USER MANUAL

Installation, Configuration & Operation Guide

iCTRL-20 V1 — Industrial Programmable I/O Controller

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1. Introduction

The **DZVOLT iCTRL-20 V1** is a modular industrial programmable I/O controller designed for automation, monitoring, and control applications. It operates as a **Modbus RTU slave** over RS-485 and supports flexible configuration via the DZVOLT UI software or direct Modbus register access.

Key capabilities include:

- **4 Digital Inputs** (24 VDC) with configurable logic inversion.
- **4 Digital Outputs** (SSR, 24 VDC, 1.6 A Continuous (2A Peak)) with timer functions.
- **8 Analog Inputs** (4× 0–10V + 4× 4–20mA, 12-bit resolution).
- **4 Analog Outputs** (0–10V DC, 12-bit resolution).
- Up to 12 configurable internal functions.
- Multiple modules are expandable on a single RS-485 bus (up to 8 units).
- Autonomous operation with non-volatile configuration storage.
- Interlock Safety function forces all digital and analog outputs to be disabled, ensuring a safe state for operators during maintenance operations.
- 3.7V Li-ion battery backup for UPS (state retention).

The iCTRL-20 features open-source hardware and is compatible with PLCs, RTUs, DCS, SCADA systems, and industrial gateways.

1.1 Guarantee

Each iCTRL-20 Industrial Programmable I/O Controller leaves our premises in flawless condition. All functions were thoroughly tested.

DZVOLT does not take any responsibility for consequential damage to people or assets that are caused using iCTRL-20.

1.2 Intended Use

The iCTRL-20 is intended for:

- Industrial automation and process control
- IoT and Industrial Internet of Things (IIoT) applications
- Remote I/O expansion for PLCs and SCADA systems
- Energy and infrastructure monitoring
- Agricultural automation (irrigation, pumping, environmental monitoring)
- Smart building automation (lighting, HVAC, access control)
- Renewable energy systems (solar plants, hybrid systems)
- R&D, education, and prototyping platforms

IMPORTANT

- You must create appropriate configurations via DZVOLT UI software or Modbus RTU.
- On the manufacturers website of DZVOLT (https://www.dzvolt.com) you will find the DZVOLT UI software & memory map for Modbus that will get you started with configuration.
- For the connection of external sensors and devices always mind the corresponding sections in this manual.
- Any use other than described in this manual is not permitted. Besides possible damage to the device, this is also associated with dangers like short circuits or electric shocks.
- The iCTRL-20 must not be altered or modified. The safety instructions as well as the maximum permissible operating and ambient conditions given in the chapter "technical data" must be observed.
- Read the whole instruction manual carefully and attentively. It contains important information on mounting, operating and handling your iCTRL-20.
- Information on the manufacturer and on iCtrl-20 can be found here: https://www.dzvolt.com

2. Abbreviations

#	Full Term	Description
DC	Direct Current	Constant voltage supply.
AI / AO	Analog Input / Output	Terminals for continuous signals (0-10V / 4-20mA).
DI (SINK)	Digital Input (Sinking)	Input that completes the circuit to ground (Requires PNP).
DO (SSR)	Digital Output (Solid State Relay)	Potential-free switching contacts for loads.
DIN Rail	DIN Rail Mounting	Standard 35mm metal rail for industrial installation.
ESD	Electrostatic Discharge	Protection against static electricity.
GPIO	General Purpose I/O	Internal pins of the MCU.
LED	Light Emitting Diode	Visual status indicators (Power, Run, Fault, Inputs).
Modbus RTU	Modbus Remote Terminal Unit	Serial communication protocol used over RS485.
RS485	Recommended Standard 485	Physical layer for industrial serial communication.
TVS	Transient Voltage Suppressor	High-speed protection against voltage spikes.
USB	Universal Serial Bus	Micro-USB Type B, used for the programming interface.
NVS	Non-Volatile Storage	Memory area used to save user settings that persist after power loss.

3. Safety Information

> **WARNING**
>
> Read this manual carefully before installing, configuring, or operating the iCTRL-20. Failure to follow these instructions may result in equipment damage, personal injury, or fire.

3.1 General Safety

- Installation and wiring must be performed by qualified personnel only.
- Disconnect all power sources before performing wiring or maintenance.
- The device is designed for installation inside a **control cabinet** (IP20 enclosure). It is not intended for direct exposure to moisture, dust, or corrosive environments.
- The power supply must be protected by an **external fuse or circuit breaker**.
- Do not exceed the rated voltage and current limits for any terminal.
- Ensure proper grounding of the RS-485 bus shield and cabinet enclosure.

3.2 Safety Interlock

The iCTRL-20 includes a hardware safety interlock (DIP switch on the front panel). When the interlock is **active (closed)**, all digital and analog outputs are immediately disabled regardless of software commands. This provides a hardware-level emergency stop mechanism.

> **IMPORTANT**
>
> The safety interlock is a last-resort protective measure. It should not be relied upon as the sole safety mechanism in critical applications. Always design your safety system in accordance with applicable standards (e.g., IEC 62061, ISO 13849).

4. Specifications

4.1 General

Manufacturer	DZVOLT
Model	iCTRL-20 V1
CPU	ESP32-S3-WROOM-1 (N16R8)
Operating System	Real-time OS
PSRAM	8 MB
Flash Memory	16 MB
Power Supply	24 VDC (12–30 VDC range)
Max Power Consumption	24 W
Battery Backup	3.7V 18650 Li-ion (~24h)
Operating Temp.	-10°C to +60°C
Cooling	Natural convection
Safety & Protection	Reverse polarity (integrated), TVS-based transient protection (IEC 61000-4-2), ESD ±15kV air / ±8kV contact
Enclosure Rating	IP20 (IEC 60529)
EMC Immunity	Zone B (EN 61131-2)
Dimensions	205 × 125 × 45 mm
Weight	~ 900g
Mounting	DIN rail or screw-mount.

4.2 Communication

Protocol	Modbus RTU
Physical Layer	RS-485 (half-duplex)
Mode	Slave
Baud Rate	9600 bps
Data Format	8N1 (8 data, no parity, 1 stop)
Max Bus Length	1200 m
Max Modules/Bus	8
Slave ID	Configurable via DIP switch
USB	Firmware update and Modbus RTU configuration (CP2102, 9600 8N1).

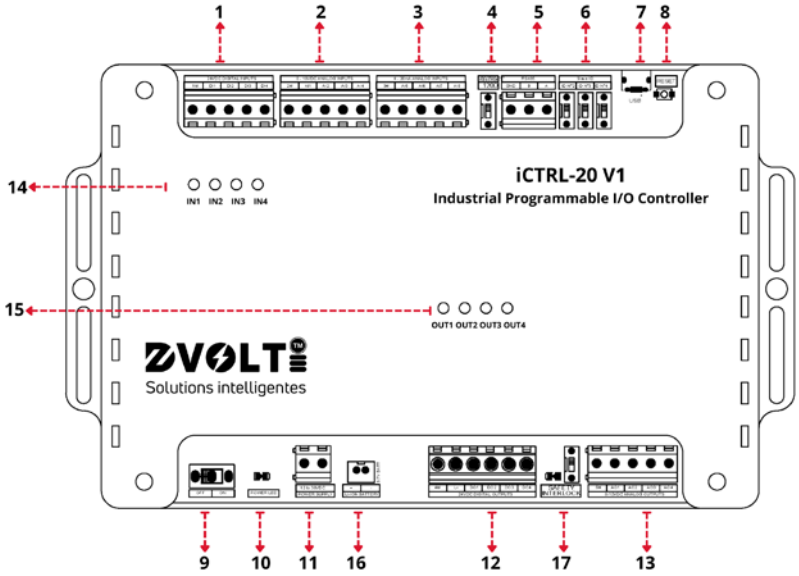
4.3 Processing

I/O Cycle Time	≤ 10 ms (typical), excl. communication latency (2 ms)
Internal Functions	Up to 12 configurable
Config Storage	Non-volatile (NVS Flash)

