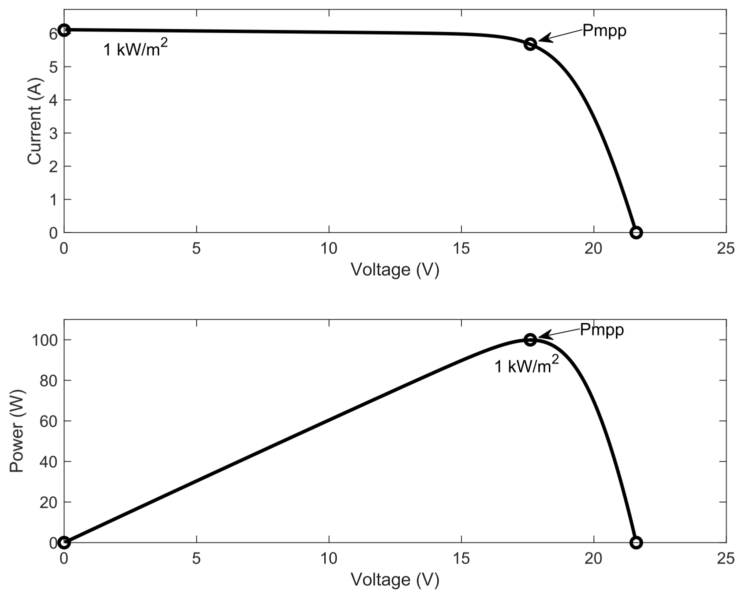

Figure 2. I-V and P-V characteristic curve

Figure 2 shows the details as follows:

- The output power of PV panel is the highest when they are at the maximum power point P_{mpp}
- The intersection of the I-V curve and the vertical axis is the short-circuit current I_{sc} of the PV panel. When the load is short-circuited, the measured output current is the short-circuit current
- The intersection of the I-V/P-V curve and the horizontal axis is the open circuit voltage V_{oc} of the PV panel (exclude the origin). When the load is open circuit, the measured output voltage is the open circuit voltage

Light intensity and temperature affect the output characteristics of the PV panel. Light intensity mainly affects the short-circuit current of the PV panel and temperature mainly affects the open-circuit voltage of the PV panel.

At a temperature of 25 °C and different light intensities, the P-V characteristic curve of PV panel is shown in Figure 3. The maximum power increases with the increase of light intensity.

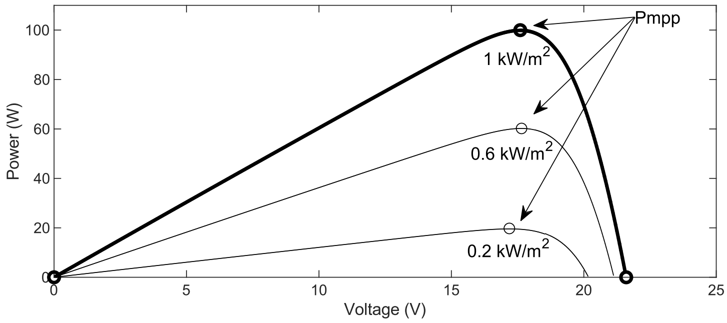

Figure 3. P-V characteristic curve under different light intensity conditions

Under the conditions of light intensity of 1000 W/m^2 and different temperatures, the P-V characteristic curve of the PV panel is shown in Figure 4. The maximum power decreases as the temperature increases.

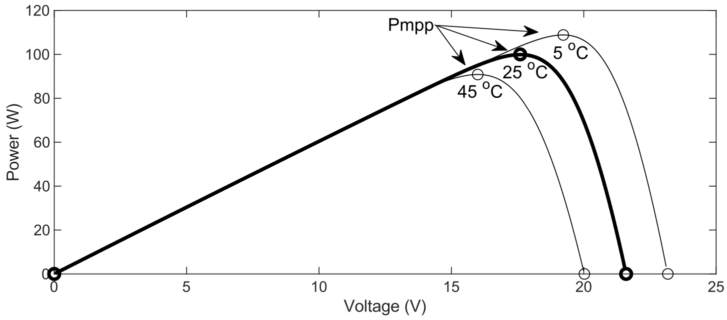

Figure 4. P-V characteristic curve under different temperature conditions

In practical applications, due to the changes in external conditions, PV cells cannot operate at the maximum power point, resulting in energy waste. The output state is dynamically changed with the DC-DC circuit and MPPT algorithm, so that the PV panel always operates near the maximum power point, therefore achieving efficient energy utilization.

2.2 PV system

PV panels are the energy source of the PV system. The power generated by PV panels can be converted into the required power through a PV power optimizer to maximize energy conversion efficiency. It is also known as the MPPT controller. The power generated by PV panels is in the form of DC, which typically implements MPPT via DC-DC conversion circuits to supply DC loads. The surplus electricity is stored in batteries. If applied in Alternating Current (AC) systems, PV inverters are also required. The PV systems can be categorized into on-grid PV systems and off-grid PV systems, depending on their grid-connection status.

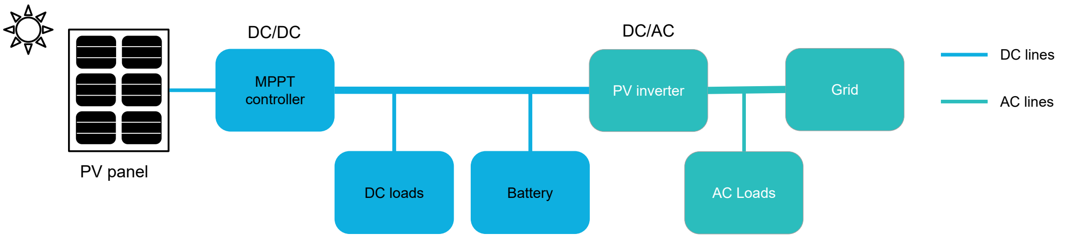

Figure 5. PV system

3 Design

The reference design makes a PV control system based on the MCX A346, with the BOOST topology. It implements MPPT control through the Perturb and Observe (P&O) method. The following are the specifications:

- Maximum power: 100 W
- PV panel input: 18 V
- Battery pack: 24 V
- Peak efficiency: 98 %

3.1 Overview

Figure 6 shows the block diagram for the reference design:

- The MCX A346 is the controller of the system.
- 18 V PV panel is used as the power input of the system.
- BOOST is the DC-DC topology to implement the MPPT algorithm.
- Sampling input and output voltage/current for BOOST control.
- To store energy for the system, the PV panel charges the 24 V battery.
- The load switch controls the energy from the 24 V battery to the DC load/electronic device.
- There are 2x Type-C charge ports for fast charging of electronic devices.
- Encoder, keys, and LCD are used for interaction and display.
- FreeMASTER is used as an upper computer.
- A temperature sensor is used to collect the ambient temperature.

