Solar optimizer with CoolGaN™ transistors in a buck configuration: Controller guide

REF_OPTI_80V20A_GaN Reference Board

About this document

Scope and purpose

This user guide helps you get started with the REF_OPTI_80V20A_GaN reference design board for solar optimizers. This document provides information on the firmware.

Intended audience

This user guide is intended for system application engineers who want to use the REF_OPTI_80V20A_GaN reference design board.

About this product group

Target applications

- Solar optimizers for residential and commercial photovoltaic systems
- Module-level power electronics (MLPE) such as DC power optimizers
- High-frequency DC-DC converters for distributed energy systems
- Smart energy storage interfaces requiring fast transient response
- Low-voltage conversion stages in renewable or hybrid power architectures Product family

Product family

This reference design highlights Infineon's CoolGaN™ 100 V power transistor family, which provides superior switching performance for compact, high-efficiency power conversion. CoolGaN™ devices offer low specific on-resistance, low output charge, and robust high-frequency operation, making them well-suited for high-density DC-DC converters.

The design also integrates complementary Infineon components that together form a complete system solution:

- CoolGaN™ 100 V Transistors – optimized for high-speed switching and minimal switching losses
- EiceDRIVER™ 1EDN71x6U gate driver family – designed for GaN compatibility with differential input and active Miller clamp
- PSOC™ PSC3 microcontroller family – providing MPPT control, sensing, and system management
- OPTIREG™ LDO TLS205B0EJV33 – low-noise, low-quiescent-current power regulation for the controller and sensing circuits

This family of Infineon components enables small-form-factor, high-efficiency solar optimizer designs with simplified integration and broad application scalability.

REF_OPTI_80V20A_GaN Reference Board

About this product group

Reference Board/Kit

Product(s) embedded on a PCB with a focus on specific applications and defined use cases that may include software. PCB and auxiliary circuits are optimized for the requirements of the target application.

Note: Boards do not necessarily meet safety, EMI, quality standards (for example UL, CE) requirements.

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1 DC optimizer controller overview

The DC optimizer demonstrates the working of a buck converter in different modes implemented on the Infineon PSOC™ Control C3M5FDS2LGQ1 MCU. This example delivers highly efficient DC-DC power conversion for various modes in a buck converter.

Key features include:

- Open-loop mode with soft start
- Average output current control mode
- Voltage control mode
- MPPT control mode
- Advanced state machine for precise operational control
- Comprehensive protection mechanisms:
  - Input undervoltage and overvoltage protection
  - Input and output overcurrent protection
  - Overtemperature protection
  - Brown-in/brown-out handling for safe startup and shutdown
  - System fault detection for robust safety

1.1 Controller operation and key features

The DC optimizer controller has a robust, event-driven startup sequence orchestrated by a functional state machine. Upon power-up, the system initializes all peripherals and parameters and enables an interrupt to occur at every 1 ms using a PWM counter (TCPWM [0] Group [0] Counter 1). This interrupt calls a scheduler in which the state machine executes.

1.2 DC optimizer state machine

The DC optimizer state machine is orchestrated by a periodic hardware interrupt routine (`Dco_SchedulerHandler`) calling its handler (`pfc_state_machine_handler`) which executes two main functions for the current state:

- Entry action (`pfc_state_machine_entry_action`): Runs once upon entering a new state to manage the transition into new state with proper initialization.
  - Hardware configuration: Sets up appropriate hardware parameters for each state
  - Safety setup: Configures protection thresholds appropriate to each operational mode
  - Controller initialization: Prepares control loops with suitable parameters
  - Power path control: Manages power flow through enabling the PWMs
- Do action (`pfc_state_machine_do_action`): Runs continuously to monitor conditions and manage transitions.
  - State-dependent processing (SDP): Executes control loops specific to each state
  - State-dependent evaluation (SDE): Continuously monitors for events (voltages, currents, faults, etc.) that might require state transitions
  - State-dependent transitions (SDT): Evaluates conditions and triggers appropriate state changes based on events or protection triggers.

- Protection handling: Continuously checks for fault conditions with priority handling
- System synchronization: Aligns operations with AC zero crossings and polarity changes

The state machine diagram shown below provides a comprehensive visual representation of the DC Optimizer normal operation and protections states.

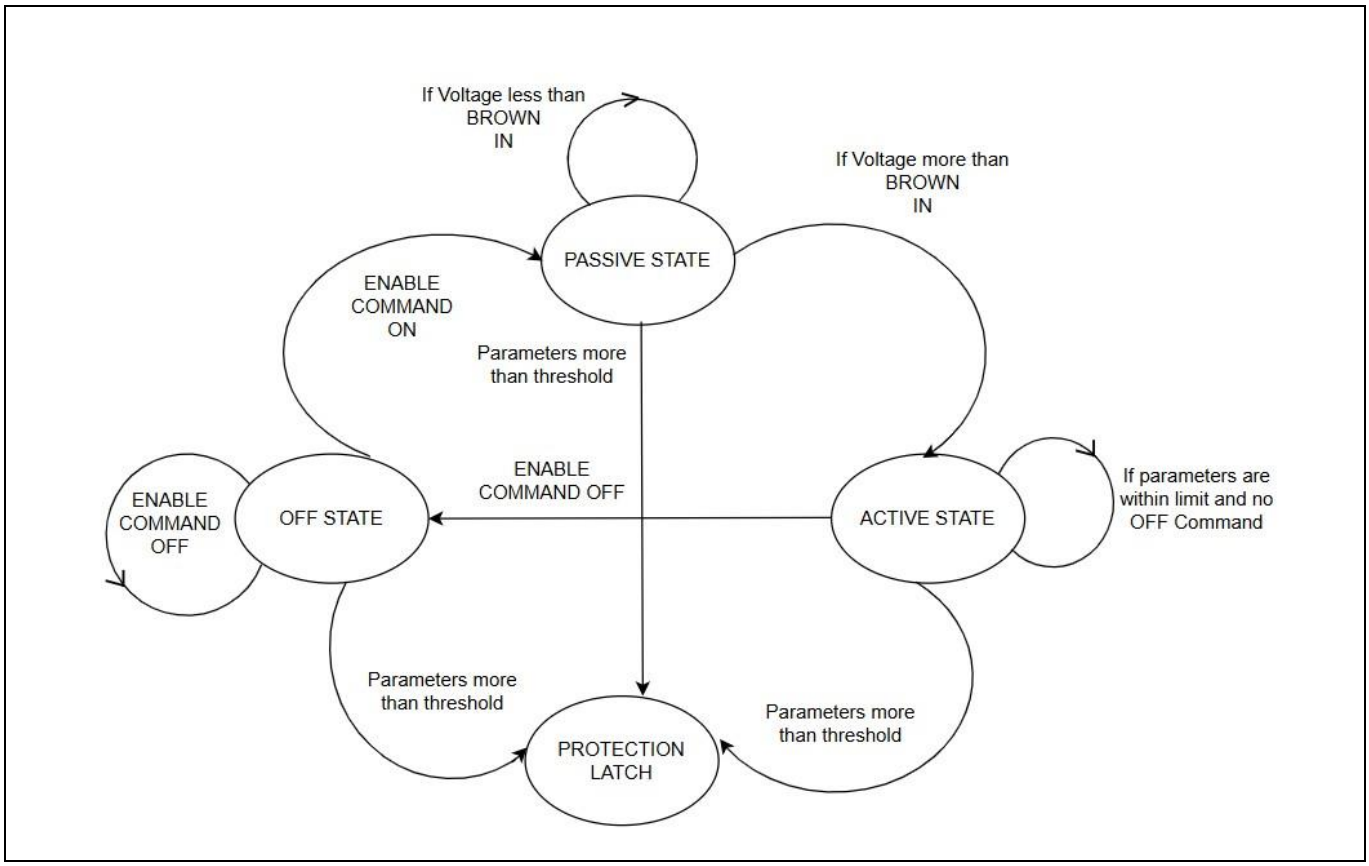

Figure 1 State machine diagram for DC optimizer

The state machine consists of the following states:

- `DCO_STATE_OFF`
- `DCO_STATE_PASSIVE`
- `DCO_STATE_STEADY`
- `DCO_STATE_PROTECTION_LATCH`

1.2.1 DCO_STATE_OFF

Initially, the state machine is in `DCO_STATE_OFF`. The state machine requires the `pfc_state_machine_entry_action` function for the “Entry” action. The entry actions enter once during the state changes. Here, the variables are configured to their initial value. At the next ISR (after 1 ms), the state machine will take the `pfc_state_machine_do_action` function to do the “do” action where the state continuously checks for the ON command.

The ON command can be received through two ways: one way is through an “enable” switch connected to GPIO 2. When a low transition is detected, an interrupt is generated and takes the `Dco_SwitchHandler` function. In

this state, the DCO_UTILITY_ENABLE_POWER_CONV utility flag is set, which in turn takes the state to DCO_STATE_PASSIVE.

The converter can be switched on using the One Eye GUI. When the enable switch is pressed in the GUI, the Dco_EnDisPowerConversionOneEye function is executed. This also sets the same DCO_UTILITY_ENABLE_POWER_CONV utility flag, and transitions to DCO_STATE_PASSIVE.

1.2.2 DCO_STATE_PASSIVE

In the passive state, temperature and voltage brown-in counters are set. In the next 1 ms, the state machine goes to the “do” action passive state, where the temperature and input voltage are monitored. If the input voltage is less than the DCO_VPV_MIN_V macro, the state continues to be in passive state. If the input voltages and temperatures are normal, the state moves to DCO_STATE_STEADY. If the converter has protection events, the state moves to DCO_STATE_PROTECTION_LATCH.

1.2.3 DCO_STATE_STEADY

The DC optimizer is run in the following modes based on the DCO_MODE_SELECTION macro:

- DCO_MODE_OPEN_LOOP
- DCO_MODE_INNER_CURRENT_CONTROL
- DCO_MODE_VOLTAGE_CONTROL
- DCO_MODE_MPPT_CONTROL

1.2.3.1 DCO_MODE_OPEN_LOOP

This mode represents the open-loop mode. You can set the following in open loop mode:

- Final duty ratio of the converter using the DCO_PWM_DUTY_RATIO macro
- Acceleration rate using DCO_RAMP_RATE macro

At the end of the entry action, the TCPWM[0] Group[0] 32-bit Counter 3 (PWM_Gen) is started. The central-aligned PWM is used for PWM generation. At the middle of period of this PWM counter, an ADC “start of conversion” is generated using trigger outputs. Averaging of eight samples is configured for output voltage and output current. At the end of eight samples, the “end of conversion” ADC interrupt calls the Dco_3P3ZControlHandler function, which reads the output currents and voltages from the ADC registers and loads the compare value into the buffer register to generate the PWMs in open-loop mode.

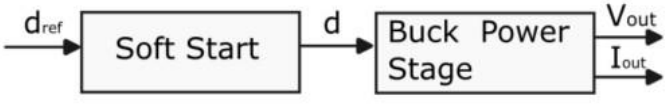

Figure 2 Block diagram for open-loop mode

1.2.3.2 DCO_MODE_INNER_CURRENT_CONTROL

If DCO_MODE_SELECTION is selected as DCO_MODE_INNER_CURRENT_CONTROL, the buck converter will be initialized to operate in output average current control mode from DCO_STATE_STEADY. This means that the duty ratio will be generated so as to pass the set output current using the DCO_IL_REF_A macro. You can choose the DCO_IL_KP and DCO_IL_KI controller constants to achieve the desired response of the current

loop. Further the control is implemented in 3P3Z generalized format. The final duty ratio from inner current control is loaded into the buffer registers from the control ISR (`Dco_3P3ZControlHandler`).

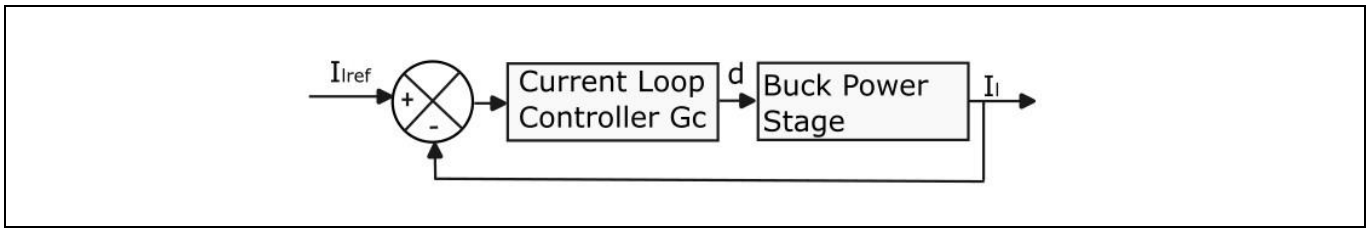

Figure. 3 Control block diagram for current control mode

1.2.3.3 DCO_MODE_VOLTAGE_CONTROL

If you select `DCO_MODE_SELECTION` as `DCO_MODE_VOLTAGE_CONTROL`, the buck converter will be initialized to operate in output voltage control mode or standard buck mode from `DCO_STATE_STEADY`.

You should set the output reference voltage using `DCO_VOUT_REF_V`, and provide the maximum reference current to be controlled by the inner current loop by `DCO_IL_REF_MAX_A`. You can choose the `DCO_IL_KP`, `DCO_IL_KI`, `DCO_VOUT_KP`, and `DCO_VOUT_KI` controller constants to achieve the desired response of the voltage loop. This control method is similar to a typical outer voltage loop followed by an inner current control. In addition, the control is implemented in 3P3Z generalized format. The 3P3Z calculations are called every 50 kHz. The duty ratio received from 3P3Z are loaded into the buffer registers of the PWM counter.

