ESPE
UNIVERSIDAD DE LAS FUERZAS ARMADAS
INNOVACIÓN PARA LA EXCELENCIA

UNIVERSIDAD DE LAS FUERZAS ARMADAS ESPE

DEPARTAMENTO DE ELÉCTRICA Y ELECTRÓNICA

CARRERA DE INGENIERÍA EN ELECTRÓNICA E INSTRUMENTACIÓN

Artículo Académico Previo a la Obtención del Título de Ingeniero en Electrónica e Instrumentación

CIT 2022 - International Congress on Science and Technology

Advanced Control Algorithms for a Horizontal Three-Phase Separator in a Hardware in the Loop Simulation Environment

Autores:
Aimacaña Cueva, Lady Elizabeth
Gahui Auqui, Oscar Jonathan

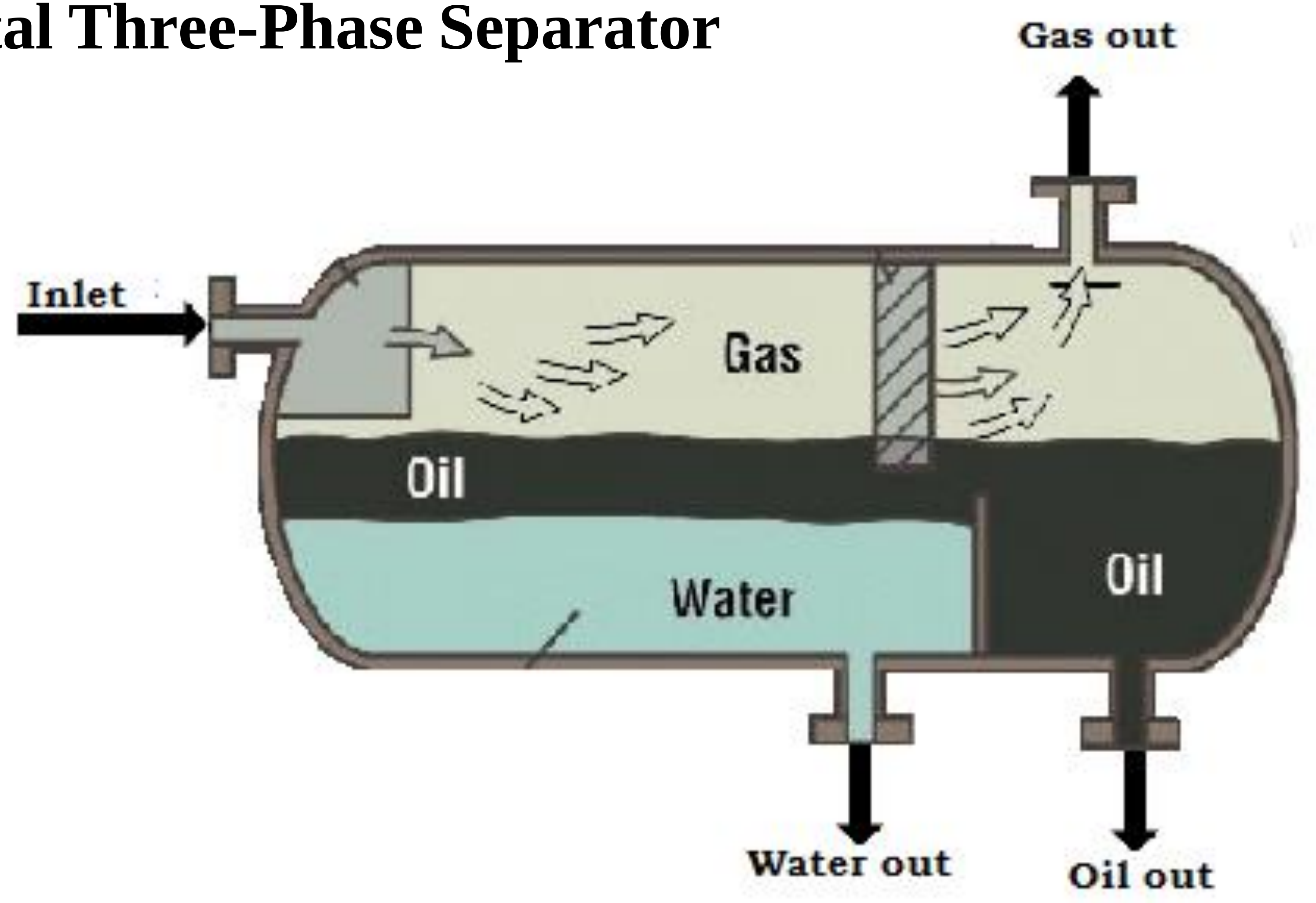
Tutor. Ing. Llanos Proaño, Jacqueline del Rosario
Co-Tutor. Ing. Ortiz Villalba, Diego Edmundo

Contents

- Introduction
- Mathematical Modeling
- Hardware in the Loop
- Controllers Design
- Results
- Conclusions