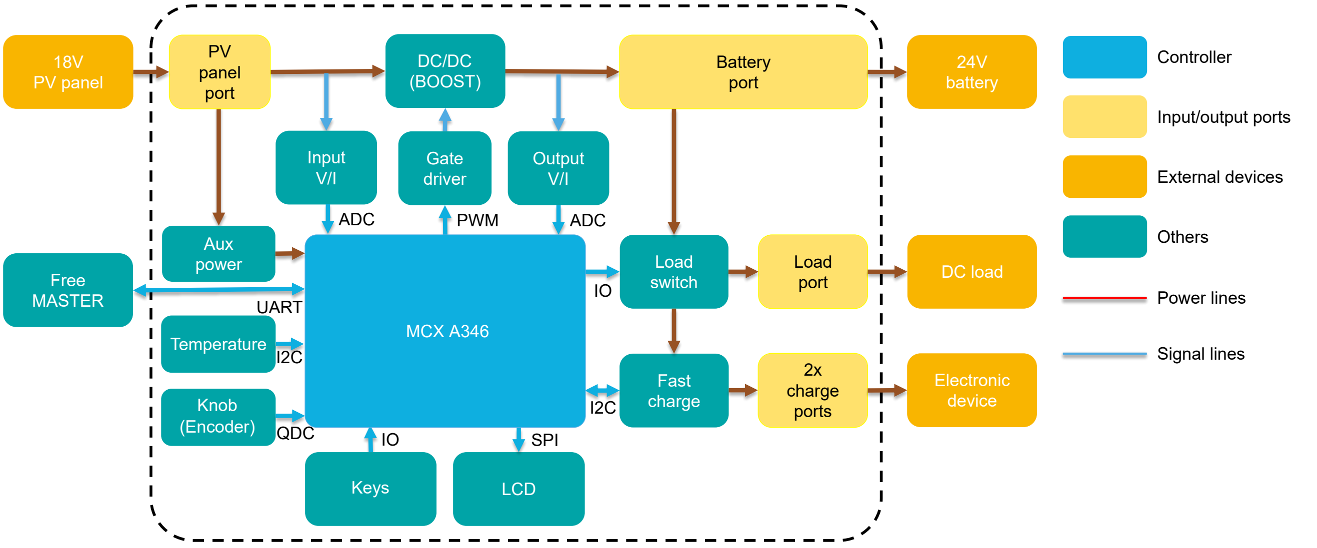

Figure 6. Block diagram

3.2 Hardware design

According to the hardware function, the hardware circuit can be divided into the following four parts:

- Power supply circuit (POWER)
- MPPT circuit (MPPT)
- MCU circuit (MCU)
- Fast charge circuit (CHARGE)

3.2.1 POWER circuit

The POWER circuit provides the required voltage for the entire system, as shown in Figure 7.

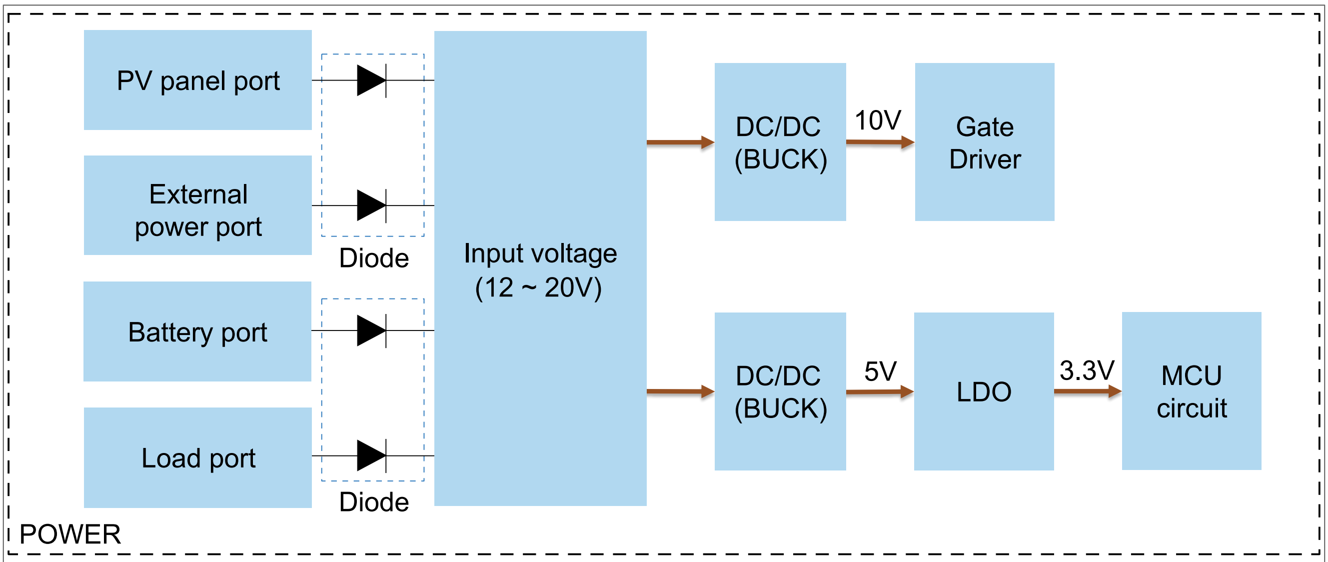

Figure 7. POWER circuit

Note: *There is an 18 V Transient Voltage Suppression (TVS) diode at the input, so the input voltage is typically less than 20 V. If you want to test with a higher input voltage, remove D51. However, the input voltage must not exceed 30 V.*

Four ports can be used for input voltage:

- PV panel port: it is the default port for providing input voltage.
- External power port: it is a power supply port used for testing.
- Battery port: it is an alternative port for power input and not selected by default.
- Load port: it is an alternative port for power input and not selected by default.

These ports are connected through diodes and fed into the input voltage. The following are the two power lines:

- 10 V power line: BUCK chip is used to generate the 10 V voltage for MOS driving voltage.
- 3.3 V power line: BUCK and Low-Dropout Regulator (LDO) chips are used to generate the 3.3 V voltage for MCU and other chips power supply.