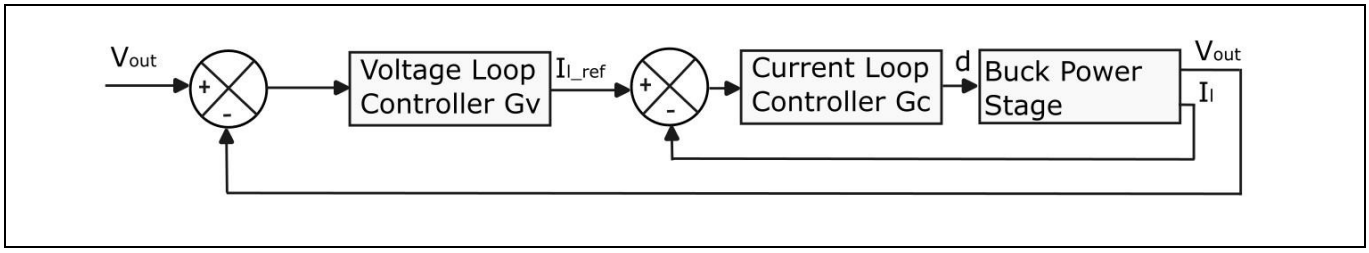

Figure 4 Control block diagram for voltage control mode

1.2.3.4 DCO_MODE_MPPT_CONTROL

The MPPT mode regulates the input voltage for the solar panel to extract maximum power, unlike in the voltage control mode. The duty ratio is generated so that the buck converter input resistances match the load resistance. By increasing the duty cycle, the output current rises, which in turn increases the input current leading to a drop in the input voltage. The input power is measured on every `DCO_MPPT_DELAY` (30 ms), a working point when the highest possible input power is reached.

In this optimizer, the MPPT algorithm gives the reference voltage feedback to the voltage control loop, which in turn generates the duty ratio. The perturb and observe algorithm is used for MPPT and 3P3Z controllers for voltage control. The MPPT algorithm executes every 30 ms and the voltage loop works every 50 kHz. This leads to a very quick response time if the load or input power changes.

The step size of the reference voltage `DCO_VPV_STEP_V` is set to ~0.4 V in order to quickly track the target voltage in case of shadowing, but still accurately reach the maximum power point. The MPPT algorithm gives the reference input voltage. The voltage loop regulates so as to achieve this input voltage. The firmware itself can be adapted to fit other voltage and current ranges by various macros described below.

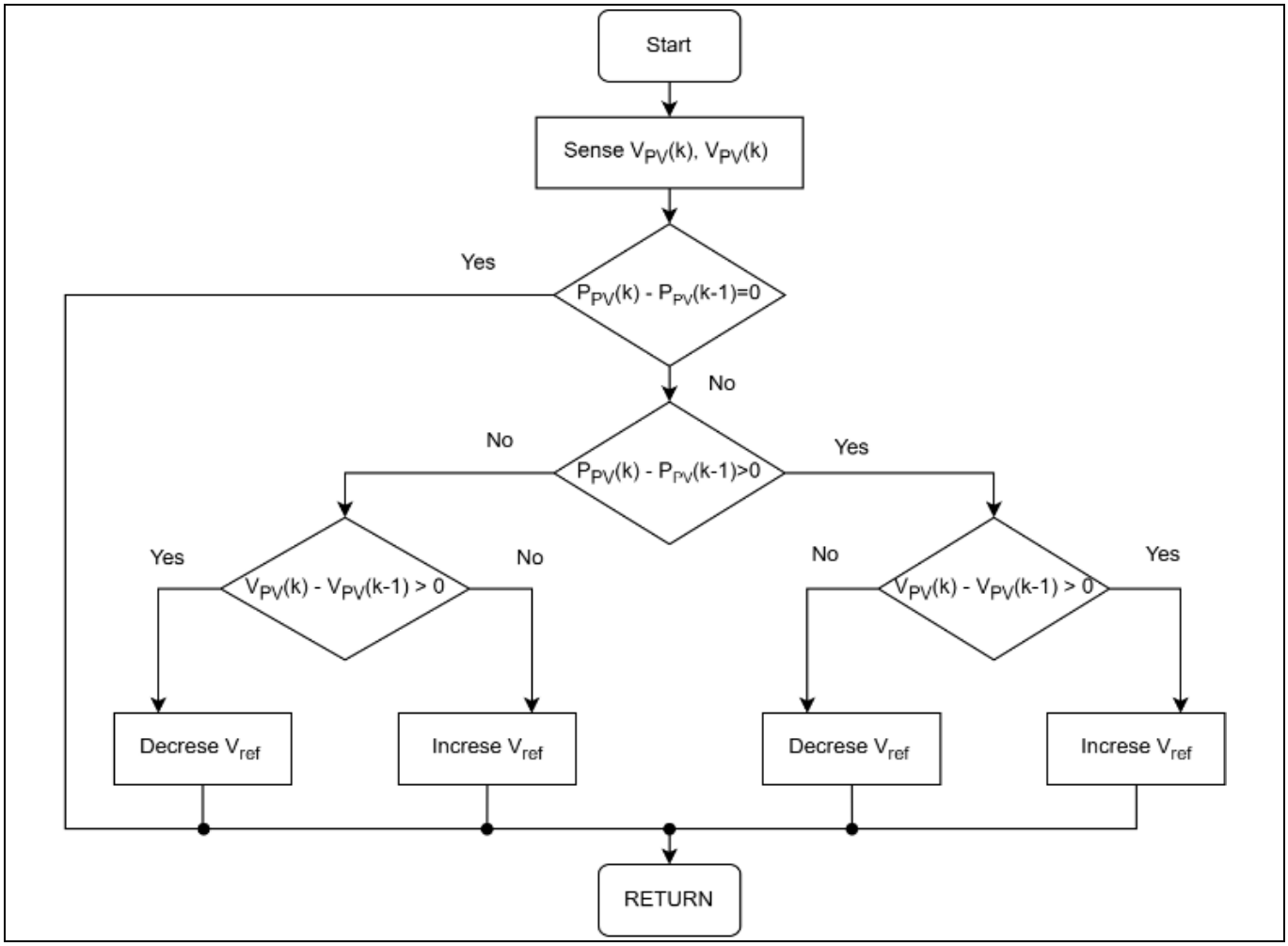

Figure 5 MPPT algorithm flowchart

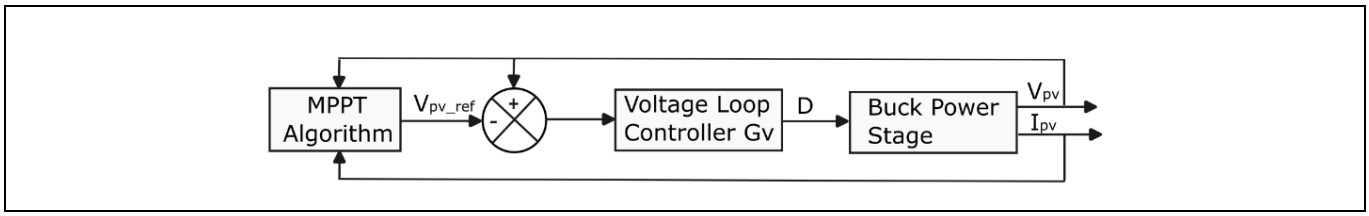

Figure 6 Control scheme for the MPPT algorithm

1.2.4 DCO_STATE_PROTECTION_LATCH

At every state, the input voltage, input current, output current, and temperature are monitored. If these exceed the limits, the state jumps to the protection latch. When a protection latch occurs, the user has to restart the controller.

