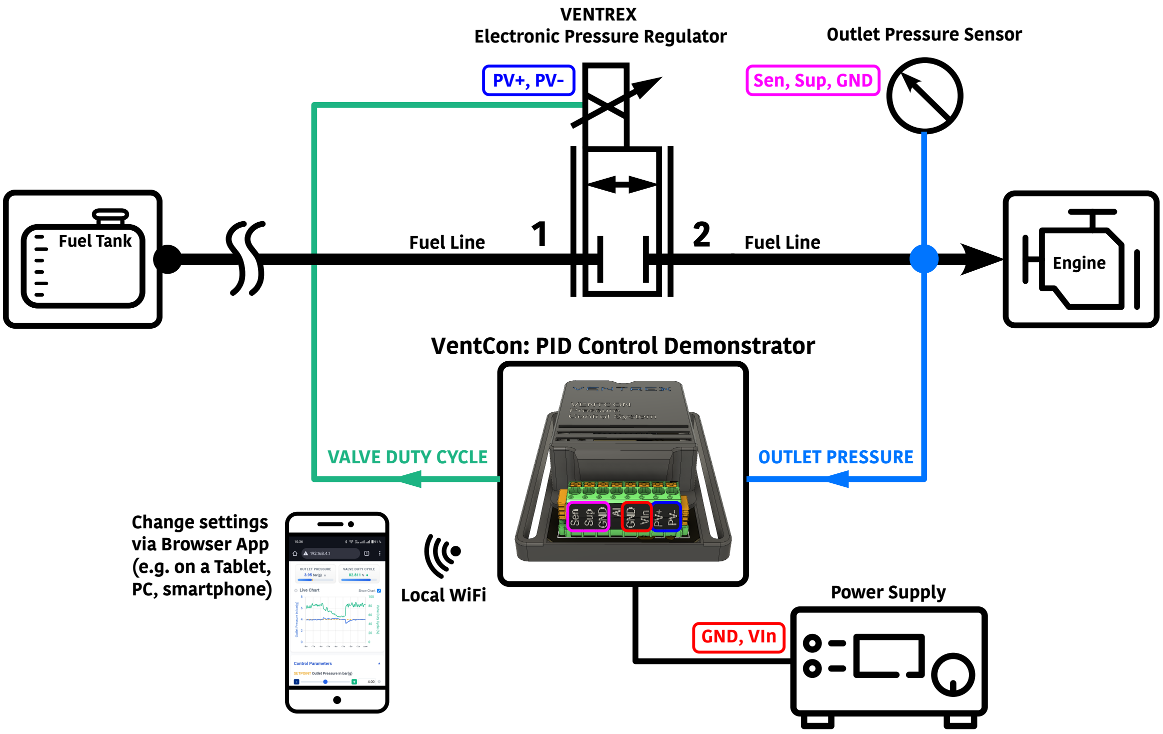
VentCon - PID Control Demonstrator

User Manual



Version 2.6

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1 System Overview

This document provides an overview of the VentCon PID control demonstrator, including its hardware components, functional principles, and user interface features. In contrast to a mechanical pressure regulator that relies on a feedback mechanism using a diaphragm and a spring, the VentCon uses an electronic control loop to maintain the desired outlet pressure. This works by modulating the proportional valve inside the VENTREX electronic pressure regulator according to the difference between the measured outlet pressure and the setpoint defined by software.

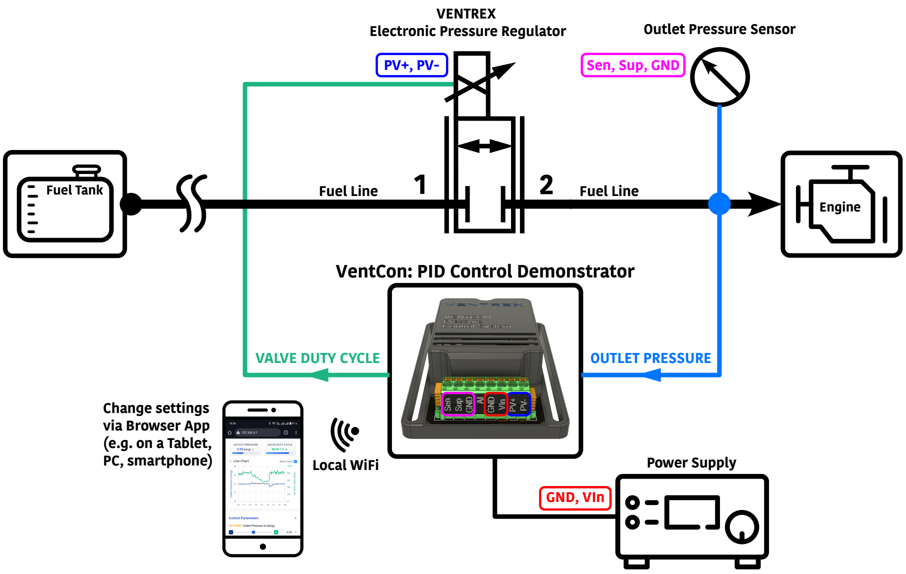


Figure 1: VentCon system overview.