Introduction

Horizontal Three-Phase Separator



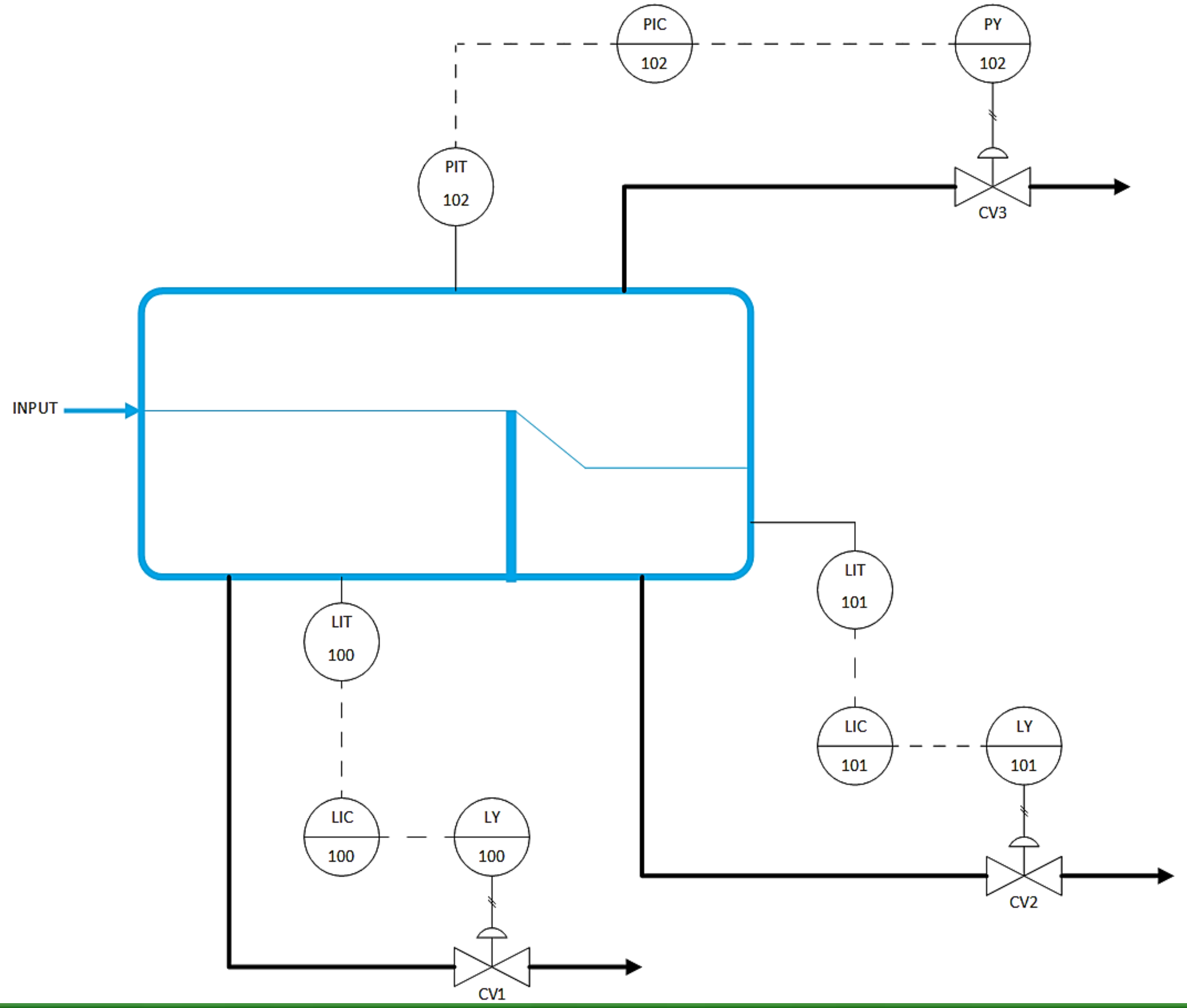
Introduction

Horizontal Three-Phase Separator Variables

Manipulated Variables		
$F(t)_{w\_in}$	Water Flow	[m/s]
$F(t)_{l\_in}$	Oil Flow	[m/s]
$F(t)_{g\_in}$	Gas Flow	[m/s]

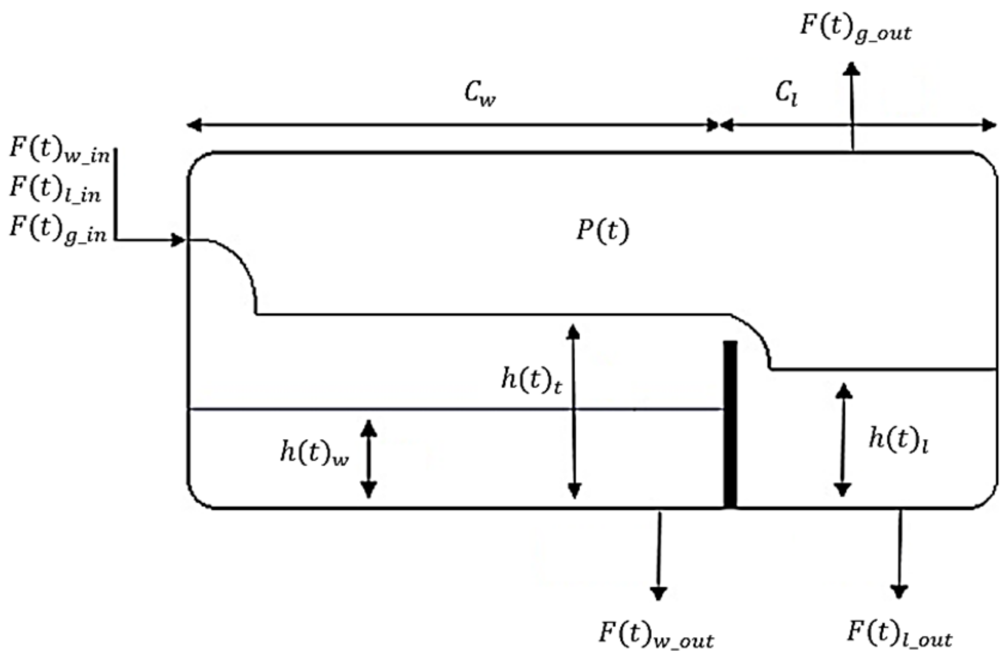
Controlled Variables		
$h(t)_w$	Water Level	[m]
$h(t)_l$	Oil Level	[m]
$P(t)$	Pressure	[bar]