4.4 I/O Specifications

Parameter	Digital Inputs	Digital Outputs	Analog Inputs	Analog Outputs
Quantity	4	4	8 (4×V + 4×mA)	4
Type	24 VDC sink	SSR (Solid State Relay)	Single-ended	DC output (filtered)
Voltage	24 VDC rated	24 VDC, 1.6 A Continuous (2A Peak)	0–10 VDC / 4–20 mA	0–10 VDC
Resolution	1 bit	1 bit	12-bit (ADC)	12-bit (DAC)
Accuracy	—	—	±2% FS (typical)	±2% FS (typical)
Response Time	≤ 3 ms	≤ 10 ms	≤ 5 ms	≤ 3 ms

5. Front Panel & Connections



5.1 Connection Overview

#	Connection	Description
1	Digital Inputs	(04) Digital Inputs, 24 VDC rated
2	Analog Inputs (V)	(04) Analog Inputs, range: 0–10 VDC
3	Analog Inputs (mA)	(04) Analog Inputs, range: 4–20 mA
4	Termination Resistor	120Ω termination for RS-485 bus
5	RS-485	A, B, GND terminals for Modbus RTU
6	DIP Switches (RS-485)	3-bit DIP switch for Slave ID configuration
7	USB Port	Micro-USB used for firmware update and Modbus RTU configuration (CP2102, 9600 8N1).
8	RESET Button	CPU hardware reset
9	ON/OFF Switch	Main power switch
10	Power LED	Indicates power-on status
11	Power Supply	12–30 VDC input terminals (+/–)
12	Digital Outputs	(04) SSR outputs, 24 VDC, 1.6 A Continuous (2 A Peak)
13	Analog Outputs	(04) Analog Outputs, range: 0–10 VDC
14	DI LED Indicators	LEDs showing digital input status (IN1–IN4)
15	DO LED Indicators	LEDs showing digital output status (OUT1–OUT4)
16	Battery Connector	3.7V 18650 Li-ion battery connection
17	Safety Interlock	DIP switch for safety interlock (enable/disable outputs)

5.2 Wiring Guidelines

> **IMPORTANT**
>
> Always disconnect power before wiring. Use appropriate wire gauge for the current rating of each terminal. Maximum wire gauge: 2.5 mm² for power terminals.

- **Power Supply:** Connect 24 VDC (12–30V range) to terminal 11. Observe polarity. Protect with an external fuse or circuit breaker (2A recommended).
- **RS-485:** Use twisted-pair shielded cable. Connect A to A, B to B, and GND to GND across all devices. Enable the 120Ω termination resistor (terminal 4) on the first and last device on the bus.
- **Digital Inputs:** Connect the 24 VDC signal to the DI terminal and common to GND. Inputs are sink- type.
- **Digital Outputs:** SSR outputs switch up to 24 VDC at 1.6 A Continuous (2A Peak). Connect external load between the DO terminal and 24V supply.
- **Analog Inputs (0–10V):** Connect signal to the AI terminal and common to GND. Ensure the signal source does not exceed 10 VDC.
- **Analog Inputs (4–20mA):** Connect in series with the current loop. The iCTRL-20 provides the shunt resistor internally.
- **Analog Outputs:** Connect to the AO terminal and common to GND. Maximum load impedance: ≥ 1 kΩ.

5.3 Terminal Descriptions

5.3.1 Pin Mapping (ESP32-S3)

Function	Channel	GPIO Pin
Digital Inputs	DI1	1
	DI2	2
	DI3	15
	DI4	47
Digital Outputs	DO1	11
	DO2	12
	DO3	38
	DO4	39
Analog Inputs 0–10V	AI1	3
	AI2	8
	AI3	9
	AI4	10
Analog Inputs 4–20mA	AI5	4
	AI6	5
	AI7	6
	AI8	7
Analog Outputs	AO1	14
	AO2	18
	AO3	19
	AO4	20
RS-485	RX	16
	TX	17
	DE (Driver Enable)	13
Power OK	—	21
Safety Interlock	—	48
DIP Switches (Slave ID)	ID 2	42
	ID 3	41
	ID 4	40

6. Installation

6.1 Mounting

- The iCTRL-20 is designed for **DIN rail mounting or screw-mount** inside a control cabinet.
- Ensure adequate ventilation around the unit for natural convection cooling.
- Leave a minimum of 20 mm clearance on all sides for airflow and cable routing.
- Mounting orientation: vertical, with terminals accessible from top and bottom.

6.2 Environmental Requirements

Ambient Temperature	-10°C to +60°C
Humidity	5% to 95% (non-condensing)
Altitude	Up to 2000 m
Enclosure	IP20 minimum (IEC 60529)

6.3 Installation Checklist

1. Mount the iCTRL-20 on DIN rail or screw-mount inside the control cabinet.
2. Connect the 24 VDC power supply (terminal 11) with external fuse protection.
3. Optionally install the 3.7V 18650 Li-ion battery (terminal 16).
4. Configure the Slave ID using the DIP switches (terminal 6).
5. Wire RS-485 bus (terminal 5). Enable termination resistor on first/last device.
6. Wire field inputs (DI, AI) and outputs (DO, AO) as needed.
7. Set the safety interlock DIP switch (terminal 17) to the desired position.
8. Switch ON (terminal 9) and verify the power LED (terminal 10) is lit.
9. Configure internal functions via DZVOLT UI software or Modbus.

7. Communication Interface (Modbus RTU)

The **iCTRL-20** operates as a Modbus RTU slave over both RS-485 and USB interfaces, responding to requests from a Modbus master (PLC, HMI, SCADA, or PC). RS-485 is the primary communication interface.

7.1 RS-485 Bus Setup

Protocol	Modbus RTU
Baud Rate	9600 bps
Data Format	8 data bits, No parity, 1 stop bit (8N1)
Max Bus Length	1200 m
Termination	120Ω (enable on first and last device)
Cable	Twisted-pair shielded (recommended: Belden 9841 or equivalent)
Topology	Daisy-chain (do NOT use star topology)

> **TIP**
>
> For bus lengths exceeding 500 m, use low-capacitance cable and ensure proper termination at both ends. Ground the cable shield at one point only to avoid ground loops.

7.2 USB Interface Setup

Protocol	Modbus RTU over USB (Virtual COM Port)
USB Interface	Micro-USB (via CP2102 USB-to-UART bridge)
Baud Rate	9600 bps
Data Format	8 data bits, No parity, 1 stop bit (8N1)
Max Bus Length	5 m (standard USB cable recommended)
Connection	Point-to-point (no multi-drop support)
Priority	Lower priority than RS-485 (RS-485 overrides when active)

7.3 Slave ID Configuration (DIP Switches)

The Modbus Slave ID is set using the 3-bit DIP switch located on the front panel (terminal 6). The following table shows all valid combinations:

ID 2	ID 3	ID 4	Slave ID
ON	ON	ON	**1** (default)
OFF	ON	ON	**2**
ON	OFF	ON	**3**
ON	ON	OFF	**4**
OFF	OFF	ON	**23**
ON	OFF	OFF	**34**
OFF	ON	OFF	**24**
OFF	OFF	OFF	**234**

> **NOTE**
>
> The Slave ID is read from the DIP switches at boot time only. Changes require a power cycle or hardware reset to take effect. Each module on the same RS-485 bus must have a unique Slave ID.