The VentCon is an electronic pressure regulator demonstrator built around an ESP32-S3 microcontroller. It implements a real-time PID control loop that maintains a user-defined outlet pressure by modulating a solenoid valve via PWM. All parameters can be adjusted through a browser-based web interface over WiFi—no additional software is required.

1.1 Functional Principle

Figure 2 illustrates the closed-loop control architecture. A pressure sensor continuously measures the outlet pressure (*Process Variable*). The PID controller computes the error between the *Setpoint* and the measured pressure, and outputs a *Valve Duty Cycle* (PWM signal) to the solenoid valve.

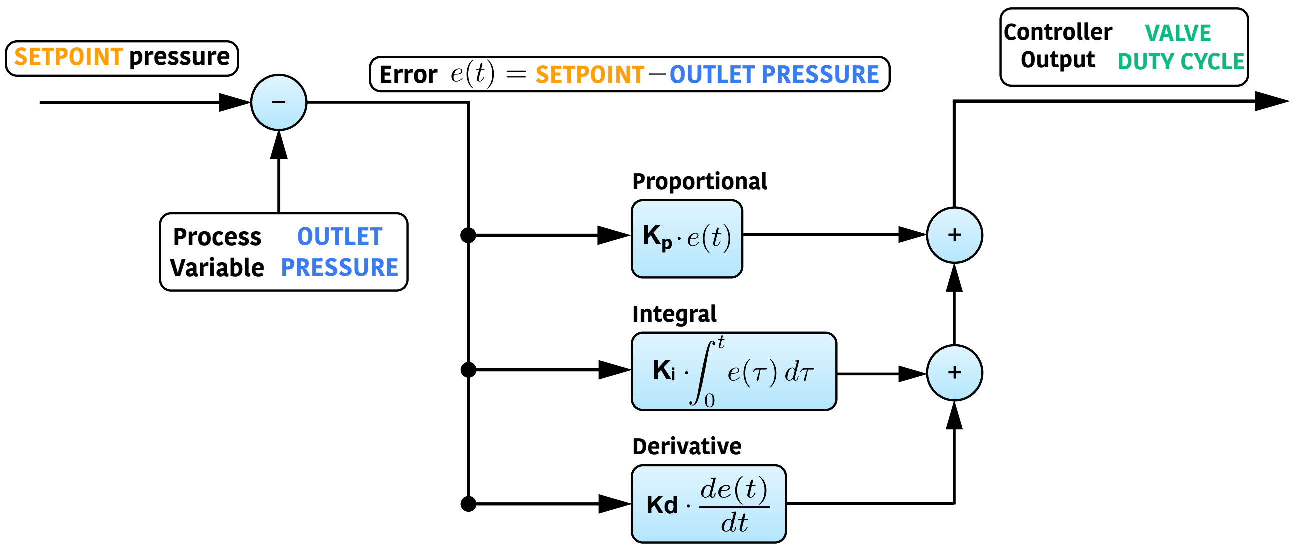


Figure 2: PID closed-loop control block diagram. The Setpoint is compared with the Outlet Pressure; the error drives the Proportional, Integral and Derivative paths whose sum controls the Valve Duty Cycle.

1.2 Hardware at a Glance

Component	Specification
Microcontroller	ESP32-S3 (Arduino Nano form factor)
Pressure Sensor	0.5–4.5 V analog, 0–10 bar range
ADC	ADS1015 12-bit (I^2C) with ESP32 fallback
Solenoid Valve	Proportional, PWM-controlled (100–10 000 Hz)
Connectivity	WiFi Access Point (WPA2-PSK)
Power Supply	External DC via terminal block

Table 1: Key hardware specifications.

The terminal block on the back of the unit (Figures 3 and 4) provides connections for the solenoid valve (`PV+`/`PV-`), the pressure sensor (`Sen`/`Sup`/`GND`), and the power supply (`VIn`/`GND`).