P&ID Diagram



Mathematical Modeling

Three-phase separator schematic diagram



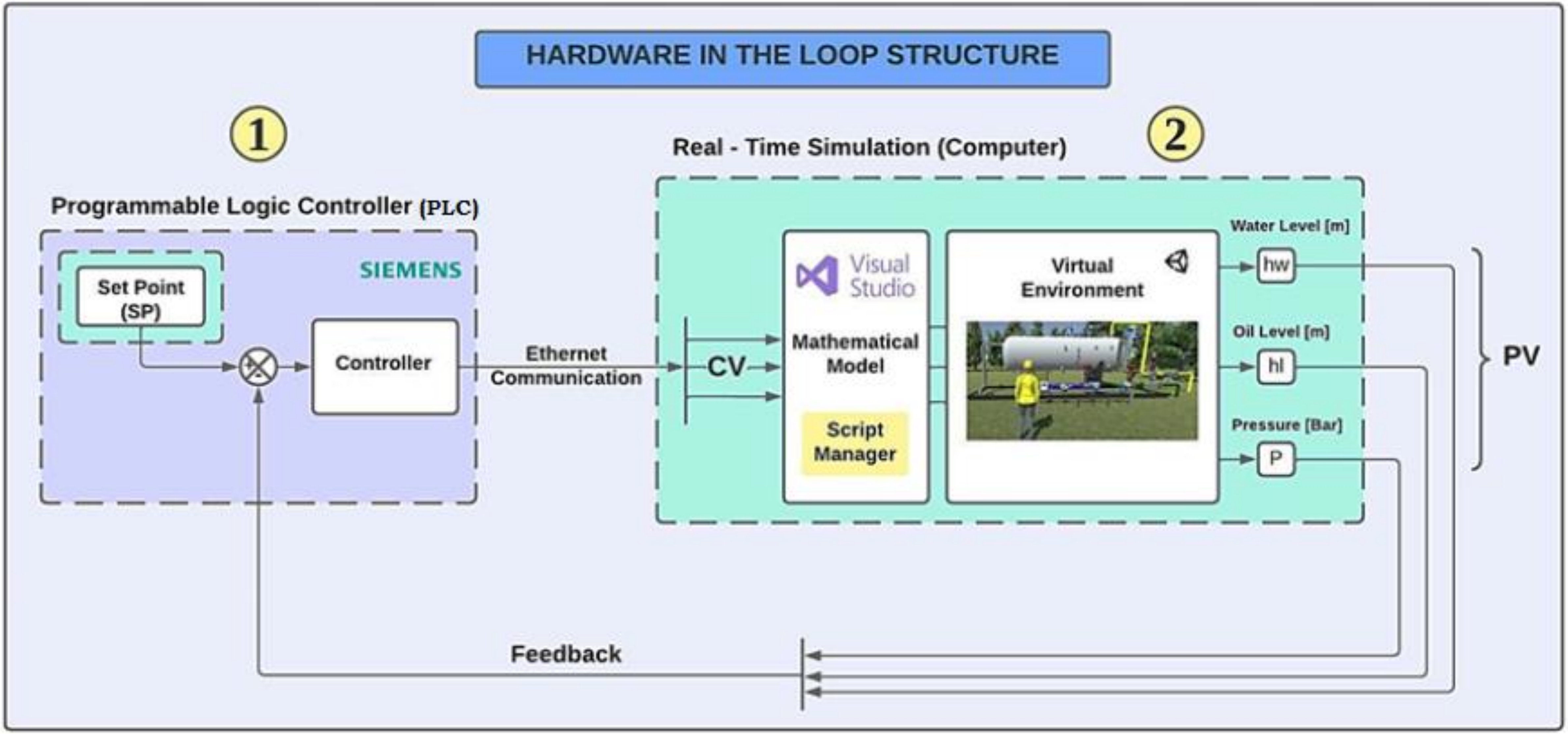
$$\frac{dh(t)_w}{dt} = \frac{F(t)_{w\_in} - F(t)_{w\_out}}{2C_w\sqrt{(D-h(t)_w)h(t)_w}}$$

$$\frac{dh(t)_t}{dt} = \frac{F(t)_{w\_in} + F(t)_{l\_in} - F(t)_{vert\_out} - F(t)_{w\_out}}{2C_w\sqrt{(D-h(t)_t)h(t)_t}}$$

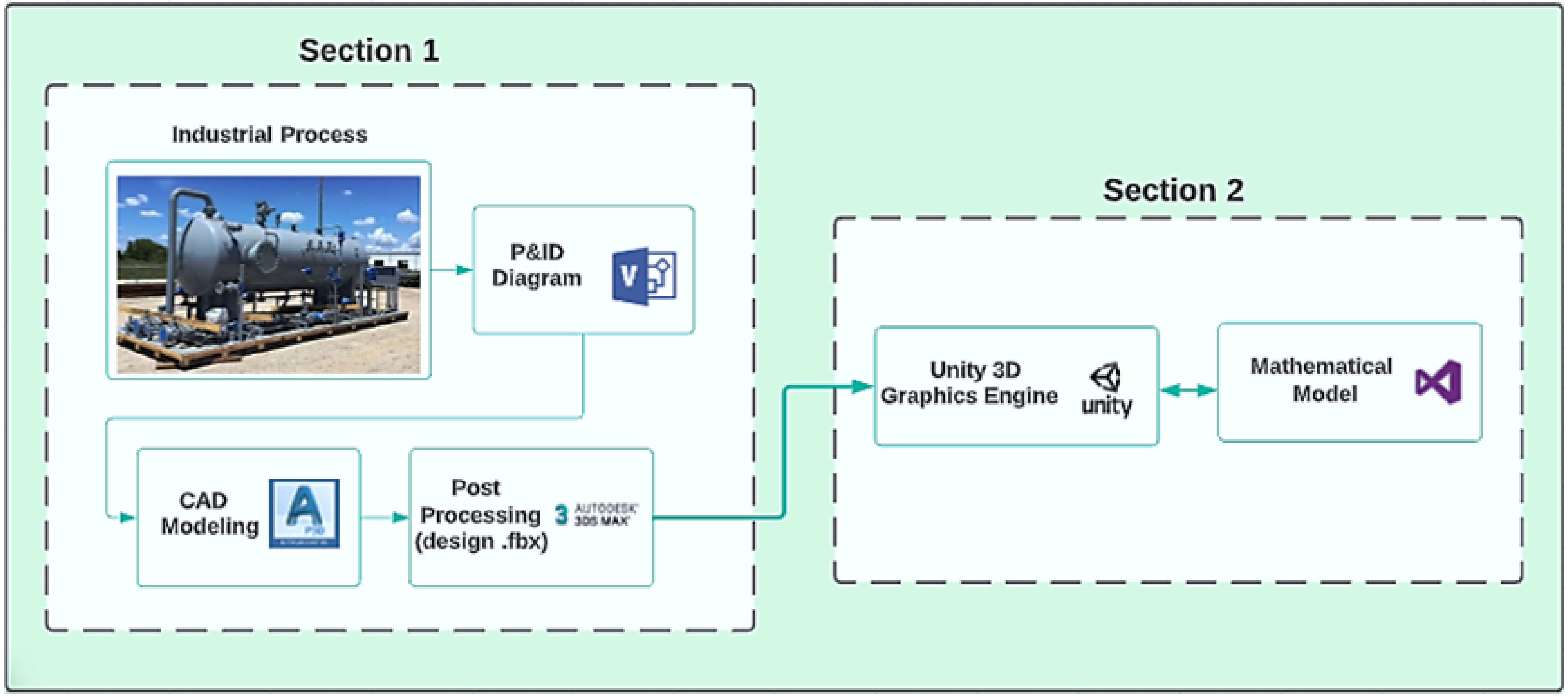
$$\frac{dh(t)_l}{dt} = \frac{F(t)_{vert} - F(t)_{l\_out}}{2C_l\sqrt{(D-h(t)_l)h(t)_l}}$$

