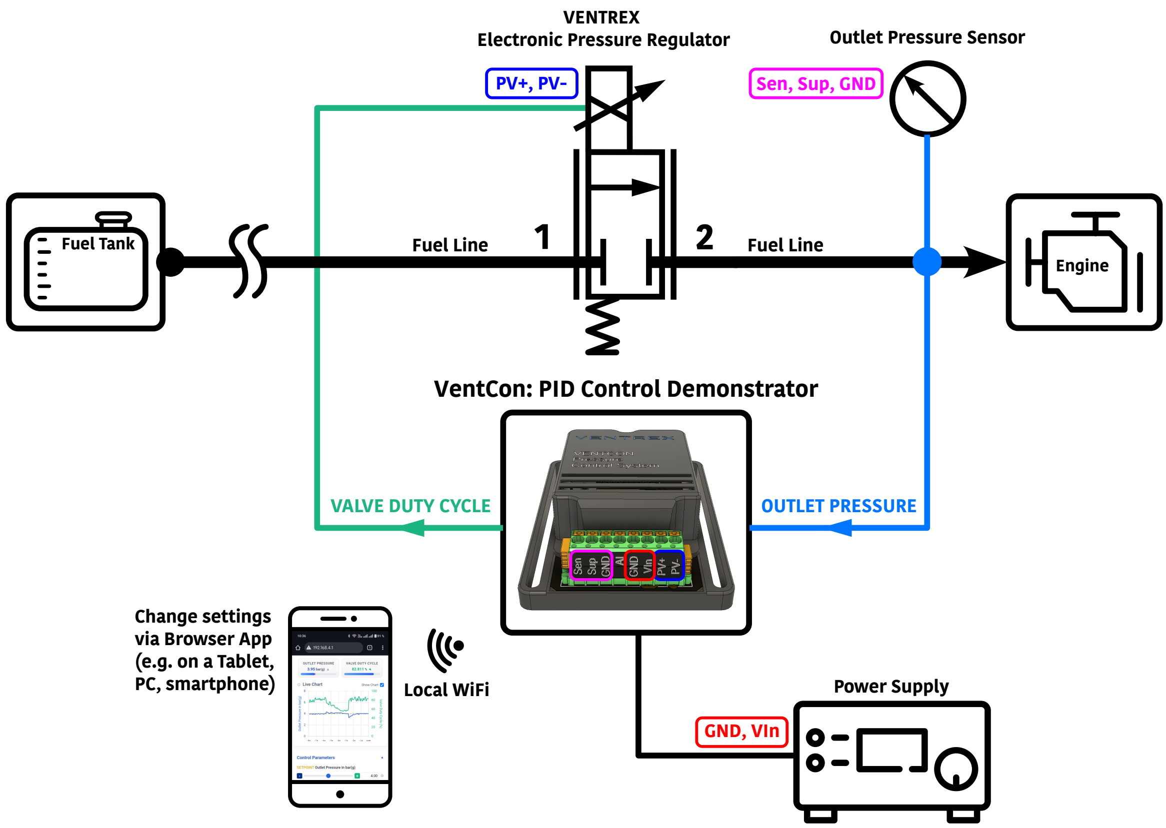
VentCon - PID Control Demonstrator

User Manual



Version 2.6

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1 System Overview

Unlike a mechanical pressure regulator, which relies on a diaphragm and spring to maintain its setpoint, the VENTREX electronic pressure regulator uses a software-based feedback control loop. A PID algorithm continuously compares the measured outlet pressure with the desired setpoint and modulates the proportional valve accordingly.

The VentCon demonstrator showcases this principle: it implements the complete control loop on an ESP32-S3 microcontroller, allowing users to observe and tune the regulator's behaviour in real time. This document covers the system's hardware, functional principles, and browser-based user interface.