3.2.2 MPPT circuit

The MPPT circuit is the main circuit to achieve MPPT. The DC-DC topology used here is BOOST, which can be used in application that requires voltage boosting as shown in Figure 8.

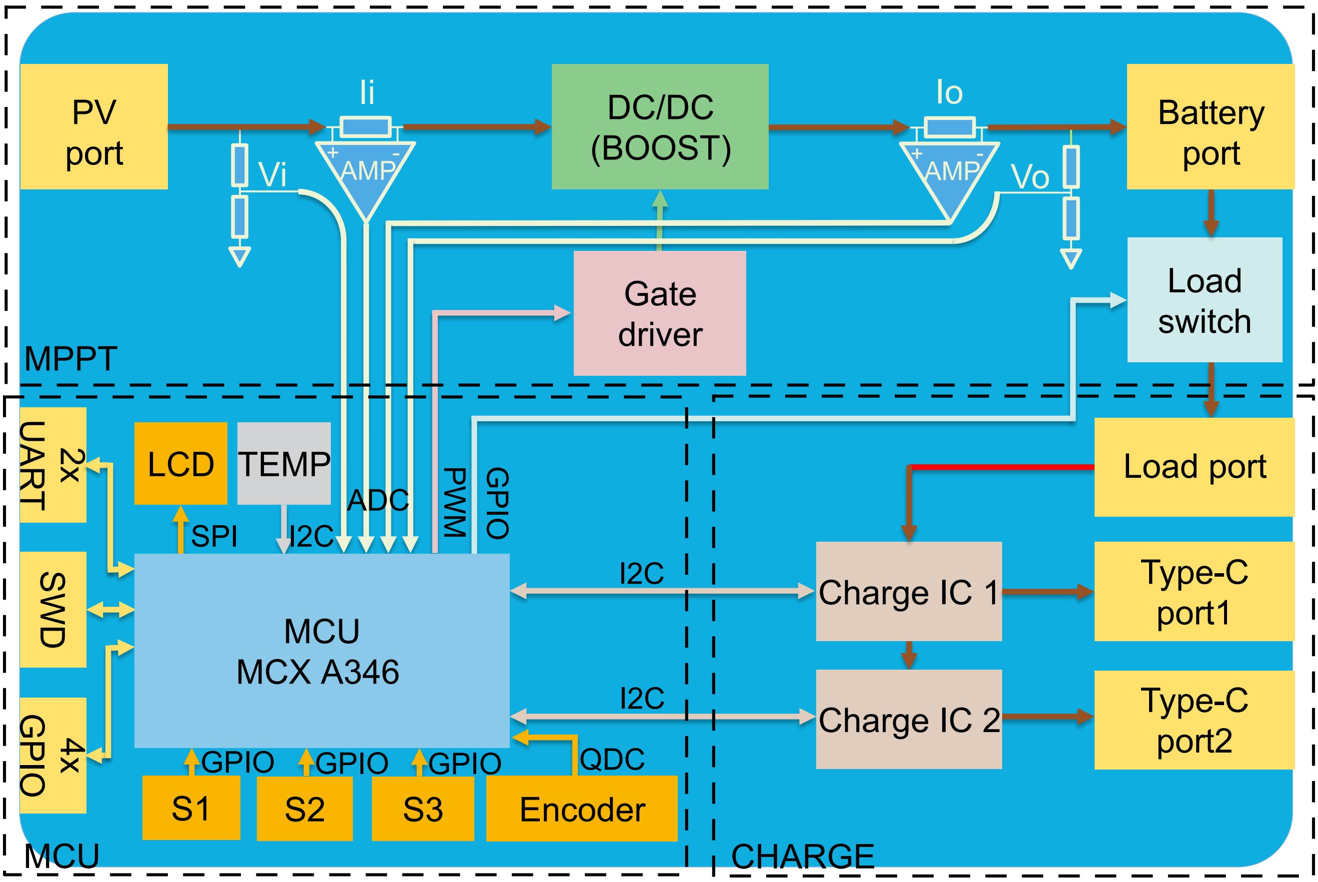

Figure 8. MPPT circuit

BOOST processes the energy from the PV panel. It charges the battery and completes the energy storage of the system. The gate driver drives the BOOST. Its driving voltage comes from the 10 V power line mentioned in the Section 3.2.1 and control signal comes from the PWM of the MCX A346. Simultaneously, the input and output voltages and currents are collected as feedback signals for the system.

3.2.3 MCU circuit

The MCU uses the MCX A346 as shown in Figure 8. The following peripherals used are as follows:

- 1x FlexPWM (a complementary pair) for BOOST control
- 1x ADC (4 channels) for input and output voltage/current sampling
- 3x I2C for charge IC and temperature sensor communication
- 1x SPI for LCD display
- 1x QDC for encoder (knob) detection
- 4x GPIO for keys input and load switch control
- 2x UART for log output and FreeMASTER communication
- 4x reserved GPIO
- 1x SWD for downloading and debugging

3.2.4 CHARGE circuit

The CHARGE circuit provides a fast charging control function. It is equipped with two independent charging control circuits and communicates with the controller via I2C.

The following are the supported functions:

- Fast charging function on-off control
- Fast charging power set
- Fast charging protocol reading
- Fast charging voltage/current reading

…

3.3 Software design

The software design is divided into the following several parts for introduction:

- Control loop
- State machine
- MPPT algorithm
- MPPT/Constant Current (CC)/Constant Voltage (CV) control

3.3.1 Control loop

Figure 9 shows the following three control loops:

- 50 kHz PWM output/ADC sampling loop
- 5 kHz CC/CV control loop
- 100 Hz MPPT control loop

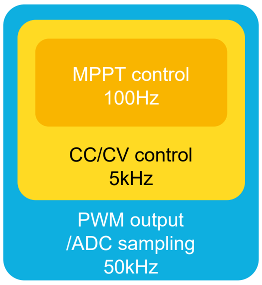

Figure 9. Control loop

The PWM control frequency is set to 50 kHz and it is the base frequency of this system. As shown in Figure 10, PWM output via INPUTMUX triggers the ADC, therefore, sampling the input and output voltage/current in each PWM cycle. When the ADC trigger sequence is completed:

- The trigger completion flag is set
- The ADC interrupt is triggered
- The CTIMER is triggered through INPUTMUX

Note: *For more details on FlexPWM, INPUTMUX, ADC, and CTIMER, see the MCX A345 and MCX A346 Reference Manual (document MCXAP144M240F60RM).*

In the Interrupt Service Routine (ISR) of CTIMER, the ADC data is averaged 10 times to obtain a control frequency of 5 kHz. It is then used for CC/CV control.