7.4 Modbus Function Codes

Code	Function	Description
FC01	Read Coils	Read DO states and auto-save flag
FC02	Read Discrete Inputs	Read DI, AI alarm, Power OK, interlock status
FC03	Read Holding Registers	Read configuration and command registers
FC04	Read Input Registers	Read Slave ID, AI raw values, serial number
FC05	Write Single Coil	Control individual DO or auto-save
FC06	Write Single Register	Write a single configuration register
FC16	Write Multiple Registers	Write multiple configuration registers at once

8. Digital Inputs

The iCTRL-20 provides **4 digital inputs** rated for 24 VDC, sampled every 10 ms.

Parameter	Value
Quantity	4 (DI1–DI4)
Rated Voltage	24 VDC
Operating Voltage Range	12 VDC to 30 VDC
Logic Low (OFF)	0 VDC to 5 VDC
Logic High (ON)	12 VDC to 30 VDC
Isolation	Galvanic Opto-isolation (up to 5000 Vrms)
Protection	TVS Overvoltage Clamp & Reverse Polarity Protection
Input Type	Sink (NPN)
Response Time	≤ 3 ms (typical)
Sampling Rate	Every 10 ms
LED Indicators	IN1–IN4 on front panel

IMPORTANT

Digital inputs are Sinking type; they require a sourcing signal (PNP) or a voltage supply to trigger.

8.1 Logic Inversion (F8)

Each digital input can be independently configured as **Normal** or **Inverted** using holding registers 40074–40077. See Section 12.7 for details.

8.2 Pulse Counter (F12)

Each digital input supports rising edge counting on the raw hardware signal (before F8 logic inversion). Counters are independently enabled or disabled via Modbus coils 00006–00009. Disabling a counter resets its value to 0.

Counter values are available as read-only input registers 30011–30014 (FC04). See Section 12.11 for full configuration details.

8.3 Modbus Access

Data	Type	Address	Access	Note
DI1 status (after logic)	Discrete Input	10002	Read	
DI2 status (after logic)	Discrete Input	10003	Read	
DI3 status (after logic)	Discrete Input	10004	Read	
DI4 status (after logic)	Discrete Input	10005	Read	
DI1 Pulse Count	Input Register	30011	Read	0–65535, rising edges
DI2 Pulse Count	Input Register	30012	Read	
DI3 Pulse Count	Input Register	30013	Read	
DI4 Pulse Count	Input Register	30014	Read	

9. Digital Outputs

The iCTRL-20 provides **4 digital outputs** using Solid State Relays (SSR). Outputs can be controlled directly via Modbus coils or driven by internal functions (DI linking, AI alarms, power alarm, timers).

Parameter	Value
Quantity	4 (DO1–DO4)
Output Type	SSR (Solid State Relay)
Nominal Output Voltage	24 VDC
Operating Voltage Range	0 VDC to 30 VDC (Dry Contact behavior)
Isolation	Optical Isolation
Protection	Integrated Flyback Diode & RC Snubber
Max Current	1.6 A Continuous (2A Peak)
Load Compatibility	Resistive and Inductive Loads (Valves, Relays, Contactors…)
Response Time	≤ 10 ms (typical)
Sampling Rate	Every 10 ms
LED Indicators	OUT1–OUT4 on front panel

9.1 Output Sources

Each digital output is the result of an **OR combination** of multiple sources, processed through the optional timer engine:

1. **Modbus Coils** (direct remote control via coils 00001–00004)
2. **DI→DO Linking** (F4: digital input mapped to output)
3. **AI Alarm→DO Linking** (F2: analog alarm triggers output)
4. **Power Alarm→DO Linking** (F3: power loss triggers output)

The combined request passes through the **Timer Engine (F5)** and then the **Safety Interlock** gate before reaching the physical output.

9.2 Modbus Access

Data	Type	Address	Access
DO1 command	Coil	00001	Read/Write
DO2 command	Coil	00002	Read/Write
DO3 command	Coil	00003	Read/Write
DO4 command	Coil	00004	Read/Write
DO1 final state	Discrete Input	10015	Read
DO2 final state	Discrete Input	10016	Read
DO3 final state	Discrete Input	10017	Read
DO4 final state	Discrete Input	10018	Read

10. Analog Inputs

The iCTRL-20 provides **8 analog inputs**: 4 channels for 0–10V voltage signals and 4 channels for 4– 20mA current signals. All inputs use the ESP32-S3 built-in 12-bit ADC with eFuse calibration and additional piecewise linear correction.

10.1 Signal Processing Chain

1. **Oversampling:** 16 samples per reading
2. **Median Trimming:** Discard top/bottom 2 outliers, average the middle 12
3. **EMA Smoothing:** Exponential moving average (α = 0.25)
4. **ADC Correction:** Piecewise linear calibration table (16 points) for 0–10V inputs
5. **Engineering Scaling:** User-configurable MIN/MAX range conversion

10.2 0–10V Inputs (AI1–AI4)

Input Range	0–10 VDC
Resolution	12-bit (ADC)
Accuracy	±2% FS (typical, after calibration)
Protection	ESD Protection, Zener Voltage Clamp & RC Low-pass Filter
Input Impedance	37kΩ (Divider Network)
Scaling Registers	40058–40065 (MAX/MIN pairs per channel)
Default Scale	0–10 (representing 0.00–10.00V)
Sampling Rate	Every 50 ms

10.3 4–20mA Inputs (AI5–AI8)

Input Range	4–20 mA
Resolution	12-bit (ADC)
Accuracy	±2% FS (typical)
Protection	ESD Protection & Low-pass Filtering
Input Impedance	120Ω (Shunt resistor)
Scaling Registers	40066–40073 (MAX/MIN pairs per channel)
Default Scale	4–20 (representing 4.00–20.00 mA)
Sampling Rate	Every 50 ms

10.4 Modbus Access

Data	Type	Address	Access	Notes
AI1–AI8 Raw (mV)	Input Register	30002–30009	Read	Scaled ×100 (e.g., 500 = 5.00V)
AI1–AI8 Alarm Status	Discrete Input	10006–10013	Read	0=Normal, 1=Alarm

11. Analog Outputs

> **IMPORTANT**
> The analog outputs are only functional when the iCTRL-20 is connected to a power supply within the 12 - 30V DC range.

The iCTRL-20 provides **4 analog outputs** generating stable 0–10V DC signals.

Quantity	4 (AO1–AO4)
Output Range	0–10 VDC
Resolution	12-bit (4096 steps)
Output Type	Stable DC voltage
Accuracy	±2% FS (typical)
Filtering	Dual-stage RC Low-pass Filter
Response Time	≤ 3 ms
Update Rate	Every 50 ms
Min Load Impedance	≥ 1 kΩ

11.1 Command Format

Analog outputs are commanded via holding registers 40001–40004. Values are expressed in **0.01V steps**:

- Value `0` = 0.00V
- Value `500` = 5.00V
- Value `1000` = 10.00V

11.2 Modbus Access

Data	Type	Address	Range	Access
AO1 command	Holding Register	40001	0–1000	Read/Write
AO2 command	Holding Register	40002	0–1000	Read/Write
AO3 command	Holding Register	40003	0–1000	Read/Write
AO4 command	Holding Register	40004	0–1000	Read/Write

11.3 AI to AO Linking (F11)

Each analog output can be driven directly by a linked analog input (AI1–AI4, 0–10V channels) instead of a Modbus register value. When linked, the AO output voltage tracks the AI input voltage proportionally. See Section 12.10 for configuration details.