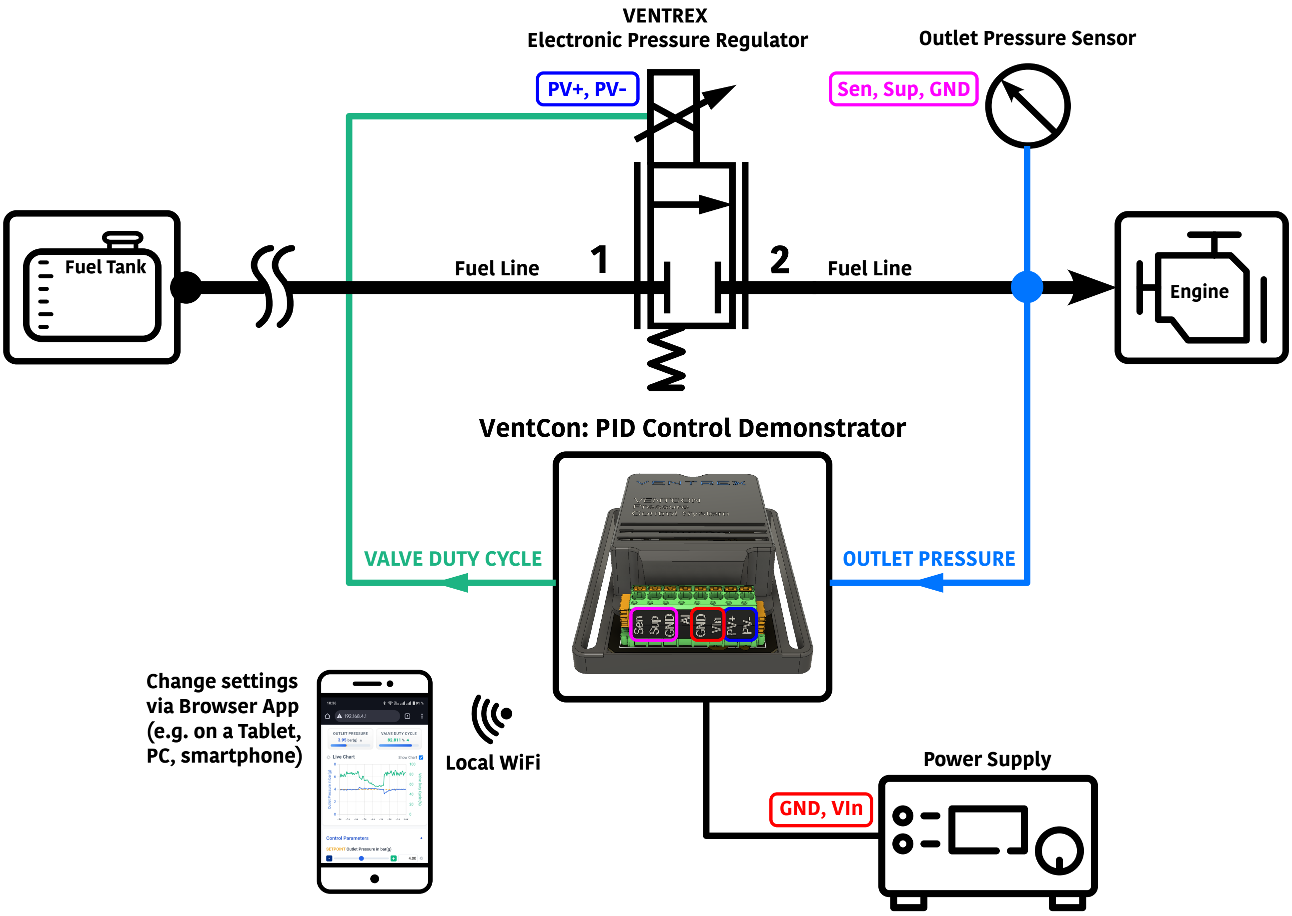

Figure 1: VentCon system overview.

All parameters can be adjusted through a browser-based interface served over WiFi directly from the device—no external software, router, or internet connection is required. The VentCon operates fully self-contained, making it usable in any environment regardless of existing network infrastructure.