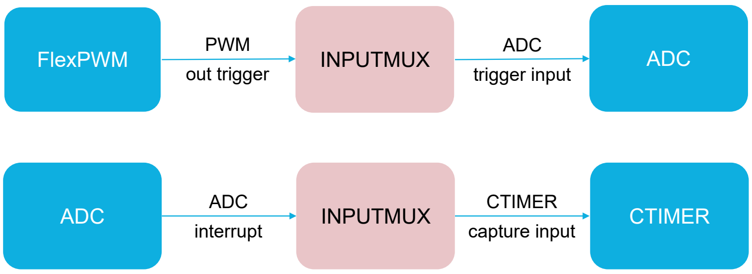

Figure 10. Triggering process

3.3.2 State machine

The MPPT is set to the following five states:

- MPPT_INIT: initialize related variables and status.
- MPPT_READY: system delay and user-defined operations.
- MPPT_WORK:
  - Continuous monitoring of system status.
  - Status check passed: enable the MPPT function.
  - Error detected: the status switches to MPPT_OFF and prints an error message.
  - Low input or battery full: the status switches to MPPT_IDLE.
- MPPT_IDLE: disable the MPPT function and wait for the system to work again.
- MPPT_OFF: disable the MPPT function and wait for the system to restart.

Figure 11 shows the state transition process.

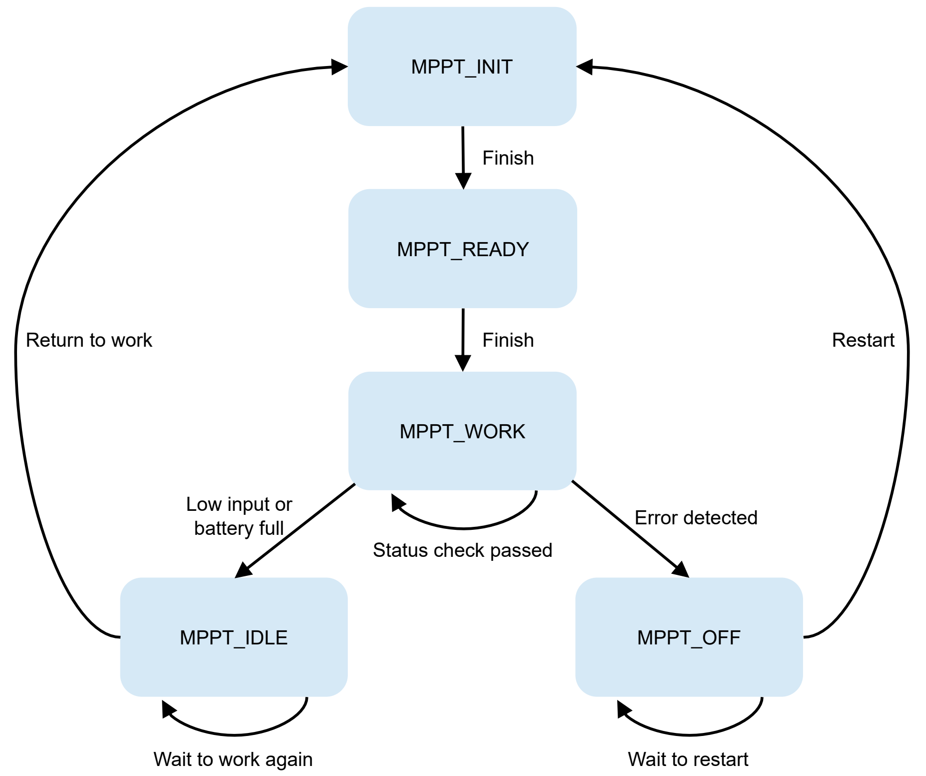

Figure 11. State machine

3.3.3 MPPT algorithm

The classic MPPT control methods mainly include the fixed fractional (FF), P&O, and incremental conductance (INC) methods. In more complex applications, fuzzy logic control and neural network methods are also used.

3.3.3.1 Principle analysis

In this demo, the P&O method is used to implement the MPPT.

The P-V characteristic curve of a PV panel is a single peak function with the maximum power point as the peak. In the P&O method, the operating point of the PV panel moves on the P-V characteristic curve by periodically applying perturbations as shown in Figure 12. The change in the output voltage (ΔV) and output power (ΔP) of the PV panel determines the correct direction of the voltage change. This change helps the operating point of the PV panel move gradually toward the maximum power point. The PV panel then works near the maximum power point. This process is called MPPT.

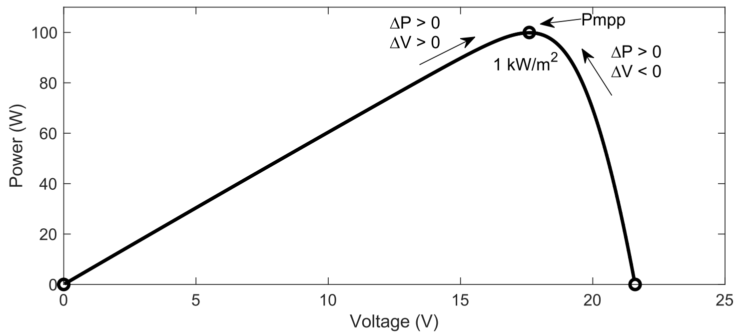

Figure 12. PV panel operating point analysis

On the left side of the curve, as the operating point moves toward the maximum power point, ΔP > 0 and ΔV > 0. At this point, the output voltage must be increased until ΔP < 0.

On the right side of the curve, as the operating point moves toward the maximum power point, ΔP >0 and ΔV < 0. At this point, the output voltage must be decreased until ΔP < 0.

Through the above analysis:

- If ΔP > 0 and ΔV > 0, then increase the PV panel output voltage
- If ΔP < 0 and ΔV > 0, then decrease the PV panel output voltage
- If ΔP > 0 and ΔV < 0, then decrease the PV panel output voltage
- If ΔP < 0 and ΔV < 0, then increase the PV panel output voltage

3.3.3.2 Program flowchart

Through the analysis in Section 3.3.3.1, the output voltage can be controlled directly by judging the sign of ΔP*ΔV. If ΔP*ΔV > 0, increase the control voltage. If ΔP*ΔV < 0, decrease the control voltage. The flowchart of the MPPT algorithm is shown in Figure 13.