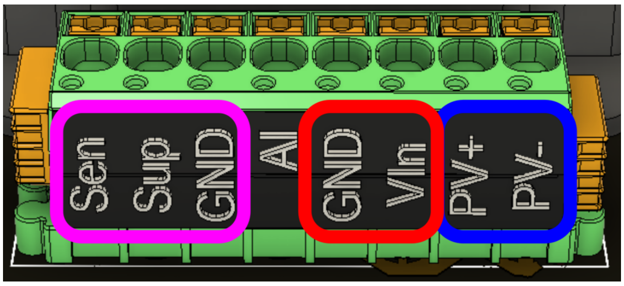


Figure 3: Terminal block connections.

Figure 4: Rear view of the VentCon unit.

2 Getting Started

2.1 Connecting to the Device

The VentCon creates its own WiFi access point—no router or internet connection is needed.

1. **Power on** the VentCon unit.
2. On your smartphone, tablet or PC, open **WiFi settings**.
3. Connect to the network `VENTCON_AP`.
4. Enter the password: `ventcon12!`
5. Open a web browser and navigate to `http://192.168.4.1`
   (alternatively `http://ventcon.local`).

Setting	**Default Value**
Network Name (SSID)	`VENTCON_AP`
Password	`ventcon12!`
IP Address	`192.168.4.1`
Max. simultaneous clients	2

Table 2: WiFi connection details.

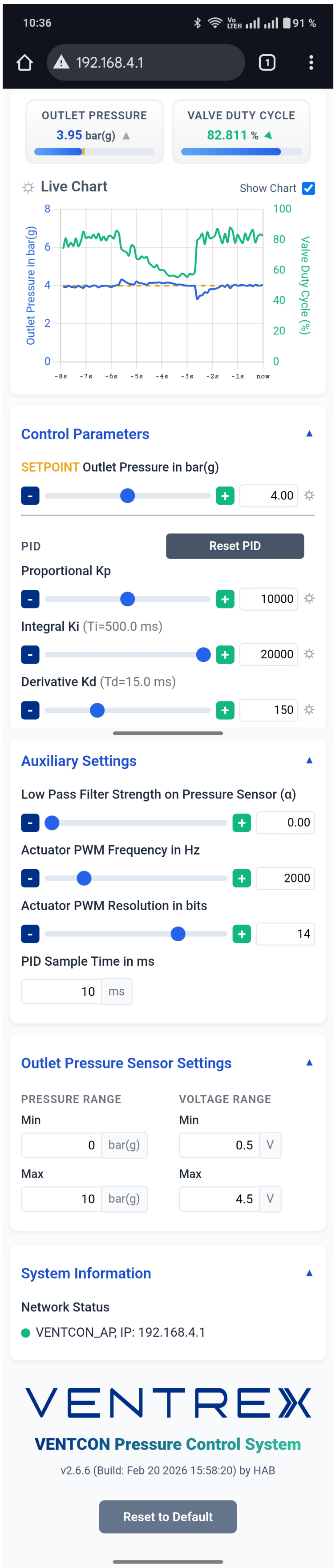
Note: The PID control loop runs independently of the WiFi connection. Disconnecting the browser does *not* stop pressure regulation.

2.2 Browser Compatibility

The web interface works with all modern browsers: Google Chrome (recommended), Safari, Firefox, and Microsoft Edge.

3 Web Interface

The web interface is divided into collapsible sections (tap a header to expand/collapse). Figure 5 provides an annotated overview.



Browser Address Bar.
IP Address of the Browser App. Alternatively, use http://ventcon.local
The PID control algorithm is working regardless of WiFi connection.

Real-Time Status Indicators.
OUTLET PRESSURE:
The regulated pressure as measured by the sensor. This is the Process Variable that the PID control algorithm is working to get close to the Setpoint pressure.

VALVE DUTY CYCLE:
Measure of electrical current and regulator orifice area. This represents the output signal sent from the PID control algorithm to the regulator valve.

Live Trend Chart.
The gear icon (⚙) opens a window to set the chart limits and grid settings.
The 'Show Chart' checkbox disables the chart (use when WiFi is poor)

The blue line tracks OUTLET PRESSURE over time. An OUTLET PRESSURE randomly hovering just above 0 bar(g) indicates a not working or not connected sensor.

The green line tracks VALVE DUTY CYCLE over time.

The orange line tracks the SETPOINT pressure over time. This represents the target pressure for the regulator algorithm and can be set during operation in the Control Parameters.

Control Parameters.
The essential PID control parameters are located here. Each parameter's value is adjusted by either Plus (+) or Minus (-) button, a slider or numerical input.
The gear icon (⚙) opens a window to set the slider limits and fidelity.