> **Important**
>
> The PID control loop runs independently of the WiFi connection. Even if the browser is closed or the device is disconnected from WiFi, pressure regulation continues uninterrupted based on the last applied settings—as long as the power supply remains on.
>
> This also means that upon switching the power supply on, the system will immediately start to regulate the pressure.

2 Getting Started

2.1 Wiring Scheme

The terminal block on the front of the unit (Figure 2) provides connections for the proportional valve (`PV+`/`PV-`), the pressure sensor (`Sen`/`Sup`/`GND`), and the power supply (`VIn`/`GND`).

The connector for the PV is included in the demo kit, thus the user only needs to connect the pressure sensor and the power supply. The pressure sensor (not included in the demo kit) requires three connections: `Sup` provides regulated 5 V supply for the sensor, while `GND` serves as the sensor's ground reference. The `Sen` terminal is the input for the sensor's pressure signal, which the controller uses to regulate the outlet pressure.

The power supply (not included) should provide a stable DC voltage. For the PV delivered in this demo kit, the recommended voltage is 12 V (connected to `VIn`)[1], while the `GND`[2] is connected to the negative terminal of the power supply.

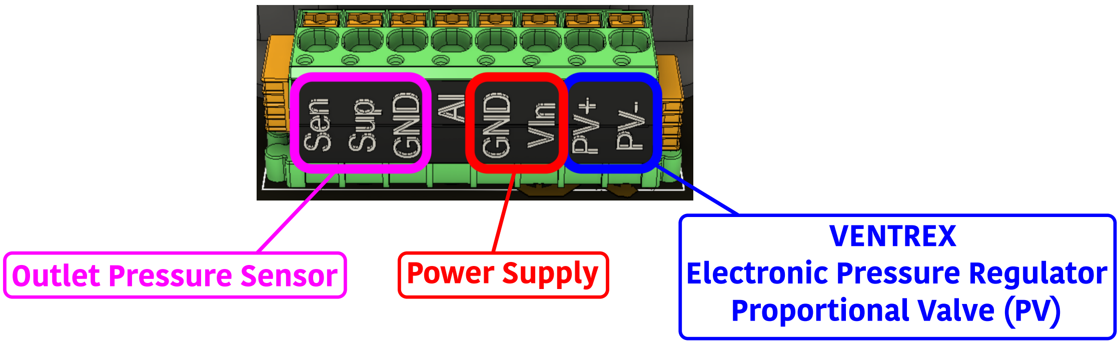

Figure 2: Terminal block connections.

[1] the device can operate with any supply voltage in the range of 12 to 30 V
[2] The `GND` terminal serves as the common ground reference for the entire system

2.2 Connecting to the Device

Figure 3: Rear view of the VentCon unit.

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 1: WiFi connection details.

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

2.3 Browser Compatibility

The web interface works with all modern browsers, e.g. Google Chrome or Safari.

2.4 Functional Principle

Figure 4 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.