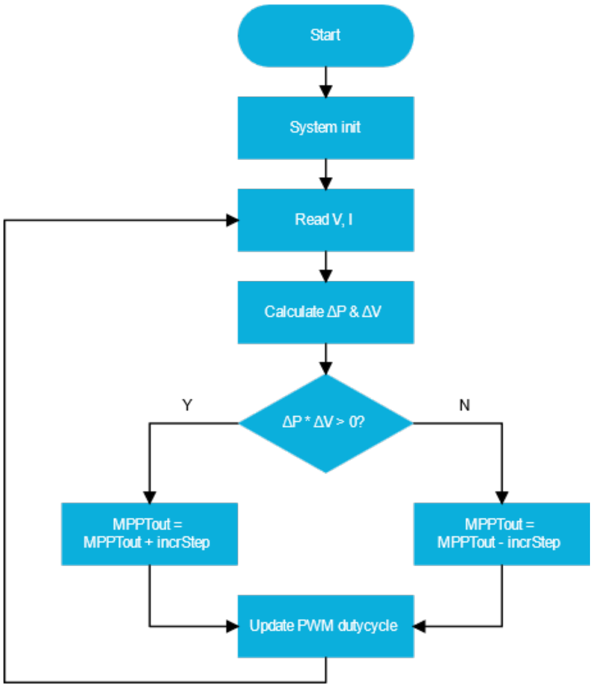

Figure 13. MPPT flowchart

3.3.4 MPPT/CC/CV control strategy

In this system, MPPT is one of the working modes. By combining with the CC/CV mode, the output of the system can be controlled to suit different loads.

When the DC-DC output is connected to the load, the switching strategies for different modes are shown in the Figure 14.

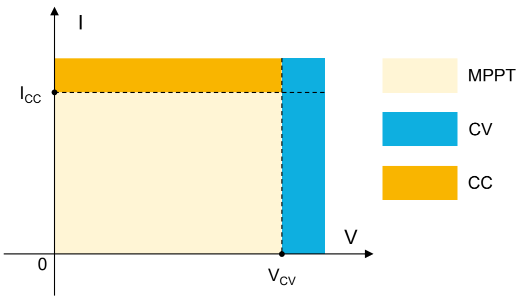

Figure 14. Control mode switch

Where:

- V_{CV} represents the CV operating point
- I_{CC} represents the CC operating point

Different colors correspond to different operating states. During normal operation, the voltage and the current do not exceed too much from the CV and CC points. When the system is in an abnormal state (with excessive current or voltage), protection is triggered through the state machine. For more details, see Section 3.3.2. At the junction of different modes, there is a problem of repeated mode switching. By adding a certain offset between the mode switching point and the actual operating point, this problem can be avoided.

When the DC-DC output is connected to the battery, the switching strategies for different modes are shown in Figure 15.

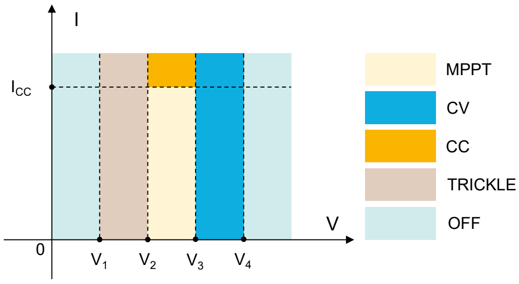

Figure 15. Charging mode switch

Where:

- V_1 represents the switching point between the OFF and TRICKLE modes.
- V_2 represents the switching point between the TRICKLE and CC modes.
- V_3 represents the switching point between the CC and CV modes.
- V_4 represents the switching point between the CV and OFF modes.

For lithium-ion batteries, there is a suitable working range. When the voltage is low or high, that is, less than V_1 or greater than V_4, the battery is damaged or problem with the battery parameter settings. Charging of the battery must be stopped. To charge the lithium-ion batteries, the battery charging process can be divided into the following four stages:

- Trickle charging (TRICKLE): also known as pre-charge. It is a restorative charge for a fully discharged battery. Usually a CC of 0.1 C is used for trickle charging.

Note: *The C-rate represents the charge and discharge rate of the battery. The 0.1 C means that the charging current is 1/10 of the battery capacity. For example, for a 1 Ah battery, 0.1 C means a charging current of 0.1 A.*

- CC charging: it is the fast charging stage of the lithium-ion batteries. As charging progresses, the battery voltage gradually increases.
- CV charging: when the battery voltage reaches nearly full charge, it enters the CV charging stage. Now, the charging current gradually decreases until the charging is completed.
- Charging off (OFF): battery full or error detected.

Figure 16 shows the charging process.

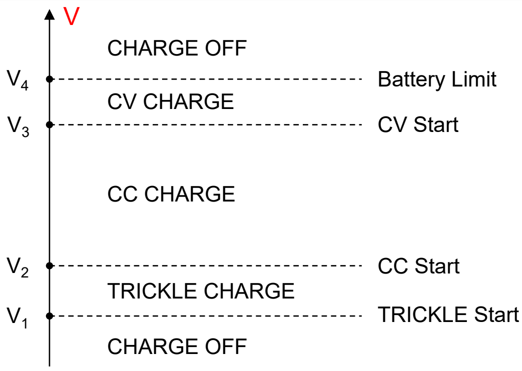

Figure 16. Charging process

4 Demo introduction

Figure 17 shows the MPPT demo V2.0 board.