2 Code configuration

2.1 MCU peripherals configuration

The DC optimizer code example is implemented on the Infineon PSOC™ Control C3M5 MCU with all hardware configuration managed using the ModusToolbox™ Device Configurator. The configuration file, "*design.modus*", contains all user-defined settings for MCU peripherals, pin assignments, and hardware features, making the setup transparent and reproducible.

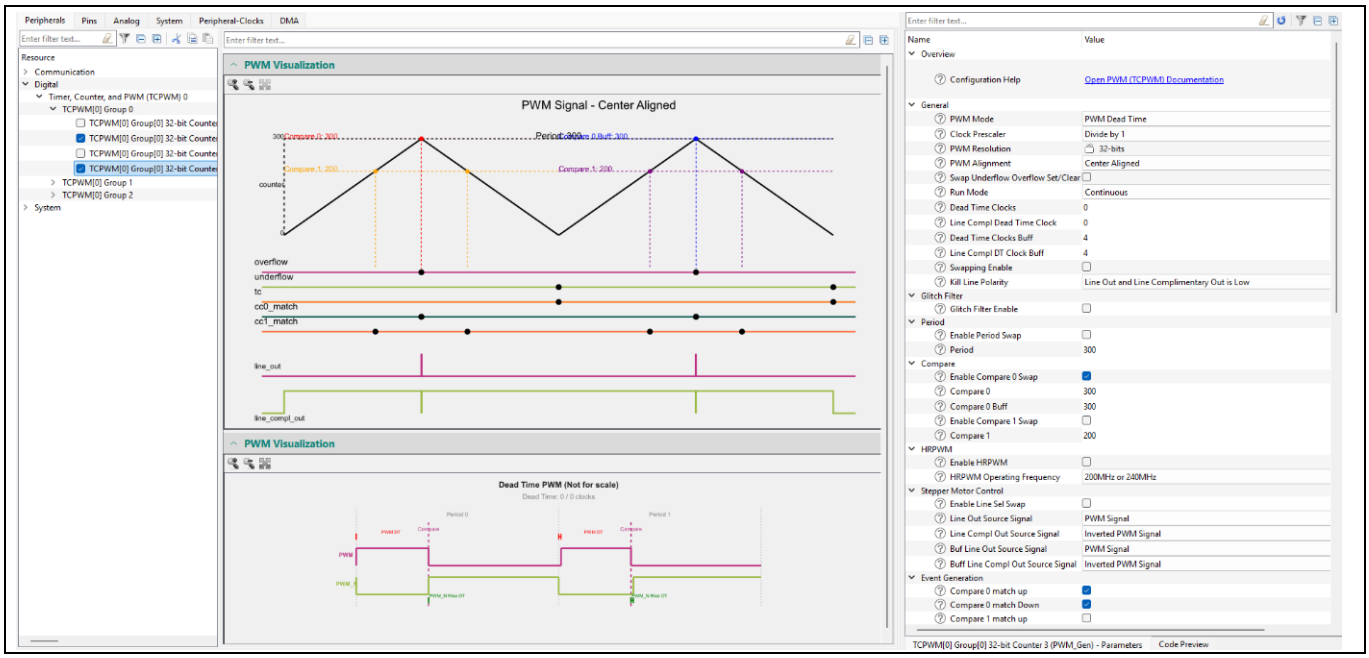

Figure 7 ModusToolbox™ Device Configurator

The table below lists all the MCU hardware used for the DC optimizer PFC application.

Table 1 Peripherals

Used peripheral	Description
DEBUG_UART	For data transfer to the host PC
P4[0] (PWMUH_P, PWM, GPIO) P4[1] (PWMUL_P, PWM, GPIO)	High-frequency PWM driving high-/low-side power switches
AN_A0(Temp)	Measures the PCB temperature
AN_A1(I_in)	Measures the input current of the DC optimizer
AN_A2(V_in)	Measures input voltage
AN_A3(I_out)	Measures the output inductor current
AN_A4(V_out)	Measures the output voltage of the converter
CMP_BUCK_IN_CURR (CSG) CMP_BUCK_OUT_CURR(CSG)	Hardware analog comparators monitoring the input overcurrent and output current protections. Both trigger protection events via CSG when limits are exceeded
P2[0](GPIO Input)	Enable switch to start the converter

2.2 Application SW configuration

You can configure the DC optimizer firmware to adapt the controller for various hardware configurations, power ranges, and component technologies. This flexibility enables fine-tuning of the existing system or adaptation to entirely different hardware platforms with minimal firmware modifications.

The following table outlines the key parameters that can be adjusted to optimize performance or port the design to different DC-DC converter applications.

Table 2 Peripherals

Parameter	Default value	Unit	Description
DCO_MODE_SELECTION	DCO_MODE_SELECTION	–	This macro helps to select the mode of operation of the DC optimizer
DCO_UI_MODE_SELECTION	DCO_UI_MODE_SELECTION	–	This macro allows you to select either the One Eye GUI or Serial Analyzer for debugging purpose
DCO_SCHEDULER_FREQ	1	kHz	Sets the scheduler frequency
DCO_IPV_OCP_HW_THRESHOLD_A	30	A	Input overcurrent protection threshold
DCO_IL_OCP_HW_THRESHOLD_A	30	A	Output overcurrent protection threshold
DCO_IL_ADC_CONVERSION_FACTOR	0.009827571	–	Output current to digital data conversion factor for Ipv
DCO_IPV_ADC_CONVERSION_FACTOR	0.009827571	–	Input current to digital data conversion factor for Ipv
DCO_VOUT_ADC_CONVERSION_FACTOR	0.02138103	–	Voltage to digital data conversion factor for output voltage
DCO_VPV_ADC_CONVERSION_FACTOR	0.02138103	–	Voltage to digital data conversion factor for input voltage
DCO_TEMP_ADC_CONVERSION_FACTOR	0.000805861	–	Voltage to digital counts conversion factor for temperature
DCO_PWM_DUTY_RATIO	0.5	–	Steady state duty ratio for open-loop mode
DCO_RAMP_RATE	0.1	S	Ramp rate for open-loop mode
DCO_IL_REF_A	4.0	A	Reference current for current control mode
DCO_PWM_DUTY_RATIO_MAX	0.99	–	Maximum duty ratio set by the inner loop
DCO_PWM_DUTY_RATIO_MIN	0.05	–	Minimum duty ratio set by the inner loop
DCO_VOUT_REF_V	20.0	V	Reference output voltage for buck mode
DCO_IL_REF_MAX_A	20.0	A	Maximum reference Il reference for current loop