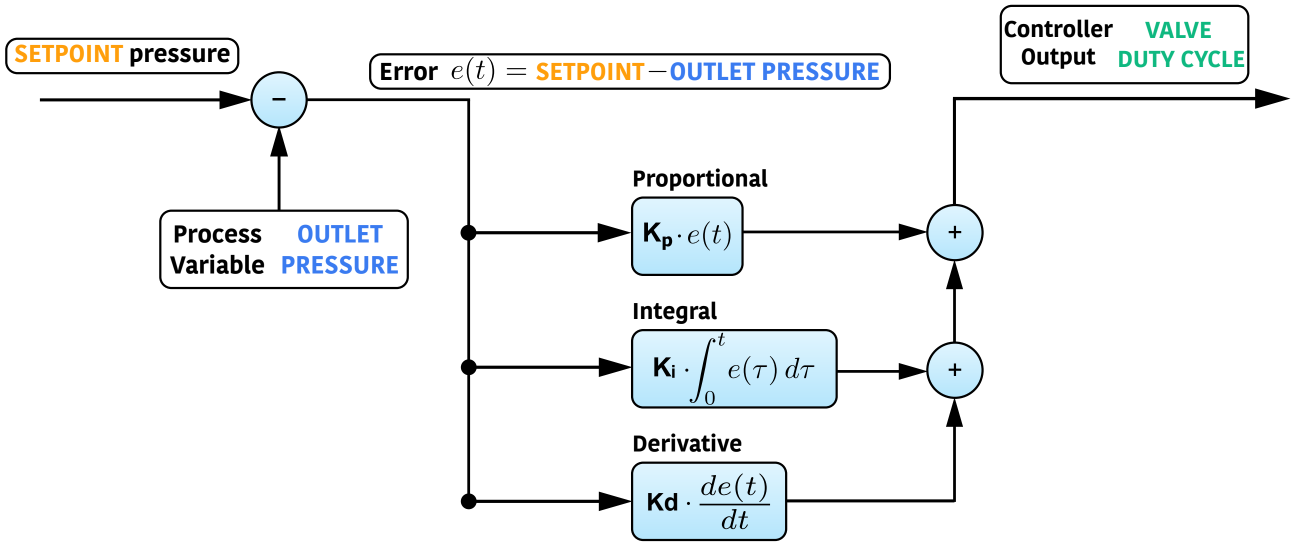

Figure 4: PID closed-loop control block diagram. The Setpoint is compared with the Outlet Pressure; the error drives the Proportional, Integral and Derivative paths whose sum controls the Valve Duty Cycle.