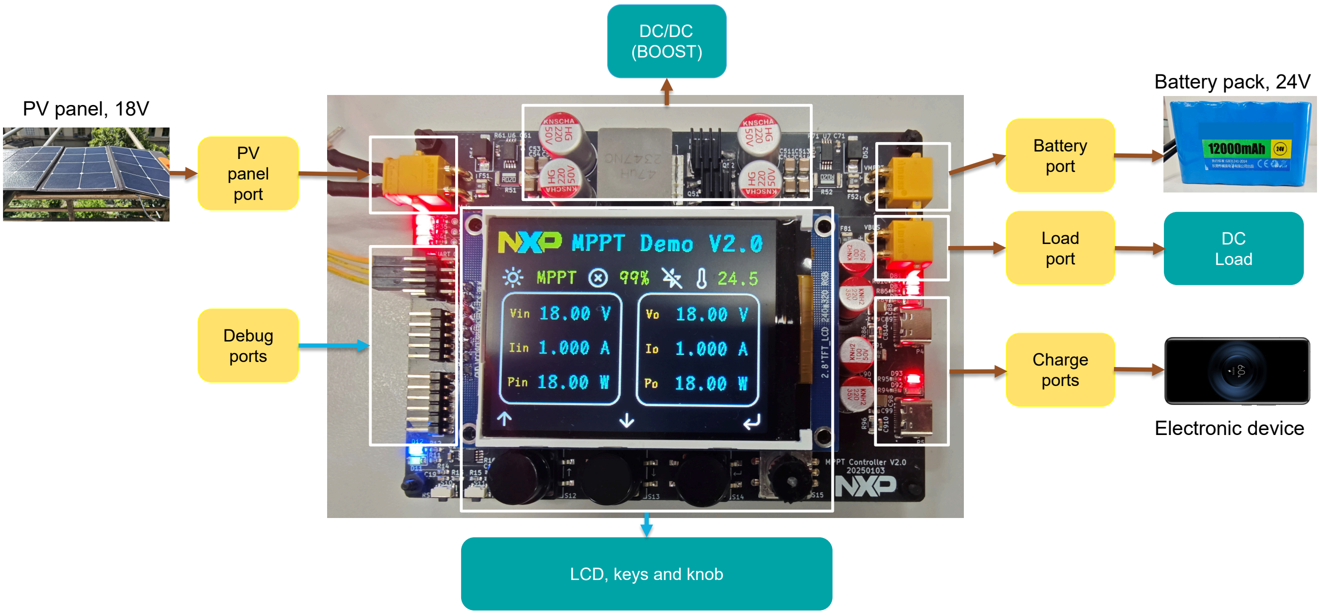

Figure 17. MPPT demo V2.0 board

Where:

- The left area is the power input port and debug ports.
  - P1: PV panel port. It supports 18 V PV panel input. Recommended input voltage: 12 ~ 20 V.
  - J1: UART ports, UART0 for printing logs, UART3 for FreeMASTER support.
  - J2 and J3: SWD ports for downloading and debugging.
  - J5: reserved GPIO.
- The upper middle area is the DC-DC circuit.
  - BOOST topology is used to implement MPPT.
- The right area is the power output ports.
  - P2: battery port, support 24 V battery pack, recommended output voltage: 12 ~ 32 V.
  - P3: load port, controlled by a load switch.
  - P4 and P5: fast charge ports. It supports PPS/PD/QC/AFC/FCP/SCP/PE/SFCP fast charge protocol.
- The middle area is the LCD display area and the lower middle area is the keys and encoder control area.
  - A 2.8 inches, 320 x 240 SPI LCD is used to display, three keys and one knob are used for input.

4.1 Display interface

Figure 18 shows the three display interfaces in this demo:

- Main interface
- Parameter interface
- Charging interface

To switch the display interface, press the up and down keys or rotate the knob.

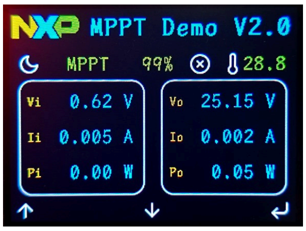

Figure 18. Display interface - main interface

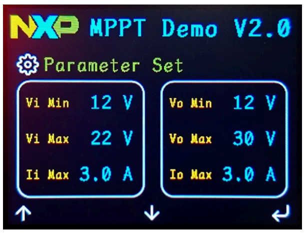

Figure 19. Display interface - parameter interface

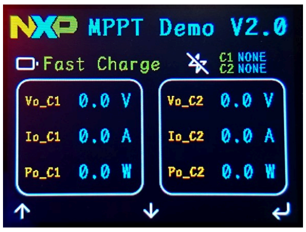

Figure 20. Display interface - charging interface

4.1.1 Main interface

Figure 21 shows the main interface for mode selection and status observation. To switch the selected mode, long press the enter keys or knob.

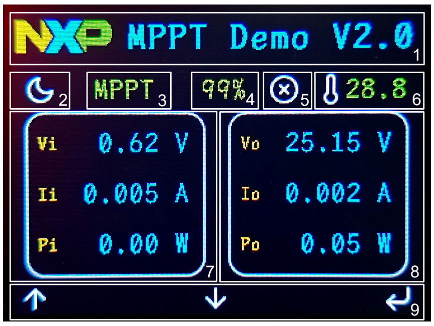

Figure 21. Main interface

Where:

- 1: NXP logo and demo name.
- 2: Input state (sun icon: suitable voltage, moon icon: low voltage).
- 3: Mode selected. Three modes are provided: MPPT, CC, and CV. To enter the selection, press the enter key. To select the mode, use the up and down keys.
- 4: Conversion efficiency.

- 5: Running status (on: play icon, off: stop icon. To switch the status, long press enter key).
- 6: Temperature display.
- 7: Input state (including input voltage, current, and power).
- 8: Output state (including output voltage, current, and power).
- 9: Key function indication (up, down, and enter, corresponding to the keys below).

4.1.2 Parameter interface

Figure 22 shows the parameter interface for mode selection and status observation.

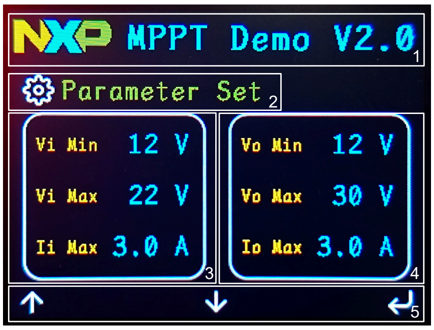

Figure 22. Parameter interface

Where:

- 1: NXP logo and demo name.
- 2: Icon and title for parameter interface. To enter the setting, press the enter key, then to switch the parameters, press the up and down keys. Long press the enter key to set the current parameter, and press the enter key to confirm.
- 3: Input parameters set (including input voltage/current).
- 4: Output parameters set (including output voltage/current).
- 5: Key function indication (up, down, and enter, corresponding to the keys).

4.1.3 Charging interface

Figure 23 shows the charging interface that shows the fast charging information. To switch the charging function, long press the enter keys or knob.

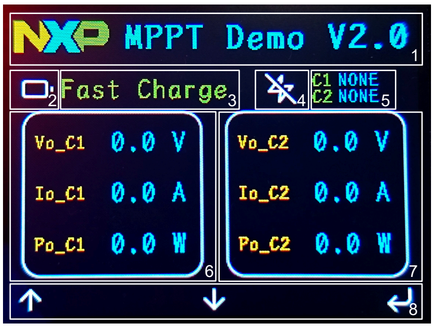

Figure 23. Charging interface

Where:

- 1: NXP logo and demo name.
- 2: Charging function switch state (off: empty battery and on: charging battery).