SETPOINT Outlet Pressure:
This is the target pressure for the PID algorithm.

Kp, Ki, Kd:
These are the weights put on the proportional, integral and derivative path:

Proportional Gain (Kp): Determines the immediate reaction to the current error, applying a correction proportional to how far the Outlet Pressure is from the Setpoint.

Integral Gain (Ki): Addresses past errors by gradually increasing the valve's response over time to eliminate any lingering offset between the Outlet Pressure and the Setpoint.

Derivative Gain (Kd): Anticipates future errors by responding to the rate at which the Outlet Pressure is changing.

Reset PID: This button resets the PID controller's internal state.
Useful when the system is saturated or is oscillating.

Auxillary Settings.

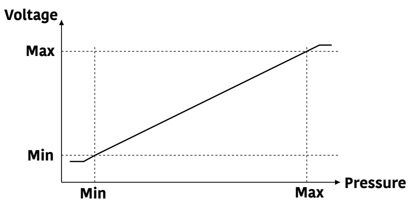
Low Pass Filter Strength on Pressure Sensor:
If the sensor is noisy (i.e. OUTLET PRESSURE), a low pass filter can be configured here.
Valid value range: 0 to 1.

Actuator PWM Frequency:
This setting determines the rate at which the valve's control signal cycles on and off to achieve the desired VALVE DUTY CYCLE. Valid value range: 100 to 10000 Hz.

Actuator PWM Resolution:
This defines the precision of VALVE DUTY CYCLE.
Valid value range: 8 to 16 bits (e.g., 14 bits provides 16384 discrete steps).

PID Sample Time:
Defines the time interval between successive calculation steps of the PID algorithm.

Outlet Pressure Sensor Settings.
Voltage Range and Pressure Range.
The upper and lower limits define the operational boundaries of the sensor, as specified in the sensor datasheet or determined through calibration.



System Information.
Network Status:
The Indicator will be green when connected, red when disconnected.

Reset to Default.
Upon confirmation, this button restores all user-adjustable settings on the Browser App to their default values.

Figure 5: Annotated overview of the VentCon browser application.

3.1 Real-Time Monitoring

- **Outlet Pressure** gauge—current pressure in bar(g) with a target marker at the setpoint and a trend indicator (▲ rising / ▼ falling / = stable).
- **Valve Duty Cycle** gauge—current PID output as a percentage (0–100 %).
- **Live Chart**—time-series plot of:
  - Blue line: Outlet Pressure (Process Variable)
  - Orange dashed line: Setpoint
  - Green line: Valve Duty Cycle

  Toggle the chart with the *Show Chart* checkbox. Disabling it can improve performance on slower devices.

3.2 Control Parameters

- **Setpoint Outlet Pressure**—target pressure in bar(g). Adjusted via slider, +/− buttons, or direct numerical input.
- **Kp, Ki, Kd**—PID gains (see Section 4).
- **Reset PID** button—clears the controller's internal state (integral sum and derivative history).

Each slider's range can be customised by tapping the gear icon next to the slider label.

3.3 Auxiliary Settings

- **Low Pass Filter (α)**—filter strength applied to the pressure sensor signal (0 = off, 1 = maximum smoothing).
- **Actuator PWM Frequency**—solenoid drive frequency (100–10 000 Hz).
- **Actuator PWM Resolution**—duty-cycle resolution (8–16 bit).
- **PID Sample Time**—control loop period in ms.

3.4 Applying Changes

Changes are **not** applied immediately. After adjusting any parameter a blue **Apply Changes** button appears at the bottom of the screen (Figure 6). Tap it to send all pending changes to the device. All applied settings are automatically persisted to flash memory and survive power cycles.

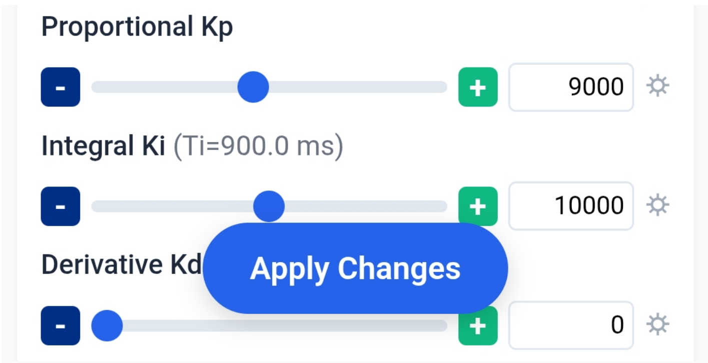


Figure 6: The floating *Apply Changes* button appears when parameters have been modified.