11.4 AO Actual Voltage Readback

The actual voltage being output on each analog output is available as read-only input registers, regardless of whether the AO is controlled by a Modbus holding register or by AI-to-AO linking (F11).

Data	Type	Address	Access	Notes
AO1 Actual Voltage	Input Register	30015	Read	Scaled ×100 (e.g., 750 = 7.50V)
AO2 Actual Voltage	Input Register	30016	Read	
AO3 Actual Voltage	Input Register	30017	Read	
AO4 Actual Voltage	Input Register	30018	Read	

IMPORTANT

These registers always reflect the real output voltage:

- If AI-linked (F11): shows the AI-driven voltage.
- If Modbus-controlled (F1): shows the holding register value.
- If interlock active (F10): shows 0.

12. Internal Functions (F1–F12)

The iCTRL-20 provides 12 configurable internal functions that enable autonomous operation without an external PLC. All functions are configured via Modbus holding registers and can be changed at runtime.

Function	Name	Description
F1	AO Configuration	Set analog output values (0–10V) via Modbus
F2	AI Threshold Alarm	Alarm detection with thresholds, linked to digital outputs
F3	Power Alarm	Link power failure detection to a digital output
F4	DI→DO Linking	Map digital inputs directly to digital outputs
F5	Timer Engine	TON, TOF, TP, TONOFF timer modes for digital outputs
F6	AI 0–10V Scaling	Convert raw 0–10V inputs to engineering units
F7	AI 4–20mA Scaling	Convert raw 4–20mA inputs to engineering units
F8	DI Logic Inversion	Configure normal or inverted logic per digital input
F9	Auto Save	Automatically stores configuration changes to non-volatile memory
F10	Interlock Safety	Forces all outputs to disabled state for safe maintenance operations
F11	AI→AO Linking	Link analog inputs (AI1–AI4) directly to analog outputs (AO1–AO4)
F12	DI Pulse Counter	Count rising edges on DI1–DI4 for flow and production.

12.2 F1: Analog Output Configuration

Analog outputs AO1–AO4 are controlled by writing values to holding registers 40001–40004. The value represents the desired output voltage in 0.01V steps (0–1000 = 0.00–10.00V). See Section 11 for details.

12.3 F2: Analog Input Threshold Alarms

Each of the 8 analog inputs can be monitored against configurable **MAX** and **MIN** thresholds. When the scaled input value exceeds the MAX threshold or falls below the MIN threshold, an alarm is triggered.

12.3.1 Configuration Registers

Parameter	Registers	Description
AI Thresholds	40010–40025	MAX/MIN — signed int16, are written as engineering value × 100. Range ±327.67 in engineering units. Resolution 0.01. Example: write 150 to alarm at 1.50 Negative thresholds are supported (e.g. write −1050 for −10.50).
AI→DO Link	40026–40033	Which DO to activate on alarm (0=none, 1=DO1, 2=DO2, 3=DO3, 4=DO4)

12.3.2 Hysteresis

A **2% deadband** is applied to prevent alarm chatter when the input value oscillates near a threshold. The deadband is calculated as 2% of (MAX − MIN):

- **`Alarm SET`**: `when value > MAX or value < MIN`
- **`Alarm CLEAR`**: `when value ≤ MAX − deadband and value ≥ MIN + deadband`

12.3.3 Status Monitoring

Alarm status is available as discrete inputs 10006–10013 (read-only, FC02).

12.4 F3: Power Alarm Linking

The Power OK input (Pin 21) monitors external power status. When power loss is detected (Power OK = inactive), a specified digital output can be activated as an emergency action.

Register	Value	Description
40009	0	No linking (disabled)
40009	1–4	Activate DO1–DO4 on power failure

Power OK status is available as discrete input 10001 (0 = Power loss, 1 = Healthy).

12.5 F4: DI to DO Linking

Each digital input can be directly linked to digital output. When the linked DI is active (after logic inversion via F8), the corresponding DO is activated.

Register	DI Source	Value Range	Description
40005	DI1	0–4	0=No link, 1=DO1, 2=DO2, 3=DO3, 4=DO4
40006	DI2	0–4	0=No link, 1=DO1, 2=DO2, 3=DO3, 4=DO4
40007	DI3	0–4	0=No link, 1=DO1, 2=DO2, 3=DO3, 4=DO4
40008	DI4	0–4	0=No link, 1=DO1, 2=DO2, 3=DO3, 4=DO4

> **TIP**
>
> Multiple DIs can be linked to the same DO. The DO will activate if *any* linked DI is active (OR logic). A single DI can only link to one DO.

12.6 F5: Timer Engine

Each digital output has an independently configurable timer that processes the combined DO request (from coils, DI linking, AI alarms, and power alarm) before the final output. The timer mode and duration are set per output.

12.6.1 Timer Mode Selection

Register	Output	Values
40054	DO1	0=Passthrough, 1=TON, 2=TOF, 3=TP, 4=TONOFF
40055	DO2	
40056	DO3	
40057	DO4	

12.6.2 Mode 0: Passthrough (Default)

No timer processing. The combined DO request is passed directly to the output.

12.6.3 Mode 1: TON (Turn-On Delay)

The output activated only after the request has been continuously active for the specified delay. If the request drops before the delay elapses, the timer resets.

Parameter	Registers	Unit	Range
TON delay	40034–40037	Seconds	0–9999

12.6.4 Mode 2: TOF (Turn-Off Delay)

The output activates immediately when the request goes active. When the request drops, the output remains active for the specified delay before turning off.

Parameter	Registers	Unit	Range
TOF delay	40038–40041	Seconds	0–9999

12.6.5 Mode 3: TP (Pulse Timer)

When the request goes active (rising edge), the output generates a single pulse of the specified duration, regardless of how long the request remains active.

Parameter	Registers	Unit	Range
Pulse duration	40042–40045	Seconds	0–9999

12.6.6 Mode 4: TONOFF (Cyclic Timer)

When the request is active, the output alternates between ON and OFF states repeatedly. When the request drops, the output stops.

Parameter	Registers	Unit	Range
Cyclic ON time	40046, 40048, 40050, 40052	Seconds	0–9999
Cyclic OFF time	40047, 40049, 40051, 40053	Seconds	0–9999

> **NOTE**
> When the timer mode is changed, all timer values for inactive modes are automatically cleared to 0 to prevent stale timing data. A timer value of 0 seconds results in immediate activation (TON/TOF) or no pulse (TP). For TONOFF, if both ON and OFF times are 0, the output remains off.

12.7 F6 & F7: Analog Input Scaling

Analog inputs can be scaled from their raw range to user-defined engineering units. This allows direct reading of physical values (e.g., temperature in °C, pressure in bar) without external conversion.

12.7.1 F6: 0–10V Input Scaling

Channel	MAX Register	MIN Register	Default MAX	Default MIN
AI1	40058	40059	10	0
AI2	40060	40061	10	0
AI3	40062	40063	10	0
AI4	40064	40065	10	0

12.7.2 F7: 4–20mA Input Scaling

Channel	MAX Register	MIN Register	Default MAX	Default MIN
AI5	40066	40067	20	4
AI6	40068	40069	20	4
AI7	40070	40071	20	4
AI8	40072	40073	20	4

> **NOTE**
>
> AI scaling MIN/MAX — signed int16. Negative scaling supported.
>
> Example. To scale AI1 (0–10V) to read temperature -50°C to 50°C: set register 40058 (MAX) = 50, register 40059 (MIN) = -50. A 5V input will read as 0°C.