$$\frac{dP(t)}{dt} = \frac{P(t)\left[F(t)_{g\_in} - F(t)_{g\_out} + F(t)_{l\_in} - F(t)_{l\_out} + F(t)_{w\_in} - F(t)_{w\_out}\right]}{V_{3\phi} - V(t)_w - V(t)_l}$$

Hardware in the Loop

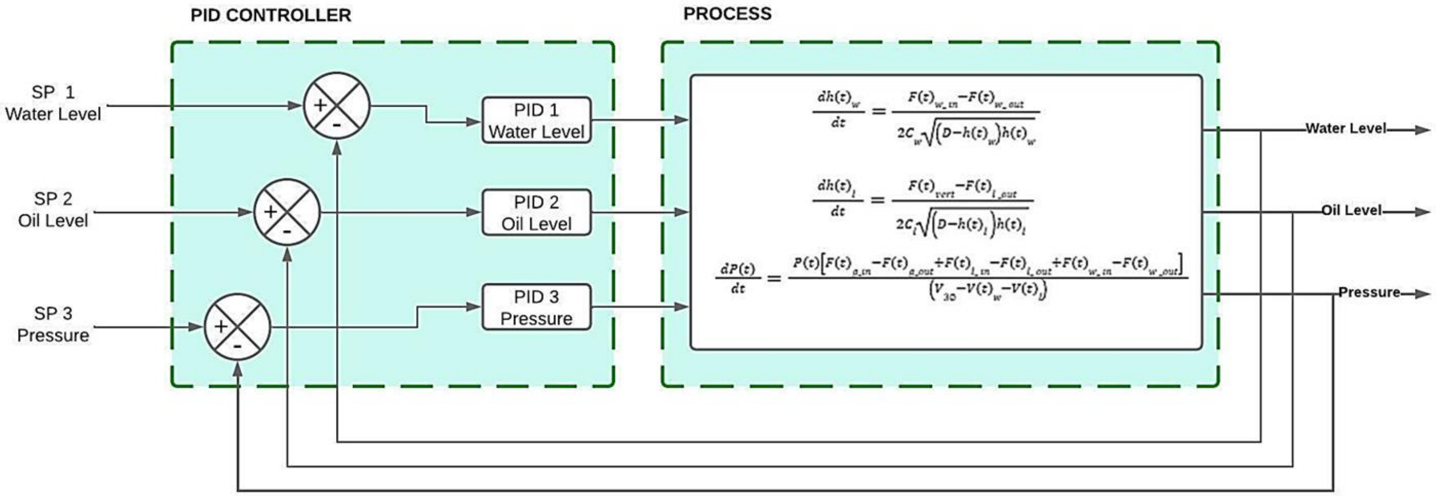


Methodology



Control Design

PID Controller



Lambda Tuning Method

$$G(s) = \frac{k}{1+Ts} e^{-\tau s}$$

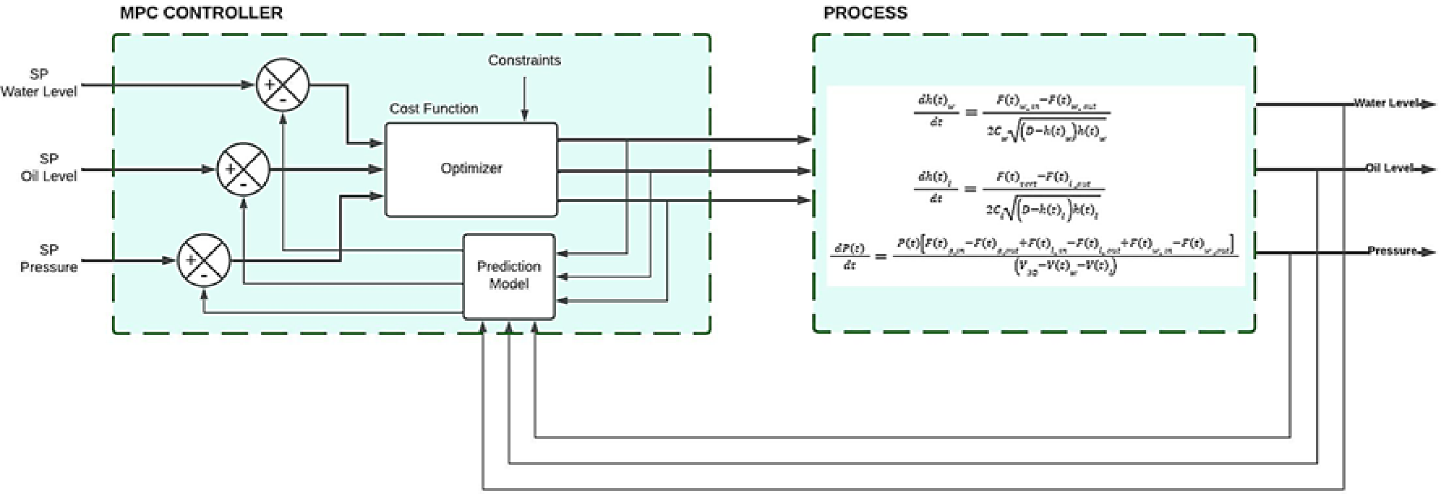
$$U(s) = K_p e(s) + K_i \frac{e(s)}{s} + sK_d e(s)$$

$$K_p = \left(\frac{1}{k}\right)\left(\frac{\frac{\tau}{2}+\lambda}{\frac{\tau}{2}+\lambda}\right) \qquad K_i = \frac{K_p}{T+\frac{\tau}{2}}$$