- 3: Title for charging interface.
- 4: Charging state (off: charging stop icon, on: charging icon).
- 5: Fast charging protocol display for Type-C port1 and port2.
- 6: Type-C port1 charging status (including charging voltage, current, and power).
- 7: Type-C port2 charging status (including charging voltage, current, and power).
- 8: Key function indication (up, down, and enter, corresponding to the keys).

4.2 FreeMASTER introduce

FreeMASTER is a user-friendly real-time debug monitor and data visualization tool that enables runtime configuration and tuning of embedded software applications.

FreeMASTER supports non-intrusive monitoring of variables on a running system. It can display multiple variables on oscilloscope-like displays as standard widgets (gauges, sliders, and more) or as data in text form, offering simple-to-use data recorders.

Figure 24 shows the MPPT demo V2.0 FreeMASTER interface. Use USB to serial port module to connect to UART3 port (J1).

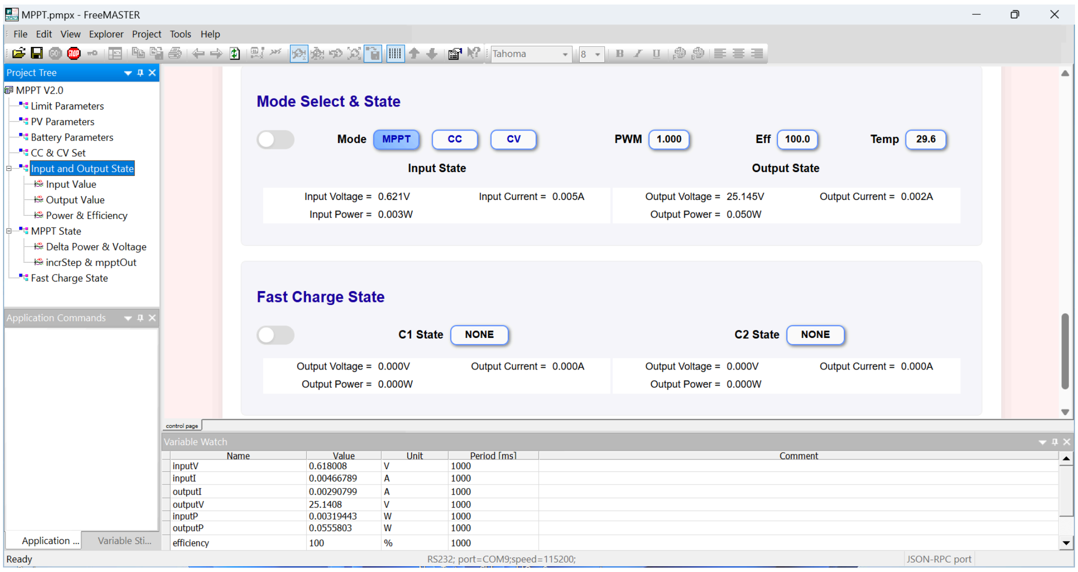

Figure 24. FreeMASTER interface

Figure 25 shows how FreeMASTER displays multiple variables on oscilloscope-like displays. Selecting the **Output Value** on the **Project Tree**, the output voltage and current data are displayed on the right-side. If needed, the data can be stored.

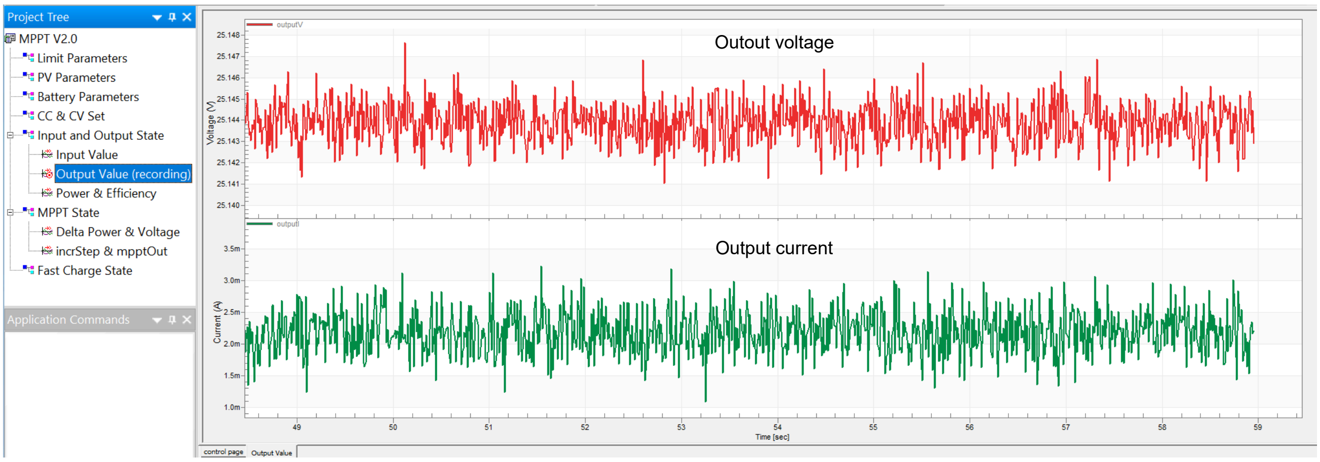

Figure 25. FreeMASTER curve display

4.3 Test result

To verify the actual tracking performance of the system, the experiments are designed to test the system. The tests are divided into the following two groups:

- Electronic load test
- Battery charging test

4.3.1 Electronic load test

In this test, the MPPT output end is connected to an electronic load and set to constant resistance mode.