12.8 F8: Digital Input Logic Inversion

Each digital input can be independently configured as Normal or Inverted logic. This affects all downstream functions (DI→DO linking, Modbus status reporting).

Register	Input	Value 0	Value 1
40074	DI1	Normal (default)	Inverted
40075	DI2	Normal (default)	Inverted
40076	DI3	Normal (default)	Inverted
40077	DI4	Normal (default)	Inverted

12.9 F9: Auto Save

The iCTRL-20 can automatically save its configuration to non-volatile storage (NVS) in flash memory. This ensures that all settings survive power cycles without requiring manual backup procedures.

12.9.1 Enabling Auto-Save

Auto-save is controlled by **Coil 00005**:

`0`	Auto-save **disabled** (configuration lost on power cycle)
`1`	Auto-save **enabled** (configuration persisted to flash)

12.9.2 What Gets Saved

- All 81 holding registers (40001–40081): AO values, links, thresholds, timers, scaling, logic.
- DO coils (00001–00004): Digital output states, and DI counter enable coils (00006–00009).
- The auto-save flag itself.

12.9.3 How It Works

- The system monitors all registers and coils continuously.
- When a change is detected and auto-save is enabled, the changed value is immediately written to NVS flash.
- On the next boot, if auto-save was enabled, all saved values are restored automatically.
- If auto-save was disabled or no saved data exists, factory defaults are loaded.

> **NVS WEAR**
>
> Flash memory has a limited write endurance (~100,000 write cycles per sector). Under normal operation (infrequent configuration changes), this is not a concern. Avoid writing registers at high frequency (e.g., every scan cycle) when auto-save is enabled.

12.10 F10: Interlock Safety

The Interlock Safety function forces all digital and analog outputs to be disabled, ensuring a safe state for operators during maintenance operations. It is controlled via a hardware DIP switch on the front panel (terminal 17).

12.10.1 Behavior

Interlock State	DIP Switch	Effect
Interlock not engaged (normal operation)	Open (OFF)	All outputs operate normally per software commands
Interlock engaged (safety lockout)	Closed (ON)	ALL digital outputs forced OFF. ALL analog outputs forced to 0V. Inputs continue operating normally.

CRITICAL

When the interlock safety is active:

- Digital Outputs DO1–DO4 are forced to 0 (OFF) regardless of Modbus commands, timers, or internal functions.
- Analog Outputs AO1–AO4 are forced to 0.00V regardless of register values.
- Digital Inputs and Analog Inputs continue to read and report values normally.
- Internal function processing continues (timers, alarms), but output is blocked at the final stage.

IMPORTANT

The interlock safety is a protective measure for maintenance operations. It should not be relied upon as the sole safety mechanism in critical applications. Always design your safety system in accordance with applicable standards (e.g., IEC 62061, ISO 13849).

12.10.2 Modbus Status

Interlock status is available as discrete input 10014: `0 = Active (interlock engaged), 1 = Interlock not engaged (normal operation)` (FC02).

12.11 F11: AI to AO Linking

Each of the 4 analog voltage inputs (AI1–AI4) can be linked directly to an analog output (AO1–AO4). When linked, the AO output voltage tracks the AI input voltage proportionally (0–10V pass-through).

12.11.1 Configuration Registers

Register	AI Source	Value Range	Description
40078	AI1	0–4	0=No link, 1=AO1, 2=AO2, 3=AO3, 4=AO4
40079	AI2	0–4	0=No link, 1=AO1, 2=AO2, 3=AO3, 4=AO4
40080	AI3	0–4	0=No link, 1=AO1, 2=AO2, 3=AO3, 4=AO4
40081	AI4	0–4	0=No link, 1=AO1, 2=AO2, 3=AO3, 4=AO4

IMPORTANT

- When linked, the AO output voltage is proportional to the AI input: a 0V input produces 0V output, a 10V input produces 10V output.
- The Modbus AO register (40001–40004) is overridden while the link is active. Setting the link register back to 0 restores normal Modbus control.
- The Safety Interlock (F10) overrides AI-to-AO linking — all outputs are forced to 0V when the interlock is active.
- Only AI1–AI4 (0–10V channels) can be linked to AO. The 4–20mA channels (AI5–AI8) are not supported for this function.

Example: To make AO2 mirror the voltage on AI1, write register 40078 = 2.

12.12 F12: DI Pulse Counter

Each of the 4 digital inputs can count rising edges (LOW→HIGH transitions) on the raw hardware signal. This is performed before F8 logic inversion is applied. The feature enables flow metering (pulse-output sensors), production counting, and energy metering applications.

12.12.1 Enable / Disable

Each counter is independently controlled via a dedicated Modbus coil:

Coil	Parameter	Description
00006	DI1 Counter Enable	0 = Disabled (counter resets to 0), 1 = Enabled (counting)
00007	DI2 Counter Enable	0 = Disabled (counter resets to 0), 1 = Enabled (counting)
00008	DI3 Counter Enable	0 = Disabled (counter resets to 0), 1 = Enabled (counting)
00009	DI4 Counter Enable	0 = Disabled (counter resets to 0), 1 = Enabled (counting)

IMPORTANT

When an enabled coil is set to OFF (0), the corresponding counter immediately resets to 0. To reset a counter without disabling it permanently, set the coil to OFF then back to ON.

12.12.2 Counter Values

Counter values are exposed as read-only input registers (FC04):

Input Register	Parameter	Range
30011	DI1 Pulse Count	0–65535
30012	DI2 Pulse Count	0–65535
30013	DI3 Pulse Count	0–65535
30014	DI4 Pulse Count	0–65535

12.12.3 Behavior

- The counter increments by 1 on each rising edge (LOW→HIGH transition) of the raw DI signal. Edge detection is performed at the DI sampling rate of 10 ms. Pulses shorter than 10 ms may not be detected.
- The counter saturates at 65535. It does not wraparound to 0.
- Counter values do not persist across power cycles. They always reset to 0 on boot.
- The enable coil states do persist via Auto Save (F9) when auto-save is enabled.
- The counter operates on the raw DI signal, before F8 logic inversion is applied. This means inverting a DI via register 40074–40077 does not affect the pulse count.

12.12.4 Example: Flow Meter havior

A pulse-output flow meter (1 pulse = 1 liter) is connected to DI1.

Step	Action	Register/Coil	Value
1	Enable DI1 counter	Write Coil 00006	1
2	Read pulse count	Read Input Register 30011	Current count = total liters
3	Reset counter	Write Coil 00006	0

13. Memory Map (Complete Register Reference)

13.1 Coils (0x) — Digital Outputs & Control

Address	Parameter	Data	Value Range	R/W
00001	DO 01	1 bit	0=Inactive / 1=Active	R/W
00002	DO 02	1 bit	0=Inactive / 1=Active	R/W
00003	DO 03	1 bit	0=Inactive / 1=Active	R/W
00004	DO 04	1 bit	0=Inactive / 1=Active	R/W
00005	Auto-Save Configuration	1 bit	0=Disabled / 1=Enabled	R/W
00006	DI1 Counter Enable	1 bit	0=Disabled / 1=Enabled	R/W
00007	DI2 Counter Enable	1 bit	0=Disabled / 1=Enabled	R/W
00008	DI3 Counter Enable	1 bit	0=Disabled / 1=Enabled	R/W
00009	DI4 Counter Enable	1 bit	0=Disabled / 1=Enabled	R/W