$$K_d = \frac{\tau\lambda}{\tau+2\lambda} \qquad \lambda = T$$

Control Design

MPC Controller



MPC Algorithm

$$J(k)=\sum_{i=N_w}^{N_p}\delta_1(k)\left[\hat{h}_w(k+i\,|\,k)-h_{wd}(k+i\,|\,k)\right]^2+\ldots$$

$$\delta_2(k)\left[\hat{h}_l(k+i\,|\,k)-h_{ld}(k+i\,|\,k)\right]^2+\ldots$$

$$\delta_3(k)\left[\hat{P}(k+i\,|\,k)-P_d(k+i\,|\,k)\right]^2+\ldots$$

$$\sum_{i=0}^{N_{c-1}}\lambda_1(k)\left[\Delta u_1(k+i-1)\right]^2+\lambda_2(k)\left[\Delta u_2(k+i-1)\right]^2+\ldots$$

$$\lambda_3(k)\left[\Delta u_3(k+i-1)\right]^2$$

Weights

$$\delta_i(k) \qquad i=1,2,3,4\ldots\ldots\ldots$$

$$\lambda_i(k) \qquad i=1,2,3,4\ldots\ldots\ldots$$

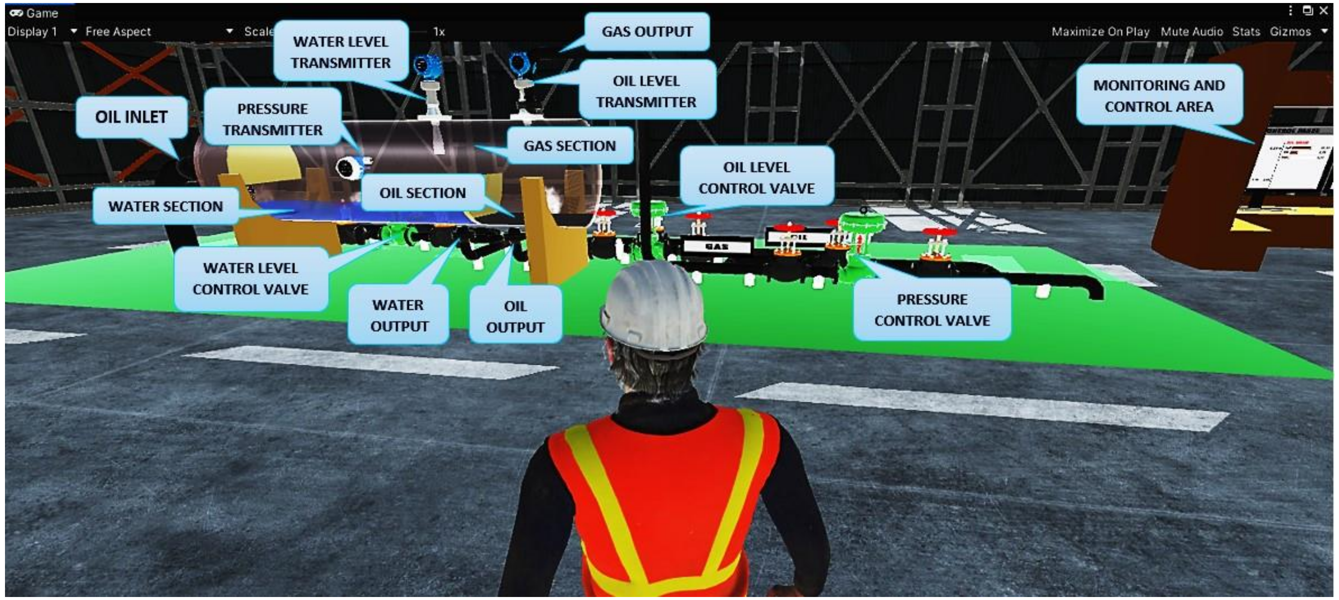
Constraints

$$h_{w\min}\le h_w\le h_{w\max} \quad h_{l\min}\le h_l\le h_{l\max} \quad P_{\min}\le P_w\le P_{\max}$$

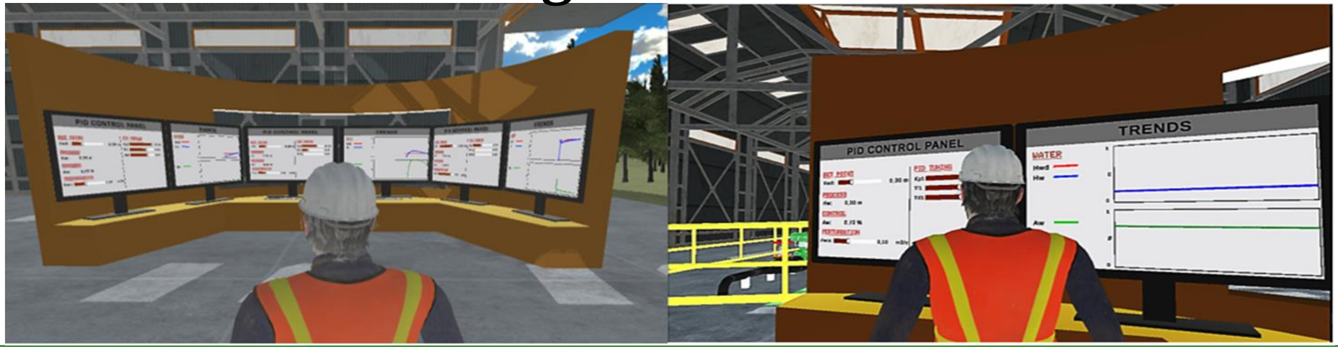
$$\Delta u_{\max}\le\Delta u_1\le\Delta u_{\max} \quad \Delta u_{\max}\le\Delta u_2\le\Delta u_{\max} \quad \Delta u_{\max}\le\Delta u_3\le\Delta u_{\max}$$