Code configuration

Parameter	Default value	Unit	Description
DCO_PIN_STEP_W	1.0	W	Dead band of power in which variation in Vref is not required
DCO_VPV_MAX_V	85.0	V	Maximum input voltage
DCO_VPV_MIN_V	12.0	V	Maximum input voltage
DCO_VPV_STEP_V	0.3	V	Voltage jumps required to track the MPPT
DCO_INTIAL_DELTA_V	4.0	V	Initial difference in voltage to start the MPPT algorithm
DCO_IL_B0	0.0018	–	Coefficients for designed current loop
DCO_IL_B1	–0.0016	–	Coefficients for designed current loop
DCO_VOUT_B0	0.05	–	Coefficients for voltage current loop
DCO_VOUT_B1	–0.049	–	Coefficients for voltage current loop
DCO_VPV_BROWN_IN_DELAY	200000	ms	Vpv minimum brown-in period
DCO_VPV_BROWN_OUT_DELAY	200000	ms	Vpv minimum brown-out period
DCO_PTC_OVER_TEMP_DELAY	500000	ms	Overtemperature counter
DCO_MPPT_DELAY	30000	ms	MPPT scheduler time
DCO_PTC_OVER_TEMP_THRESHOLD	90	C	Overtemperature threshold

3 Test results and measurements

3.1 Open-loop mode

If DCO_MODE_SELECTION is selected as DCO_MODE_OPEN_LOOP, the converter operates in open-loop mode. The duty ratio is ramped as defined by DCO_RAMP_RATE and reaches a steady state value of DCO_PWM_DUTY_RATIO.

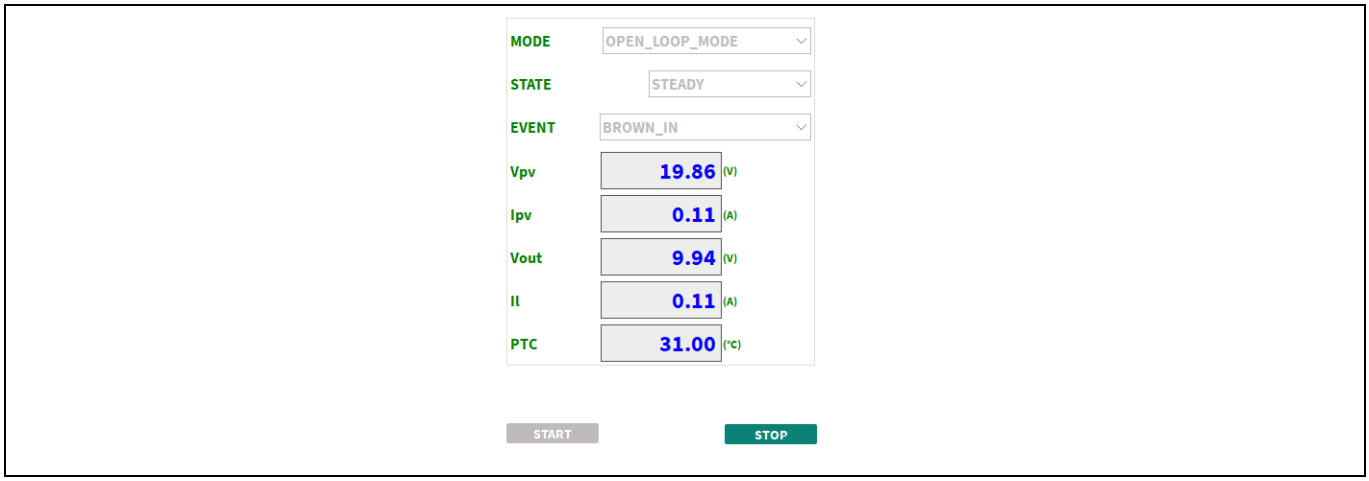

Figure 8 Open-loop mode in One Eye GUI

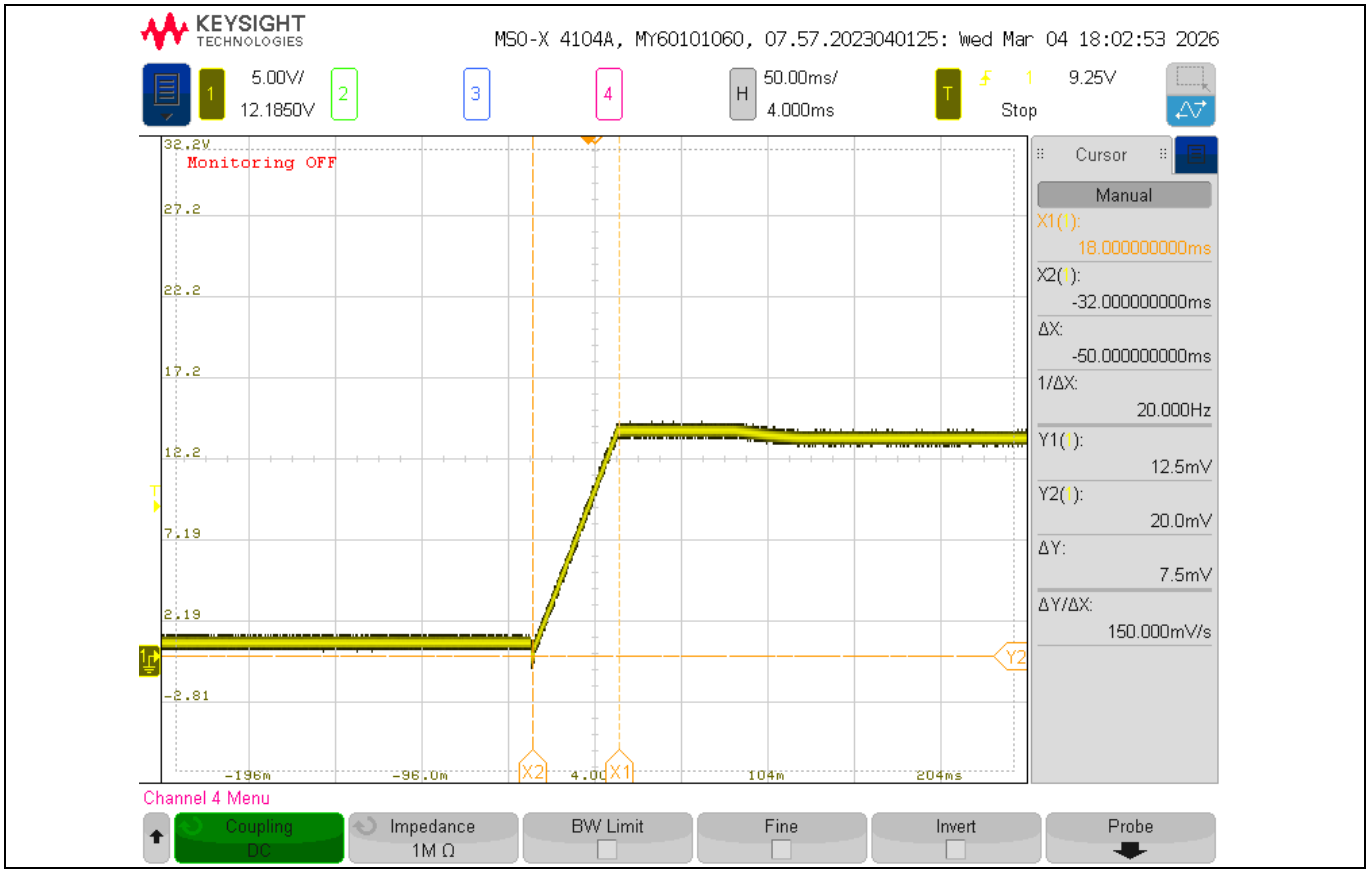

Figure 9 Output voltage in open-loop mode

3.2 Current control mode

If `DCO_MODE_SELECTION` is selected as `DCO_MODE_INNER_CURRENT_CONTROL`, the converter operates in output current mode. The target `DCO_IL_REF_A` is set by the user. The duty ratio is generated to pass the reference current set by the user.