13.2 Discrete Inputs (1x) — Read-Only Status

Address	Parameter	Data	Value Range	R/W
10001	DI Power OK	1 bit	0=Power loss / 1= Healthy (OK)	R
10002	DI 01 (after logic)	1 bit	0=Inactive / 1=Active	R
10003	DI 02 (after logic)	1 bit	0=Inactive / 1=Active	R
10004	DI 03 (after logic)	1 bit	0=Inactive / 1=Active	R
10005	DI 04 (after logic)	1 bit	0=Inactive / 1=Active	R
10006	AI 01 Threshold Alarm	1 bit	0=Normal / 1=Alarm	R
10007	AI 02 Threshold Alarm	1 bit	0=Normal / 1=Alarm	R
10008	AI 03 Threshold Alarm	1 bit	0=Normal / 1=Alarm	R
10009	AI 04 Threshold Alarm	1 bit	0=Normal / 1=Alarm	R
10010	AI 05 Threshold Alarm	1 bit	0=Normal / 1=Alarm	R
10011	AI 06 Threshold Alarm	1 bit	0=Normal / 1=Alarm	R
10012	AI 07 Threshold Alarm	1 bit	0=Normal / 1=Alarm	R
10013	AI 08 Threshold Alarm	1 bit	0=Normal / 1=Alarm	R
10014	DI Interlock (Safety)	1 bit	0=Active (OK) / 1=Inactive	R
10015	Raw state of DO1	1 bit	0=Inactive / 1=Active	R
10016	Raw state of DO2	1 bit	0=Inactive / 1=Active	R
10017	Raw state of DO3	1 bit	0=Inactive / 1=Active	R
10018	Raw state of DO4	1 bit	0=Inactive / 1=Active	R

13.3 Input Registers (3x) — Read-Only Telemetry

Address	Parameter	Data	Unit	R/W	Notes
30001	Slave ID (Device Address)	Int (2 bytes)	—	R	From DIP switch
30002	Analog Input 01	Int (2 bytes)	—	R	Scaled ×100
30003	Analog Input 02	Int (2 bytes)	—	R	
30004	Analog Input 03	Int (2 bytes)	—	R	
30005	Analog Input 04	Int (2 bytes)	—	R	
30006	Analog Input 05	Int (2 bytes)	—	R	
30007	Analog Input 06	Int (2 bytes)	—	R	
30008	Analog Input 07	Int (2 bytes)	—	R	
30009	Analog Input 08	Int (2 bytes)	—	R	
30010	Serial Number	Int (2 bytes)	—	R	Factory set
30011	DI1 Pulse Counter	Int (2 bytes)	—	R	Rising edge count (0–65535)
30012	DI2 Pulse Counter	Int (2 bytes)	—	R	
30013	DI3 Pulse Counter	Int (2 bytes)	—	R	
30014	DI4 Pulse Counter	Int (2 bytes)	—	R	
30015	AO1 Actual Voltage	Int (2 bytes)	V	R	Scaled ×100 (e.g., 750 = 7.50V)
30016	AO2 Actual Voltage	Int (2 bytes)	V	R	
30017	AO3 Actual Voltage	Int (2 bytes)	V	R	
30018	AO4 Actual Voltage	Int (2 bytes)	V	R	

13.4 Holding Registers (4x) — Configuration & Commands

Address	Parameter	Data	Value Range	Unit	R/W
40001–40004	Set value AO 01–04	Int (2 bytes)	0–1000	V	R/W
40005–40008	Link DI 01–04 to DO	Int (2 bytes)	0: None, 1–4: DO1–DO4	—	R/W
40009	Link Power OK to DO	Int (2 bytes)	0: None, 1–4: DO1–DO4	—	R/W
40010–40025	AI 01–08 Thresholds	Int (2 bytes)	Range ±32767	—	R/W
40026–40033	Link AI 01–08 Alarm to DO	Int (2 bytes)	0: None, 1–4: DO1–DO4	—	R/W
40034–40037	TON (On Delay) DO 01–04	Int (2 bytes)	0–9999	Sec	R/W
40038–40041	TOF (Off Delay) DO 01–04	Int (2 bytes)	0–9999	Sec	R/W
40042–40045	TP (Pulse Timer) DO 01–04	Int (2 bytes)	0–9999	Sec	R/W
40046–40053	Cyclic ON/OFF DO 01–04	Int (2 bytes)	0–9999	Sec	R/W
40054–40057	Timer Mode DO 01–04	Int (2 bytes)	0=None, 1=TON, 2=TOF, 3=TP, 4=TONOFF	—	R/W
40058–40065	AI 01–04 Scale (MAX/MIN)	Int (2 bytes)	Range ±32767	—	R/W
40066–40073	AI 05–08 Scale (MAX/MIN)	Int (2 bytes)	Range ±32767	—	R/W
40074–40077	Logic DI 01–04	Int (2 bytes)	0: Normal / 1: Inverted	—	R/W
40078–40081	Link AI 01–04 to AO	Int (2 bytes)	0: None, 1–4: AO1–AO4	—	R/W

14. Startup & Operation

14.1 Boot Sequence

When the iCTRL-20 is powered on, the following sequence occurs:

1. **Hardware initialization** (0–2s): CPU starts.
2. **System state initialization**: All I/O values set to safe defaults (outputs OFF, inputs cleared).
3. **GPIO configuration**: All pins configured for their assigned functions (DI, DO, AI, AO, RS-485, DIP switches, interlock).
4. **Slave ID reading**: Hardware DIP switches read to determine Modbus Slave ID.
5. **Modbus initialization**: RS-485 communication stack started. If auto-save was enabled, saved configuration is restored from NVS.
6. **System startup**: All internal processing modules launch and begin operation.
7. **Operational**: System is fully operational within approximately 3–5 seconds of power-on.

14.2 Normal Operation

During normal operation, the iCTRL-20 continuously:

- Reads digital inputs (sampling rate: 10 ms)
- Reads and processes analog inputs (sampling rate: 50 ms)
- Evaluates internal functions (linking, alarms, timers)
- Updates digital and analog outputs
- Responds to Modbus RTU requests

14.3 Default Values (First Boot)

Parameter	Default Value
All DI	Inactive (0)
All DO	OFF (0)
All AI	0.0
All AO	0.00V
AI 0–10V Scaling	MAX=10, MIN=0
AI 4–20mA Scaling	MAX=20, MIN=4
All links (DI, AI, Power)	0 (none)
All timers	0 (passthrough mode)
DI Logic	0 (normal, non-inverted)
DI Pulse Counters	0 (reset on every boot)
DI Counter Enable (Coils 00006–00009)	Disabled (0)
Auto-save	Disabled (0)
Interlock	Inactive (outputs allowed)
Serial Number	Manufacturer-assigned (varies per unit)

15. Troubleshooting

Symptom	Possible Cause	Solution
Power LED not lit	No power supply or wrong polarity	Check 24V supply connections and polarity. Verify fuse/breaker.
No Modbus communication	Wrong Slave ID, wiring, or baud rate	Verify DIP switch settings and power cycle. Check RS-485 wiring (A↔A, B↔B, GND↔GND). Ensure 9600/8N1 on master.
Intermittent Modbus errors	Missing termination or cable issues	Enable 120Ω termination on first/last device. Use shielded twisted-pair cable. Check cable length (≤1200m).
Digital outputs not switching	Safety interlock active	Check interlock DIP switch (terminal 17). Read discrete input 10014 to verify status.
Digital outputs not responding to Modbus	Output controlled by internal function	Check DI→DO links (40005–40008), AI alarm links (40026–40033), and power link (40009). Outputs use OR logic.
Analog input reading inaccurate	Incorrect scaling or noise	Verify scaling registers (40058–40073). Ensure signal source is within range. Check for electrical noise.
Analog output voltage incorrect	Load impedance too low	Ensure load impedance is ≥ 1 kΩ. Verify register value (0–1000 = 0.00–10.00V).
Configuration lost after power cycle	Auto-save not enabled	Enable auto-save by writing 1 to Coil 00005.
Timer not working	Timer mode not set or value is 0	Check timer mode register (40054–40057) and corresponding delay value. Ensure mode matches desired behavior.
DI pulse counter not incrementing	Counter not enabled or no rising edges	Verify the enable coil (00006–00009) is set to 1. Ensure the DI signal has clean LOW→HIGH transitions. Check that pulses are longer than 10 ms. Read input register 30011–30014 to verify.
AO actual voltage register shows 0 despite AO being set	Interlock safety active	Check interlock DIP switch (terminal 17). Read discrete input 10014 to verify interlock status.
Multiple modules conflict on bus	Duplicate Slave IDs	Ensure each module has a unique Slave ID via DIP switches. Power cycle after changes.