Results

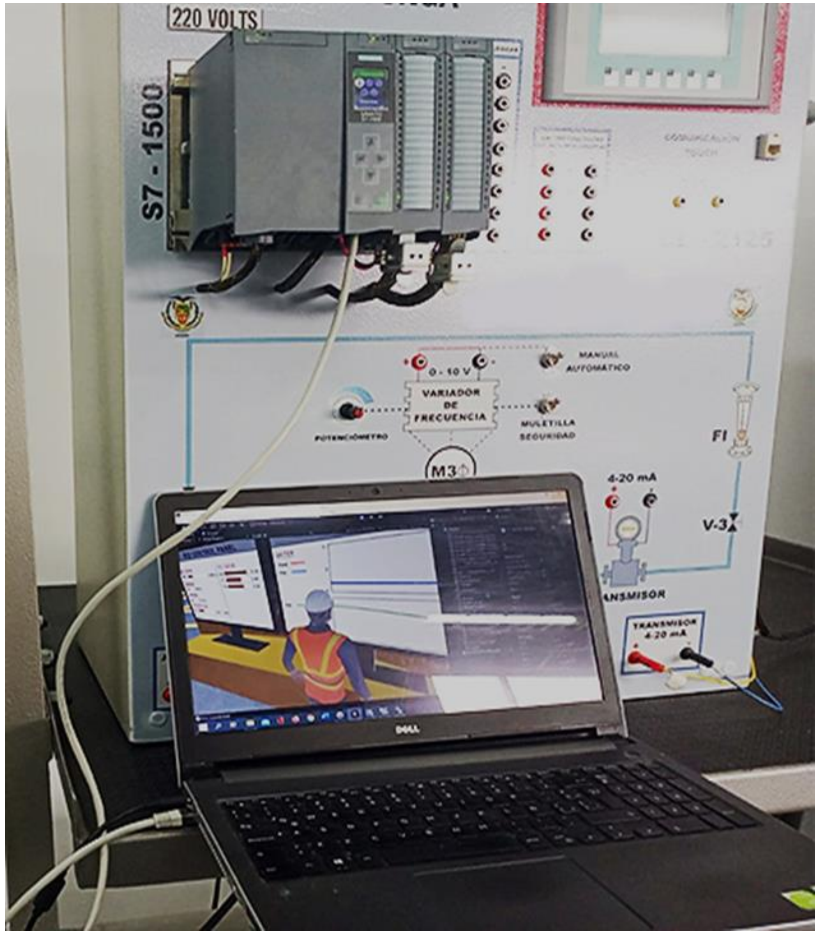
Virtual Environment



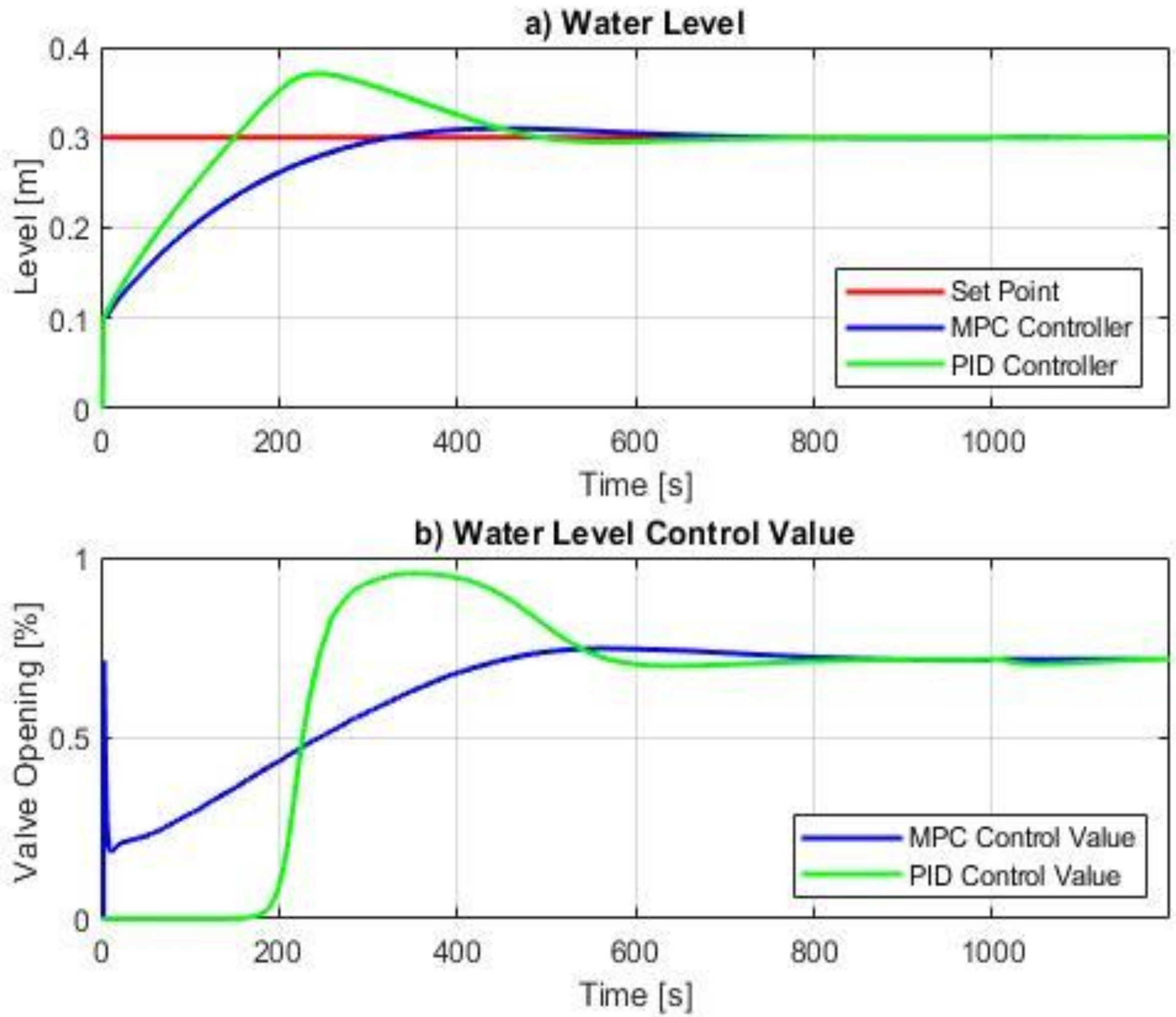
Monitoring and Control Area



HIL Implementation

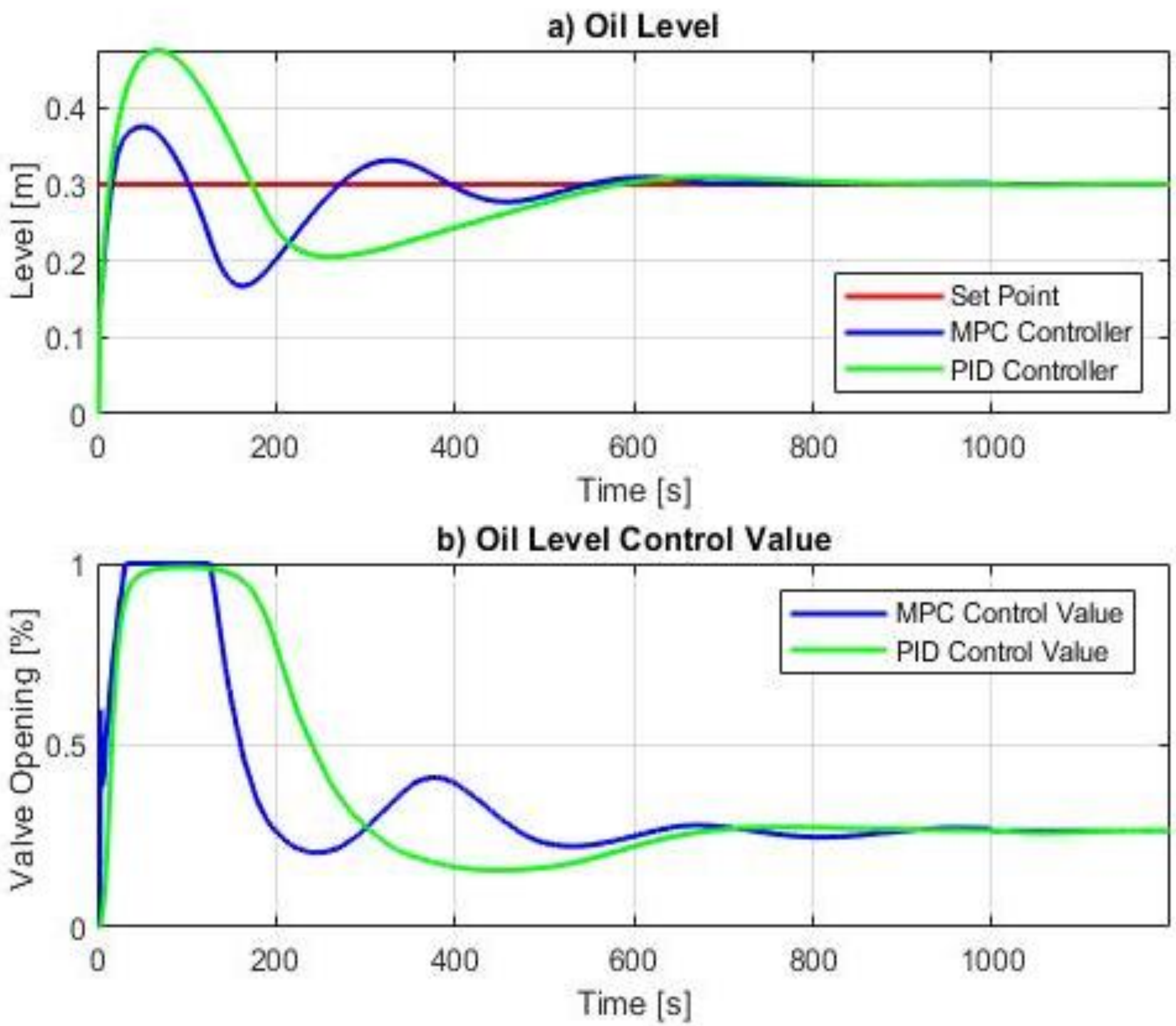