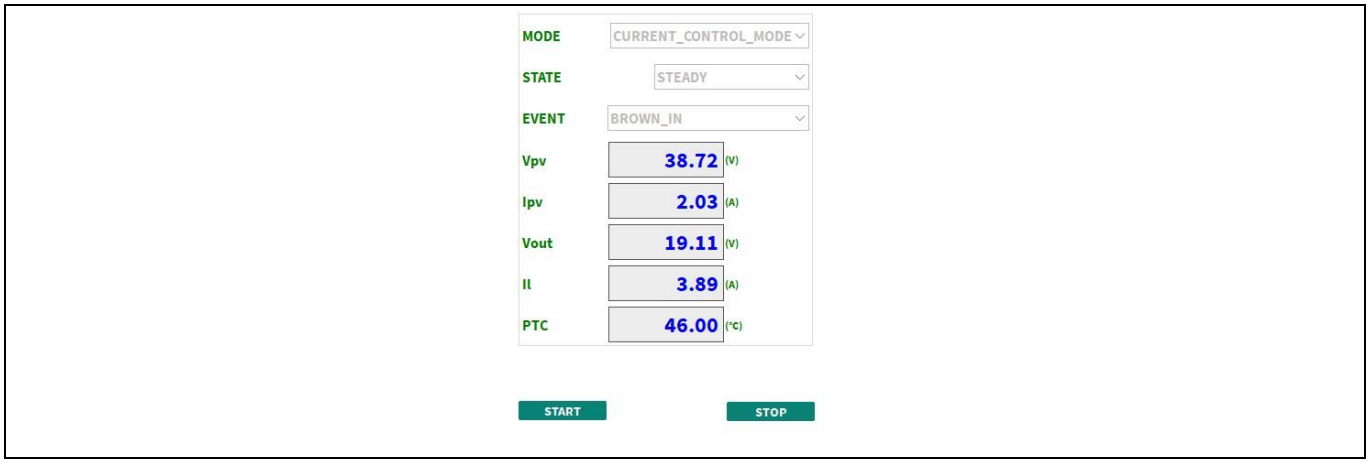

Figure 10 Current control mode in One Eye GUI

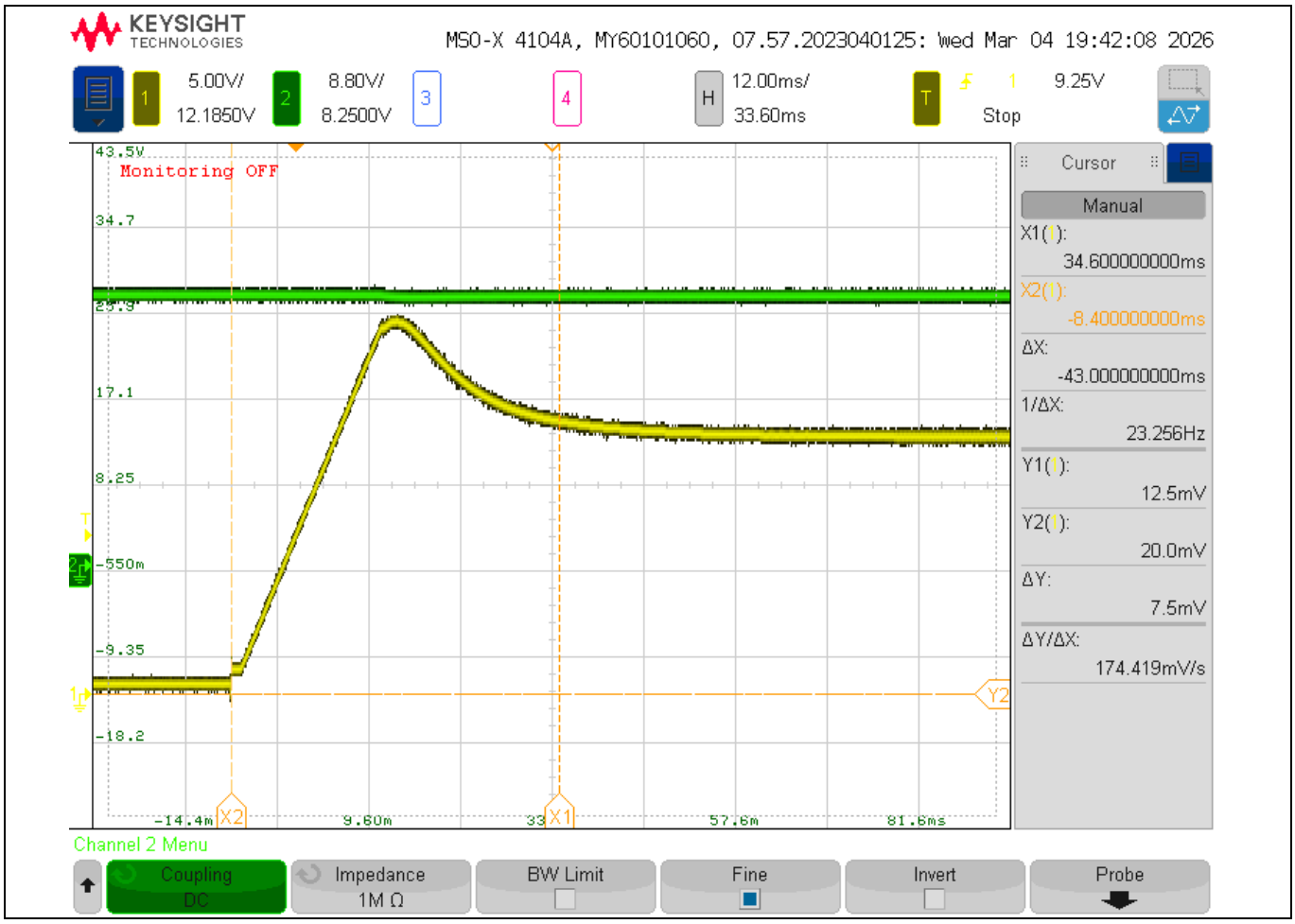

Figure 11 Output voltage for current control mode

3.3 Output voltage control mode

If DCO_MODE_SELECTION is selected as DCO_MODE_VOLTAGE_CONTROL, the converter operates in output voltage control or buck mode. The target DCO_VOUT_REF_V is set by the user. The duty ratio is generated to set the reference voltage by the user.