16. Mechanical Dimensions

Length	205 mm
Width	125 mm
Height	45 mm
Tolerance	±1 mm
Mounting	DIN rail (35 mm standard) or screw-mount
Mounting Holes	Ø4.7 mm (4 corners)
Weight	~ 900 g
Material	Stainless steel top/bottom plates (open construction)

Appendix A: Technical Reference

This appendix provides additional technical details about the iCTRL-20 hardware platform for integrators and advanced users.

A.1 Processing Unit

CPU	ESP32-S3-WROOM-1 (N16R8)
Architecture	Dual-core Xtensa LX7 @ 240 MHz
PSRAM	8 MB
Flash	16 MB
Operating System	Real-time multitasking with deterministic scheduling
Connectivity	RS-485 (Modbus RTU). Wi-Fi and Bluetooth reserved for future use.

A.2 Internal Processing Overview

The iCTRL-20 firmware processes I/O and internal functions in a deterministic real-time loop. The overall I/O processing cycle time is ≤ 30 ms (typical), excluding communication latency.

Processing Module	Sampling / Update Rate	Description
Digital I/O	Every 10 ms	Reads DI, applies logic inversion (F8), writes DO outputs
Analog I/O	Every 50 ms	Reads AI (with calibration & filtering), writes AO DC outputs
Logic Processing	Continuous	DI→DO linking (F4), AI alarm detection (F2), power alarm (F3)
Timer Engine	Continuous	Combines DO sources, applies timer modes (F5)
Communication	Continuous	Modbus RTU slave: responds to master requests, syncs registers
Configuration	On change	Auto-save (F9): persists changes to non-volatile memory

A.3 Signal Processing Chain (Analog Inputs)

Analog inputs are processed through a multi-stage filtering and calibration pipeline to achieve ±2% FS accuracy:

1. **Oversampling:** 16 samples per reading
2. **Outlier rejection:** Top and bottom 2 samples discarded, middle 12 averaged

3. **Exponential smoothing:** Moving average filter for noise reduction
4. **ADC linearization:** Piecewise linear correction compensating for ESP32-S3 ADC nonlinearity at higher voltage ranges
5. **Engineering scaling:** User-configurable MIN/MAX conversion (F6/F7)

A.4 Safety & Protection Details

Protection	Specification	Standard
Reverse polarity	Integrated on power supply input	—
Overvoltage & transients	TVS-based protection on all I/O and communication ports	IEC 61000-4-2
ESD	±15 kV (air) / ±8 kV (contact)	IEC 61000-4-2
EMC immunity	Zone B industrial environment	EN 61131-2
Enclosure	IP20	IEC 60529
Interlock safety (F10)	Hardware DIP switch disables all outputs	—

Appendix B: Application Examples

The following examples demonstrate end-to-end use of the iCTRL-20, from wiring to configuration to expected behavior and monitoring.

B.1 Temperature Monitoring with Alarm

Application: Monitor a process temperature using a 0–10V transmitter. Sound an alarm (activate a buzzer or warning light on DO1) when temperature goes out of range.

15.0.1 Wiring

- Connect the 0–10V temperature transmitter output to **AI1** (terminal 2, first channel). Connect transmitter common to GND.
- Connect a 24V buzzer or warning lamp between **DO1** (terminal 12) and the 24V supply.
- Power the iCTRL-20 with 24 VDC (terminal 11). Power the transmitter from the same or separate 24V supply.

15.0.2 Configuration

Step	Register	Value	Description
1	40058	100	F6: AI1 MAX scale = 100°C (10V = 100°C)
2	40059	0	F6: AI1 MIN scale = 0°C (0V = 0°C)
3	40010	80	F2: AI1 alarm MAX threshold = 80°C
4	40011	5	F2: AI1 alarm MIN threshold = 5°C
5	40026	1	F2: Link AI1 alarm → DO1
6	00005	1	F9: Enable auto-save

15.0.3 Expected Behavior

- When temperature is between 5°C and 80°C: DO1 remains OFF (normal operation).
- When temperature exceeds 80°C or drops below 5°C: DO1 activates (buzzer sounds).
- The alarm clears automatically when temperature returns within range (with 2% hysteresis deadband).

15.0.4 Monitoring via Modbus

- Read **Input Register 30002** (FC04) to get the current scaled temperature (value ÷ 100 = °C).
- Read **Discrete Input 10006** (FC02) to check alarm status (0 = normal, 1 = alarm).
- Read **Discrete Input 10015** (FC02) to verify DO1 final output state.

B.2 Push-Button with On-Delay Timer

Application: A push-button must be held for 3 seconds before activating a motor contactor on DO1. This prevents accidental activation and serves as an intentional start confirmation.

15.0.1 Wiring

- Connect a normally-open 24V push-button between the 24V supply and **DI1** (terminal 1).
- Connect a motor contactor coil (24V) between **DO1** (terminal 12) and the 24V supply.
- Ensure the motor contactor has its own overload protection (thermal relay or motor protection circuit breaker).

15.0.2 Configuration

Step	Register	Value	Description
1	40005	1	F4: Link DI1 → DO1
2	40054	1	F5: Set DO1 timer mode = TON (on-delay)
3	40034	3	F5: Set TON delay = 3 seconds
4	00005	1	F9: Enable auto-save

15.0.3 Expected Behavior

- Press and hold the button: the 3-second countdown begins.
- If the button is released before 3 seconds: nothing happens, timer resets.
- If the button is held for 3+ seconds: DO1 activates (contactor closes, motor starts).
- Release the button: DO1 deactivates immediately (motor stops).

15.0.4 Monitoring via Modbus

- Read **Discrete Input 10002** (FC02) to check DI1 status (button state).
- Read **Discrete Input 10015** (FC02) to check DO1 final output (motor running).

B.3 Cyclic Irrigation Pump Control

Application: An irrigation pump should run 30 minutes ON, then 10 minutes OFF, cycling continuously while the system enable switch (DI2) is active. This provides timed irrigation cycles without an external PLC.

15.0.1 Wiring

- Connect a 24V ON/OFF selector switch to **DI2** (terminal 1, second channel) to serve as the system enable.
- Connect the pump contactor coil (24V, max 2A) to **DO2** (terminal 12, second channel).
- Protect the pump circuit with an appropriate circuit breaker and motor protection relay.