Results



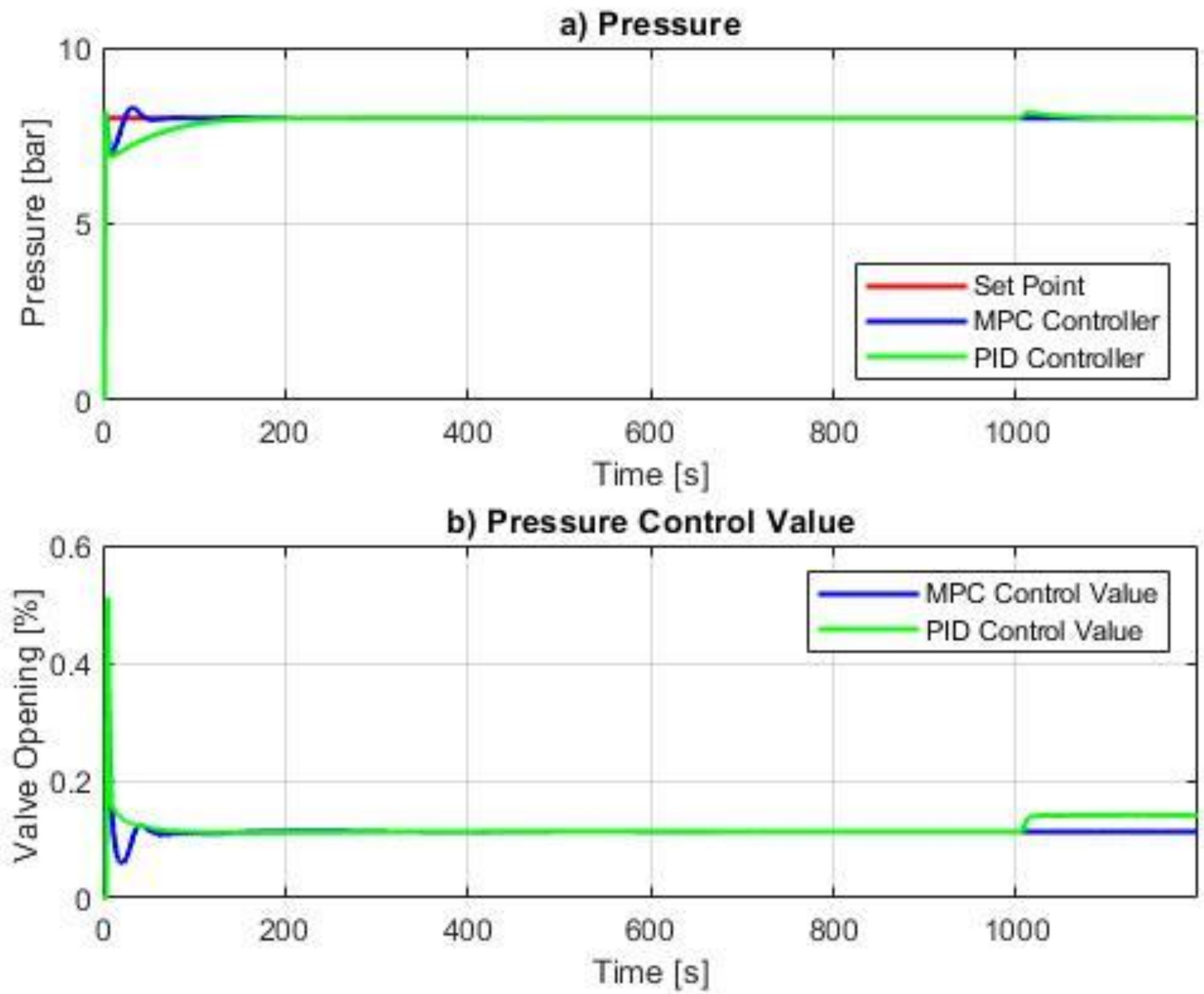
Parameters	PID Controller	MPC Controller
	Water Level	Water Level
Overshoot [%]	*20*	*0*
Settling time [s]	*750*	*625*
Steady-state error [m]	*2.9x10-4*	*1.17x10-5*