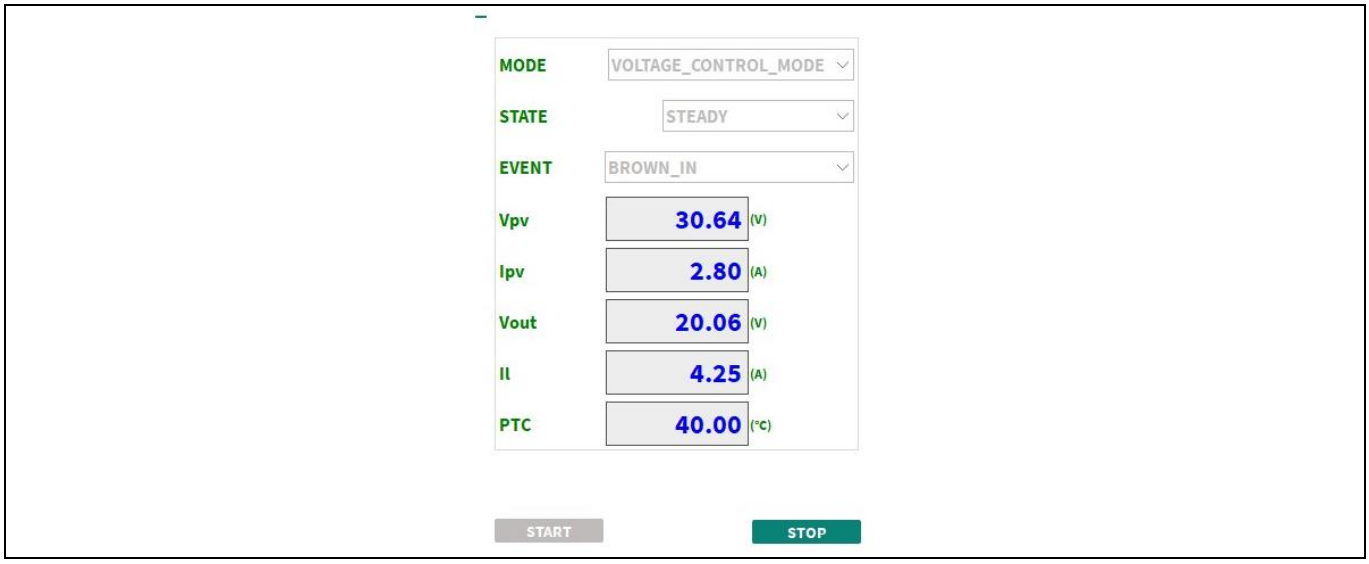

Figure 12 Output voltage control mode in One Eye GUI

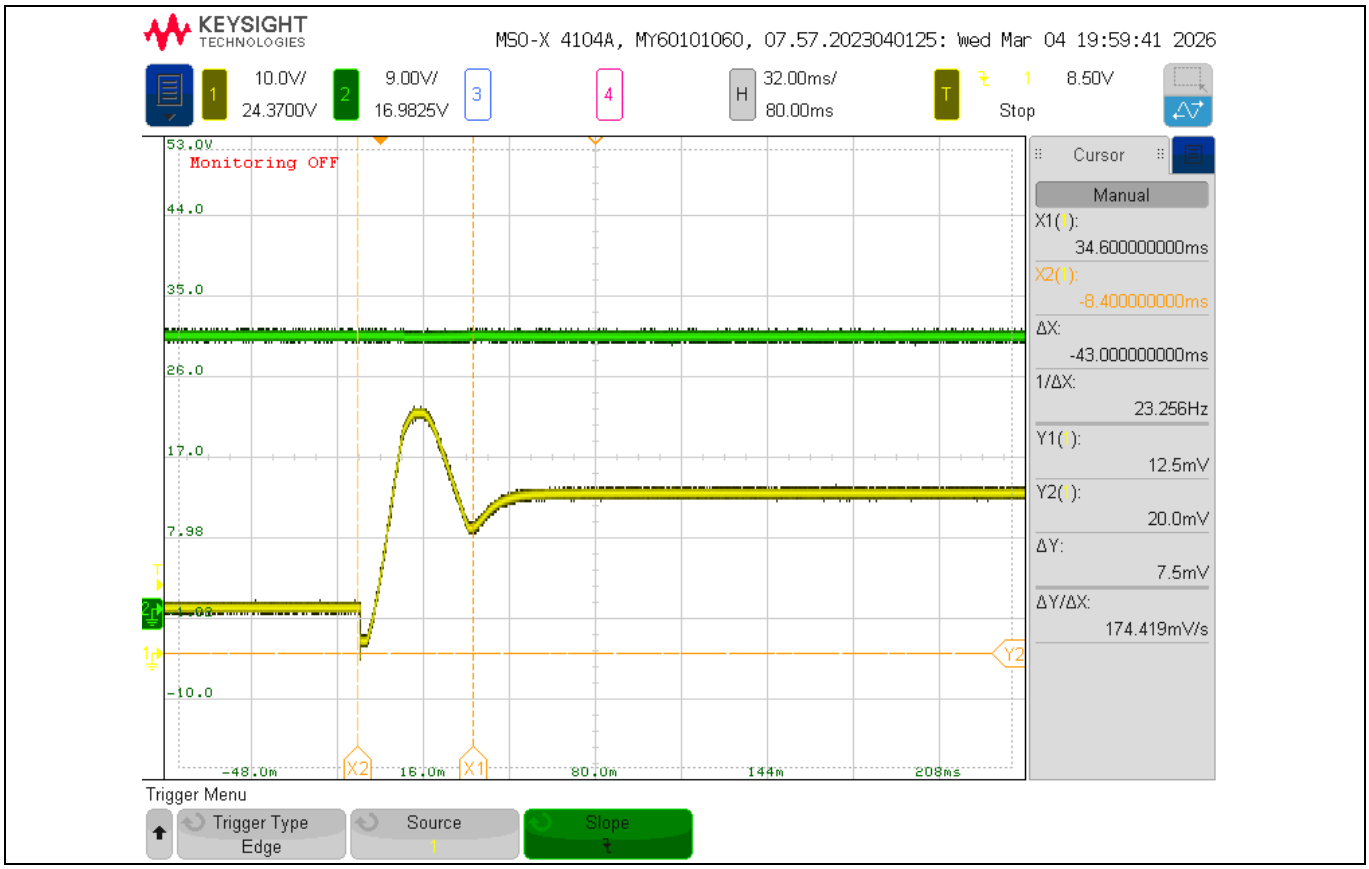

Figure 13 Output voltage control mode

3.4 MPPT control mode

If DCO_MODE_SELECTION is selected as DCO_MODE_MPPT_CONTROL, the converter operates in maximum power transfer control mode. The user can set the following macros for MPPT control modes:

- DCO_PIN_STEP_W
- DCO_VPV_MAX_V
- DCO_VPV_MIN_V
- DCO_VPV_STEP_V
- DCO_INTIAL_DELTA_V

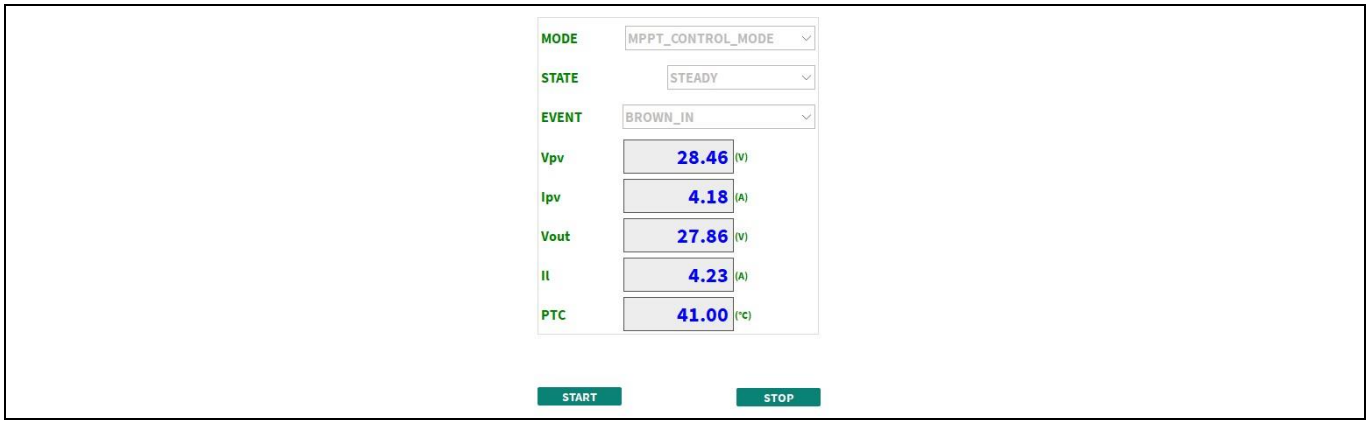

Figure 14 MPPT control mode in One Eye GUI

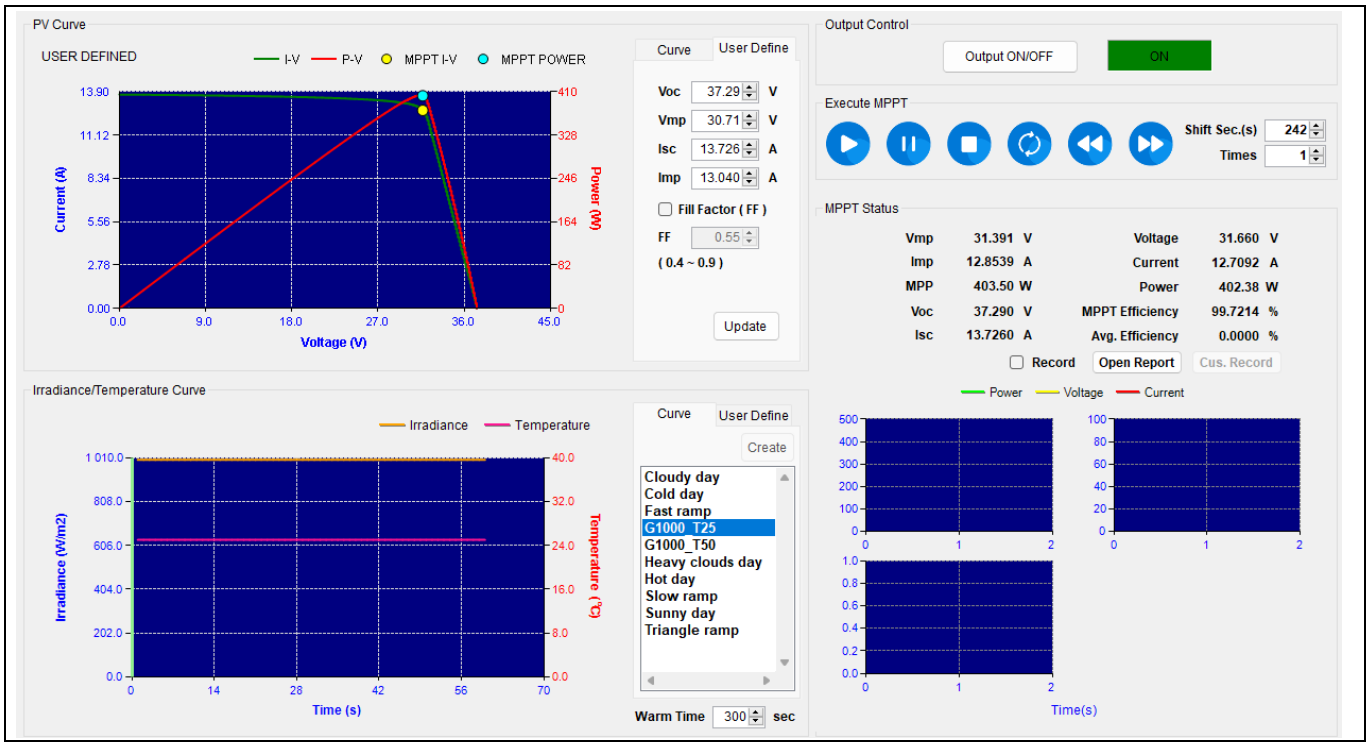

Figure 15 MPPT mode for a temperature of 25°C and constant irradiance

4 Summary

This firmware note has presented the design, implementation, and performance evaluation of a DC optimizer, developed on Infineon's POCMOC- modular design platform. The system features a fully digital control approach based on a PSOC™ Control C3M8 microcontroller and leverages Infineon's latest power semiconductor technologies, including CoolSiC™ and CoolMOS™ devices.

This platform provides a robust and scalable reference design for developers seeking to implement high-performance DC-DC power converters in different working modes.

5 Related resources

- REF_OPTI_80V20A_GAN
- Power optimizer solutions
- Basics of MCU solar PV inverters: deep dive into Infineon’s right fit solutions
- Solar optimizer with CoolGaN™ transistors in a buck configuration

Revision history

Document revision	Date	Description of changes
V 1.0	2026-03-27	Initial release

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85579 Neubiberg
Germany

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Safety & Operating Instructions:
Customer shall check the Evaluation Board for any physical damage which may have occurred during transport. If customer detects any damages or defects in the Evaluation Board, customer shall not connect the Evaluation Board to a power source. Customer shall contact Infineon for further support. If customer observes unusual operating behavior during the evaluation process, customer shall immediately shut off the power supply to the Evaluation Board and consult Infineon for support.
Customer shall not touch the Evaluation Board during operation and keep a safe distance.
Customer shall not touch the Evaluation Board after disconnecting the power supply, several components may still store electrical voltage and can discharge through physical contact. Several parts, like heat sinks and transformers, may still be very hot. Allow the components to cool before touching or servicing.
The electrical installation must be completed in accordance with the appropriate safety requirements.