Figure 26 shows the experimental connections:

DC power supply → MPPT demo → electronic load

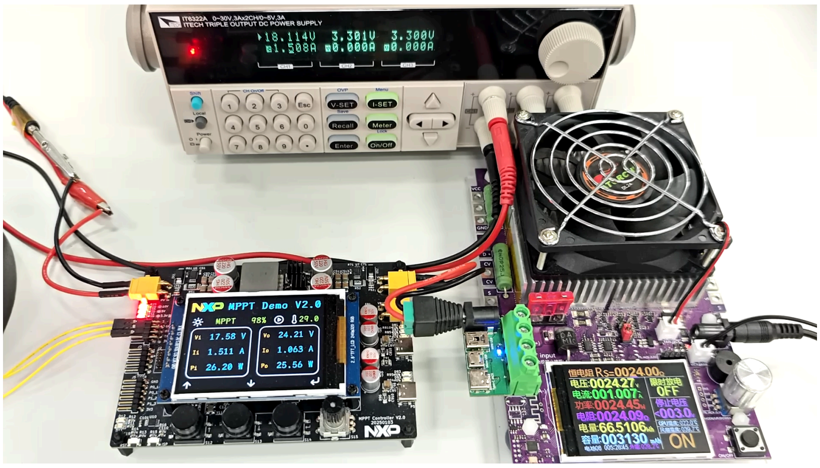

Figure 26. Electronic load test

The DC power supply is used here to verify the function. If there is no PV simulator, this method is a relatively simple test method. For a specific DC power supply configuration, the maximum power point is at the switching point between CV and CC. When the load is gradually increased from zero, the DC power supply maintains a CV. However, it increases the output current gradually until the current reaches the set value. After the current reaches the set value, the DC power supply maintains a CC while the output voltage decreases rapidly. At the switch point between CV and CC, the output power is maximum.

Note: *This method can test the MPPT function. As the characteristic curve is different from the characteristics of the PV panel, the MPPT parameters are slightly different.*

The MPPT/CC/CV modes are tested respectively. Table 1 shows the final test results.

Table 1. Electronic load test result

DC power supply (voltage/current)	Load resistance	Working mode	Output voltage/ output current	Tracking time	Efficiency
18 V/2 A	16 Ω	MPPT	22.7 ~ 24.2 V/ 1.44 ~ 1.46 A	2.5 s	98.5 %
18 V/2 A	20 Ω	CC (1.2 A)	23.7 ~ 24.6 V/ 1.19 ~ 1.21 A	5 s	98.1 %
18 V/2 A	20 Ω	CV (25.2 V)	24.9 ~ 25.5 V/ 1.24 ~ 1.25 A	2 s	98.1 %

Note:

- *Output voltage/Output current: Output voltage/current peak value after stabilization.*
- *Efficiency = output power/input power, data collected by the MPPT demo board.*

4.3.2 Battery charging test

In this test, the MPPT output end is connected to the 24 V lithium-ion battery pack.

Figure 27 shows the experimental connections:

DC power supply → MPPT demo board → 24 V lithium-ion battery pack

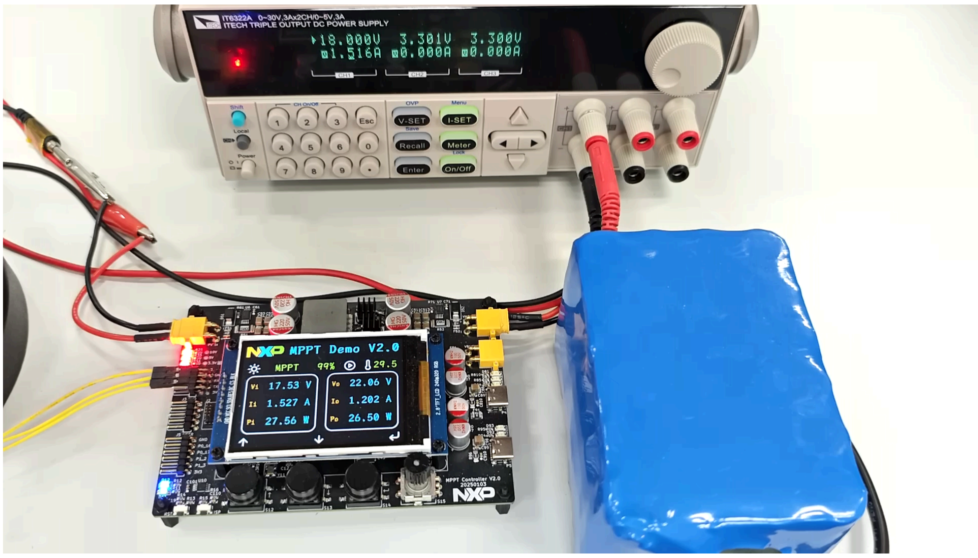

Figure 27. Battery charging test

The DC power supply is used to verify the function. If there is no PV simulator, this method is a relatively simple test method.

The MPPT/CC/CV modes are tested respectively. Table 2 shows the final test results:

Table 2. Battery charging test results

DC power supply (voltage/current)	Battery pack	Working mode	Charging voltage	Charging current	Efficiency
18 V/1.5 A	24 V	MPPT	22.75 → 22.78 V	1.02 ~ 1.15 A	99.2 %
18 V/3.1 A	24 V	CC (1.2 A)	22.96 → 22.98 V	1.02 ~ 1.34 A	99.2 %
18 V/3.1 A	24 V	CV (25.2 V)	25.19 ~ 25.24 V	0.8 → 0.65 A	99.0 %

Note:

- *Charging voltage: In MPPT and CC modes, the battery voltage gradually increases. Here, it is the initial mean battery voltage → final mean battery voltage. In CV mode, the battery voltage changes slightly. Here, it is the peak voltage of the battery.*
- *Charging current: In MPPT and CC modes, the charging current changes slightly. Here is the peak value of the charging current. In CV mode, the charging current gradually decreases. Here is the initial average value of the charging current → the final average value of the charging current.*
- *Efficiency = output power/input power, data collected by the MPPT demo board.*

5 Acronyms

Table 3 lists the acronyms used in this document.

Table 3. Acronyms

Acronym	Description
AC	Alternating Current
ADC	Analog-to-Digital Converter
CC	Constant Current
CV	Constant Voltage
DC	Direct Current
eQDC	Quadrature Decoder
FF	Fixed Fractional
GPIO	General-Purpose Input/Output
INC	Incremental Conductance
ISR	Interrupt Service Routine
LDO	Low-Dropout Regulator
LPI2C	Low-Power Inter-Integrated Circuit
LPSPI	Low-Power Serial Peripheral Interface
LPUART	Low-Power Universal Asynchronous Receiver-Transmitter
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
P&O	Perturb and Observe
PV	Photovoltaic
PWM	Pulse Width Modulator
SWD	Serial Wire Debug

Table 3. Acronyms*...continued*

Acronym	Description
TVS	Transient Voltage Suppression

6 References

Table 4 lists the references used to supplement this document.

Table 4. Related documentation/resources

Document	Link/how to access
MCX A345 and MCX A346 Reference Manual (document MCXAP144M240F60RM)	MCXAP144M240F60RM

7 Revision history

Table 5. Revision history

Document ID	Release date	Description
AN14856 v.1.0	11 December 2025	Initial public release

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Date of release: 11 December 2025
Document identifier: AN14856