3 Web Interface

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

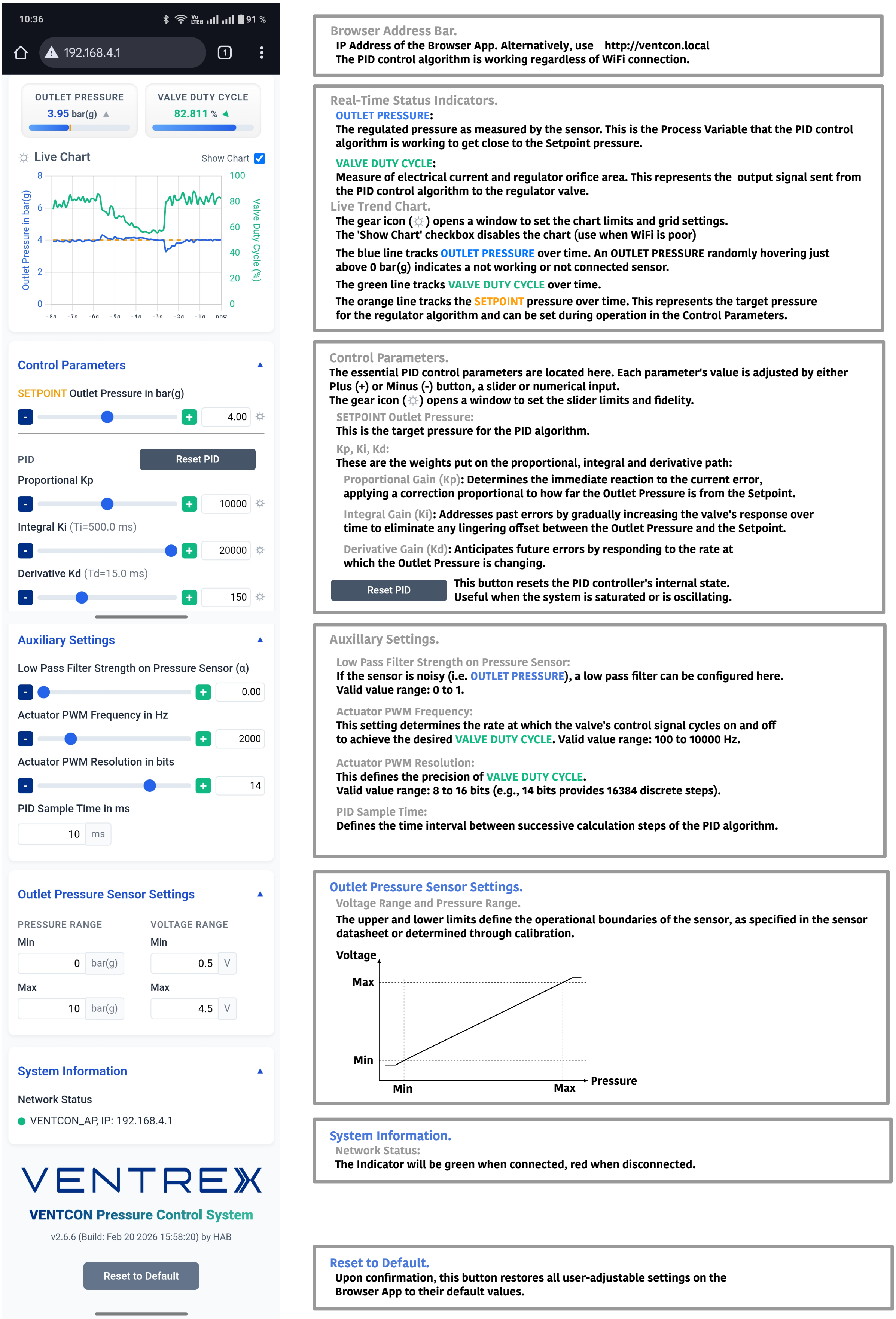

Figure 5: Annotated overview of the VentCon browser application.

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.

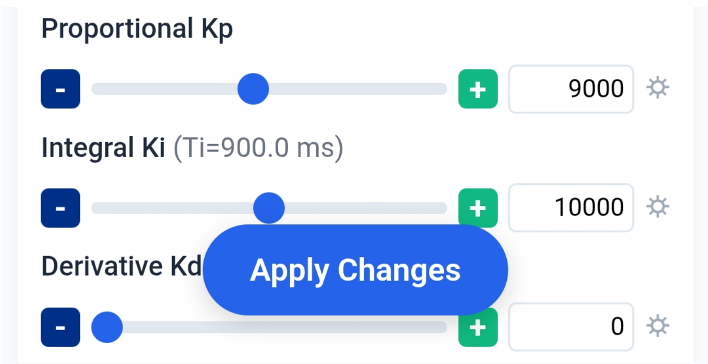

Figure 6: The floating *Apply Changes* button appears when parameters have been modified.

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 2: 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.

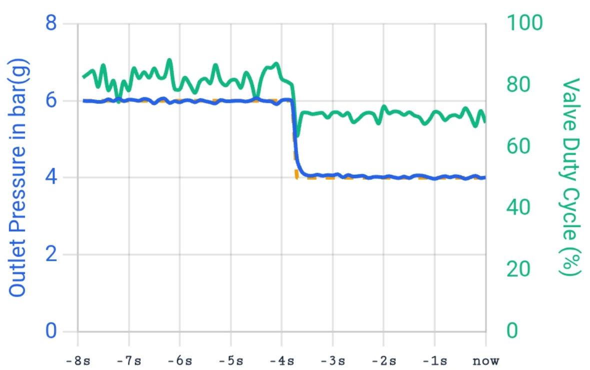

Figure 7: Setpoint step from 4 to 6 bar.

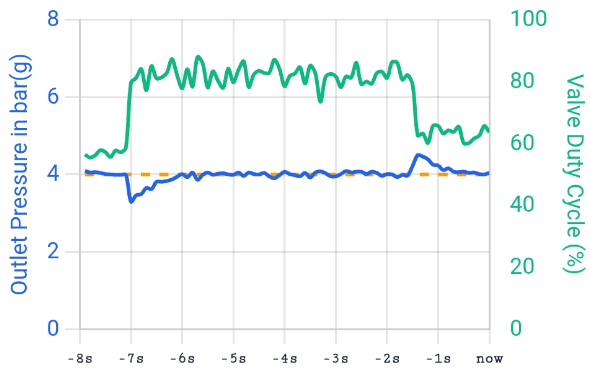

Figure 8: Disturbance rejection under varying mass flow.

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 3: Quick reference card.