Results



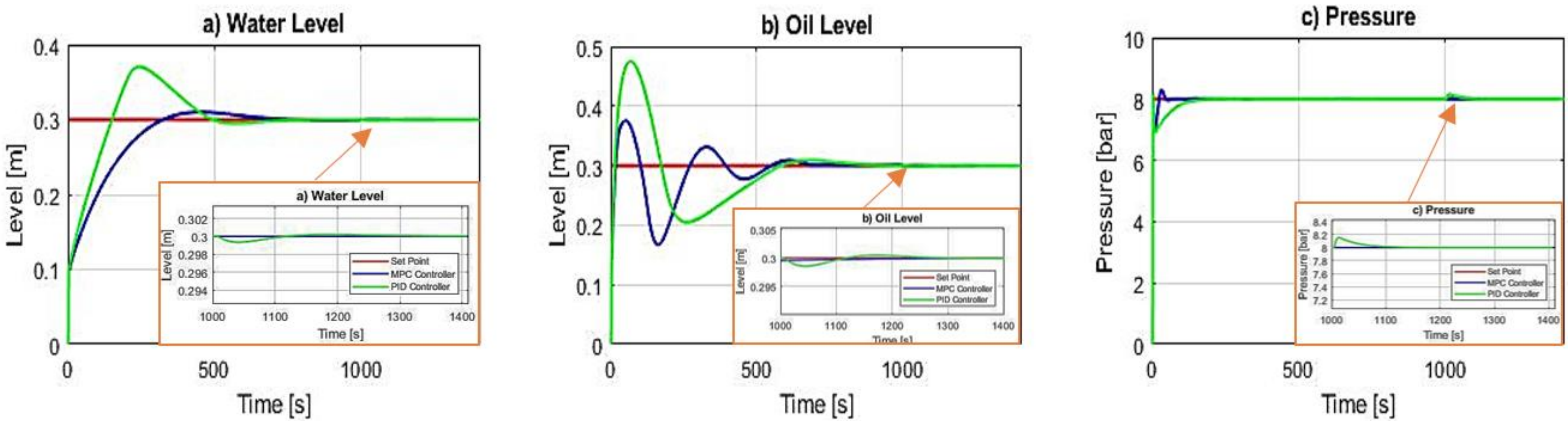
Parameters	PID Controller	MPC Controller
	Oil Level	Oil Level
Overshoot [%]	*56.6*	*16.6*
Settling time [s]	*890*	*675*
Steady-state error [m]	*6.6x10-4*	*2.7x10-4*

Results



Parameters	PID Controller	MPC Controller
	Pressure	Pressure
Overshoot [%]	*1.25*	*3.75*
Settling time [s]	*188*	*55*
Steady-state error [bar]	*3.1x10-3*	*5.92x10-5*

Results


a) Water Level
Level [m]
Time [s]
0.4
0.3
0.2
0.1
0
0
500
1000
a) Water Level
Level [m]
0.302
0.3
0.298
0.296
0.294
1000
1100
1200
1300
1400
Time [s]
Set Point
MPC Controller
PID Controller
b) Oil Level
Level [m]
Time [s]
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
b) Oil Level
Level [m]
0.305
0.3
0.295
1000
1100
1200
1300
1400
Set Point
MPC Controller
PID Controller
c) Pressure
Pressure [bar]
Time [s]
10
8
6
4
2
0
0
500
1000
c) Pressure
Pressure [bar]
8.4
8.2
8
7.8
7.6
7.4
7.2
1000
1100
1200
1300
1400
Time [s]
Set Point
MPC Controller
PID Controller

Conclusions

- The proposed HIL system is flexible enough and allows not only to connect the PLC control device but any other device as it would only change the programming of the control algorithms depending on the language that handles the controller device. Moreover, it is flexible to implement any control algorithm, including advanced controllers.

- The MPC controller has a better performance as it has an average overshoot of 6.78% among the three variables compared to PID controller whose average overshoot is 25.95%. It also has a lower settling time than the traditional controller and a minimum steady-state error. Therefore the MPC controller has a better response in nonlinear and multivariable processes.

- Regarding the control value, it is observed that with the MPC controller, the control valves have a better response because their control value is smoother compared to the control values of the PID controller, which are a little more abrupt. Thus, by implementing the MPC controller, longer life of the actuators can be achieved.

- Regarding the disturbance analysis, it is determined that the MPC controller does not show variations and remains at the set point, which is not the case with the PID controller when the disturbance occurs.