Pump Control System with PID & Alarm Handling

Studio 5000 Emulator-Based Control Project

1. Project Objective

This project implements a pump control system using Studio 5000 with a ControlLogix-based architecture and emulator-compatible I/O. It controls a water tank level using a VFD-driven pump. The system supports both **manual (operator speed)** and **automatic (PID-regulated)** modes, with analog signal scaling, alarm management, and structured ladder routines.

This project mirrors real-world industrial control designs and is structured for clarity, modularity, and extensibility.

2. Scope of Work

- Build logic to control pump operation based on tank level
- Implement **Manual Mode** (fixed speed input) and **Auto Mode** (PID control)
- Perform analog scaling on tank level and flow rate inputs (4–20 mA)
- Output analog VFD speed via analog output module
- Implement alarm system for overfill and underfill conditions
- Design modular routines: IO, MODE_SELECTION, CTRL, ALARMS_NOTIFICATION
- Ensure the system runs entirely on **Studio 5000 Emulator**

3. Modes of Operation

⭕ Manual Mode:

- Operator manually sets pump speed via MANUAL_VFD_SPEED
- Pump starts and runs at constant analog speed output

🔄 Auto Mode:

- Operator enters desired flow (FLOW_SP)
- PID controller adjusts pump speed to maintain flow using FLOW_LEVEL feedback

🟢 **System Logic:**

- Start system via START_PB
- Stop and clear modes via STOP_PB
- LT_AUTO_MODE and LT_MANUAL_MODE indicate active mode

4. Hardware Configuration

Slot	Module	Description
0	Emulator CPU	Studio 5000 Logix Emulator
1	1756-IA16	Digital Inputs – Pushbuttons
2	1756-OA16	Digital Outputs – Pump, VFD, Lights
3	1756-IF8	Analog Inputs – Tank Level, Flow Rate
4	1756-OF8	Analog Output – VFD Speed Control

✅ All modules configured for simulation; logic runs without hardware.

5. Analog Signal Scaling

Signal	Raw Range	Scaled Range	Use
Tank Level	6554–32767	0–100%	Controls start/stop logic
Flow Rate	6554–32767	0–500 LPM	PID process variable
VFD Speed Output	6554–32767	0–100%	VFD command output

✅ Scaling is done using CPT blocks and clamped to valid engineering ranges.

6. Control Logic Overview

- **Pump Start**: TANK_LEVEL < 20% (held for 5 sec)
- **Pump Stop**: TANK_LEVEL > 80% (held for 5 sec)
- TRIGGER_PUMP and TRIGGER_PUMP_STOP control latching
- In **Manual Mode**:
  → MANUAL_VFD_SPEED → VFD_SPEED → analog output

- In **Auto Mode**:
  → FLOW_SP → PID.SP, FLOW_LEVEL → PID.PV, PID.CV → VFD_SPEED → analog output
- PID block only runs when AUTO_MODE and PUMP = TRUE

7. Alarm and Notification System

The system monitors the tank level and provides both **Low-Level** and **High-Level** alarms using structured logic:

🔻 **Low-Level Alarm:**

- Triggered when TANK_LEVEL < 10% for 5 seconds
- Activates LL_ALARM, LL_NOTIFICATION
- Uses a one-shot pulse (TRIGGER_LL_ALM) and latch

🔺 **High-Level Alarm:**

- Triggered when TANK_LEVEL > 90% for 5 seconds
- Activates HH_ALARM, HH_NOTIFICATION
- Uses TRIGGER_HH_ALM and a similar latch

🔄 **Reset Logic:**

- RESET_ALARM clears all alarms and indicators
- FAULT_LT output turns on when any alarm is active

✅ Alarm system is clean, debounced, and HMI-ready

8. Tag and Interface Overview

- **Digital Inputs**: START_PB, STOP_PB, AUTO_PB, MANUAL_PB
- **Digital Outputs**: OUT_PUMP, OUT_VFD, LT_MANUAL_MODE, LT_AUTO_MODE, FAULT_LT
- **Analog Inputs**: RAW_TANK_LEVEL, RAW_FLOW_LEVEL
- **Analog Output**: RAW_VFD_SPEED
- **Control Tags**: FLOW_SP, MANUAL_VFD_SPEED, RESET_ALARM
- **PID Block**: PID_CTRL (SP, PV, CV)

9. Functional Test Criteria

Test Case	Expected Behavior
Force TANK_LEVEL < 20%	Pump starts after 5 seconds
Force TANK_LEVEL > 80%	Pump stops after 5 seconds
Set MANUAL_VFD_SPEED = 60	Output analog = 22281 (≈ 13.6 mA)
Set FLOW_SP = 300, flow = 250	PID raises VFD_SPEED to reach setpoint
TANK_LEVEL < 10% for 5s	Low-level alarm active, FAULT_LT ON
TANK_LEVEL > 90% for 5s	High-level alarm active, FAULT_LT ON
Press RESET_ALARM	Clears alarms and FAULT_LT
Press STOP_PB	Cancels all operations and resets modes

10. Summary & Portfolio Highlights

This Studio 5000 project demonstrates:

- ✓ PID-based process control with flow feedback
- ✓ Analog scaling and signal clamping (4–20 mA)
- ✓ Structured ladder routines (IO, CTRL, MODE_SELECTION, ALARMS)
- ✓ Realistic control logic (delayed starts, stop conditions, fault handling)
- ✓ Alarm latching, operator reset, and notification architecture
- ✓ Designed for full testing using Studio 5000 Emulator