15.0.2 Configuration

Step	Register	Value	Description
1	40006	2	F4: Link DI2 → DO2
2	40055	4	F5: Set DO2 timer mode = TONOFF (cyclic)
3	40048	1800	F5: Set cyclic ON time = 1800 seconds (30 min)
4	40049	600	F5: Set cyclic OFF time = 600 seconds (10 min)
5	00005	1	F9: Enable auto-save

15.0.3 Expected Behavior

- Turn the enable switch ON (DI2 active): pump starts immediately (DO2 ON for 30 minutes).
- After 30 minutes: pump stops (DO2 OFF for 10 minutes).
- After 10 minutes off: pump restarts (DO2 ON for 30 minutes). Cycle repeats.
- Turn the enable switch OFF (DI2 inactive): pump stops immediately, cycle resets.

15.0.4 Monitoring via Modbus

- Read **Discrete Input 10003** (FC02) to check DI2 enable switch status.
- Read **Discrete Input 10016** (FC02) to check DO2 pump output state.

B.4 Power Failure Emergency Valve

Application: When external power fails, automatically close an emergency shut-off valve (connected to DO3) to prevent uncontrolled flow. The iCTRL-20's battery backup (UPS) keeps the controller running long enough to activate the valve.

15.0.1 Wiring

- Connect the external power status signal to the **Power OK** input (Pin 21). This signal should be HIGH when power is healthy and LOW when power fails.
- Connect a normally-open solenoid valve (24V) to **DO3** (terminal 12, third channel). When DO3 activates, the valve closes.
- Install a 3.7V 18650 Li-ion battery in terminal 16 to provide UPS backup.

15.0.2 Configuration

Step	Register	Value	Description
1	40009	3	F3: Link Power OK → DO3
2	00005	1	F9: Enable auto-save

15.0.3 Expected Behavior

- Normal operation (power healthy, Power OK = HIGH): DO3 remains OFF (valve open, flow allowed).
- Power failure detected (Power OK = LOW): DO3 activates immediately (valve closes, flow stopped).
- Power restored: DO3 deactivates (valve re-opens). The system resumes normal operation.

- Battery backup ensures the iCTRL-20 stays powered to execute the emergency action.

15.0.4 Monitoring via Modbus

- Read **Discrete Input 10001** (FC02) to check Power OK status (0 = power loss, 1 = healthy).
- Read **Discrete Input 10017** (FC02) to check DO3 valve output state.

B.5 Solar Panel Monitoring System

Application: Monitor a solar panel array's voltage and current using analog sensors. Set up alarms for over-voltage or under-current conditions and control an inverter relay via digital output.

15.0.1 Wiring

- Connect a DC voltage transducer (0–10V output, scaled to 0–60V panel voltage) to **AI1** (terminal 2).
- Connect a DC current transducer (4–20mA output, scaled to 0–30A panel current) to **AI5** (terminal 3).
- Connect the inverter enable relay (24V coil) to **DO1** (terminal 12). DO1 ON = inverter enabled.
- Connect a fault indicator lamp (24V) to **DO2** (terminal 12, second channel).
- Connect the iCTRL-20 to a SCADA system or data logger via RS-485 (terminal 5).

15.0.2 Configuration

Step	Register	Value	Description
1	40058	60	F6: AI1 MAX scale = 60V (10V input = 60V panel)
2	40059	0	F6: AI1 MIN scale = 0V
3	40066	30	F7: AI5 MAX scale = 30A (20mA input = 30A)
4	40067	0	F7: AI5 MIN scale = 0A (4mA input = 0A)
5	40010	55	F2: AI1 alarm MAX threshold = 55V (over-voltage)
6	40011	18	F2: AI1 alarm MIN threshold = 18V (under-voltage)
7	40026	2	F2: Link AI1 (voltage) alarm → DO2 (fault lamp)
8	40018	28	F2: AI5 alarm MAX threshold = 28A (over-current)
9	40019	1	F2: AI5 alarm MIN threshold = 1A (panel disconnect)
10	40031	2	F2: Link AI5 (current) alarm → DO2 (fault lamp)
11	00001	1	Coil: Enable DO1 (inverter relay ON)
12	00005	1	F9: Enable auto-save

15.0.3 Expected Behavior

- Normal operation: AI1 reads panel voltage (e.g., 38V), AI5 reads current (e.g., 12A). DO1 keeps inverter running. DO2 (fault lamp) is OFF.
- Over-voltage (>55V) or under-voltage (<18V): DO2 activates (fault lamp ON). Operator or SCADA can then disable the inverter by writing coil 00001 = 0.
- Over-current (>28A) or panel disconnect (<1A): DO2 activates (fault lamp ON).
- SCADA reads real-time values from input registers 30002 (voltage) and 30006 (current) for trending and logging.

15.0.4 Monitoring via Modbus

- Read **Input Register 30002** (FC04) for panel voltage (÷ 100 = V).
- Read **Input Register 30006** (FC04) for panel current (÷ 100 = A).
- Read **Discrete Inputs 10006, 10010** (FC02) for voltage/current alarm status.
- Write **Coil 00001** (FC05) to remotely enable/disable inverter.

B.6 Building HVAC Zone Control

Application: Control the temperature of a building zone using a temperature sensor, a motorized hot water valve (0–10V proportional), and a ventilation fan with cyclic operation.

15.0.1 Wiring

- Connect a room temperature sensor (0–10V, range 0–50°C) to **AI1** (terminal 2).
- Connect a motorized proportional valve actuator (0–10V control input) to **AO1** (terminal 13). The valve controls hot water flow to the heating coil.
- Connect the ventilation fan contactor (24V) to **DO1** (terminal 12).
- Connect an over-temperature alarm indicator (24V lamp) to **DO2** (terminal 12, second channel).
- Connect a room occupancy sensor (24V, normally-open contact) to **DI1** (terminal 1).

15.0.2 Configuration

Step	Register	Value	Description
1	40058	50	F6: AI1 MAX scale = 50°C
2	40059	0	F6: AI1 MIN scale = 0°C
3	40001	700	F1: Set AO1 = 7.00V (valve ~70% open for heating)
4	40005	1	F4: Link DI1 (occupancy) → DO1 (fan)
5	40054	4	F5: Set DO1 timer mode = TONOFF (cyclic fan)
6	40046	900	F5: Fan ON time = 900 seconds (15 min)
7	40047	300	F5: Fan OFF time = 300 seconds (5 min)
8	40010	35	F2: AI1 alarm MAX threshold = 35°C (over-temp)
9	40011	5	F2: AI1 alarm MIN threshold = 5°C (freeze risk)
10	40026	2	F2: Link AI1 alarm → DO2 (alarm lamp)
11	00005	1	F9: Enable auto-save

15.0.3 Expected Behavior

- When the room is occupied (DI1 = ON): the fan cycles 15 minutes ON, 5 minutes OFF to circulate air.
- When the room is unoccupied (DI1 = OFF): the fan stops, saving energy.
- The valve remains at the set position (7V = ~70% open) regardless of occupancy, maintaining a base temperature. The valve position can be adjusted remotely via Modbus by writing register 40001.
- If temperature exceeds 35°C or drops below 5°C: DO2 (alarm lamp) activates.

- A BMS or SCADA system can monitor the room temperature and adjust AO1 (valve) in real-time via Modbus for optimal comfort.

15.0.4 Monitoring via Modbus

- Read **Input Register 30002** (FC04) for current room temperature (÷ 100 = °C).
- Write **Holding Register 40001** (FC06/FC16) to adjust valve position remotely (0–1000 = 0.00–10.00V).
- Read **Discrete Input 10002** (FC02) for occupancy status.
- Read **Discrete Input 10006** (FC02) for temperature alarm status.
- Read **Discrete Input 10015** (FC02) for fan output state.

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