4 PID Control Basics

The VentCon uses the *Parallel Form* (non-interacting form) of the PID algorithm. Each control action is computed independently and summed:

$$y(t) \;=\; K_p\, e(t) \;+\; K_i \int_0^t e(\tau)\, d\tau \;+\; K_d\, \frac{de(t)}{dt} \tag{1}$$

where $y(t)$ is the controller output (Valve Duty Cycle), $e(t)$ is the error (Setpoint − Outlet Pressure), and K_p, K_i, K_d are the tunable gains.

Term	Role	Focus
K_p (Proportional)	Present	Reacts to *how far* you are from target
K_i (Integral)	Past	Reacts to *how long* you have been away
K_d (Derivative)	Future	Reacts to *how fast* you are approaching/leaving

Table 3: PID term summary.

Proportional (K_p). Output proportional to the current error. Higher K_p gives a more aggressive response but can cause overshoot.

Integral (K_i). Accumulates past error to eliminate steady-state offset. Too high a value causes oscillation (integral windup).

Derivative (K_d). Damps the response by reacting to the rate of change of the error. Reduces overshoot but amplifies sensor noise if set too high.

5 Tuning Guide

Follow these steps for initial tuning. Observe the **Live Chart** after each change.

1. **Set a Stable Operating Point.** Choose a moderate setpoint (e.g. 4.00 bar) and let the system settle.
2. **Start with P-only control.** Set $K_i = 0$ and $K_d = 0$. Begin with a low K_p and increase gradually. Find the value where the pressure just begins to oscillate steadily (*ultimate gain*), then back off slightly.
3. **Introduce Integral action.** Slowly increase K_i to remove the remaining steady-state offset. Stop increasing when further gains cause oscillation.
4. **Add Derivative action (if needed).** If the response overshoots or is slow to settle, increase K_d cautiously to add damping.
5. **Iterate.** Make small single-parameter changes and observe. The goal is a fast, smooth response with minimal overshoot.

5.1 Example: Step Response

Figure 7 shows a typical step-response recording where the setpoint is changed from 4 to 6 bar. Figure 8 demonstrates the controller rejecting a mass-flow disturbance while maintaining the setpoint.

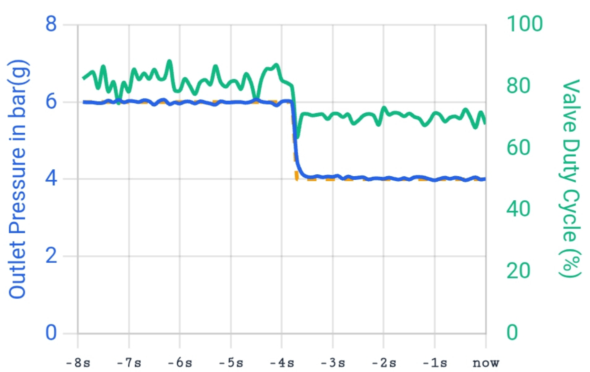


Figure 7: Setpoint step from 4 to 6 bar.

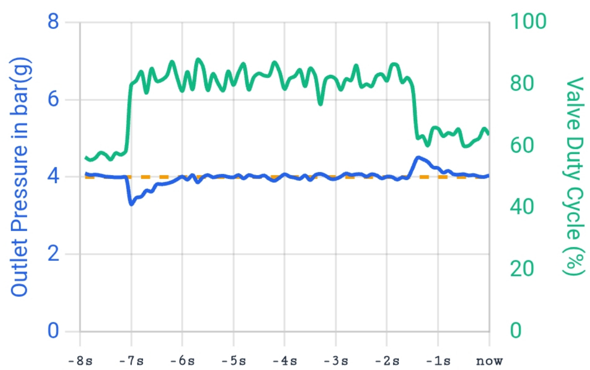


Figure 8: Disturbance rejection under varying mass flow.

6 Quick Reference

Action	How To
Connect to device	WiFi: `VENTCON_AP` / Password: `ventcon12!`
Open web interface	Browser → `http://192.168.4.1`
Expand / collapse sections	Tap section header
Adjust setpoint	Drag slider or use +/− buttons
Fine-tune PID	Adjust K_p, K_i, K_d sliders
Customise slider range	Tap gear icon next to slider label
Apply changes	Tap blue *Apply Changes* button
Reset PID state	Tap *Reset PID* button
Toggle live chart	Use *Show Chart* checkbox
Reset to factory defaults	Use *Reset to Default* in System Info

Table 4: Quick reference card.