Applied Modeling and Control Techniques for Solar Collector Field Systems

Case study in the SCF Virtual Lab tool

Handbook for experiments

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Summary

Introduction

The SCF (Solar Collector Field) system operates by capturing thermal energy from sunlight to heat a specific HTF (Heat Transfer Fluid) pipeline. Sunlight absorbed by the pipeline transfers heat to the HTF flowing inside, which then carries the thermal energy to a secondary system. The primary, or "hot," circuit contains the SCF components, while the secondary, or "cold," circuit is the load system where thermal energy is delivered. Given the intermittent nature of solar energy, fluctuations in heat supply can occur, especially during cloudy days or at night. To maintain consistent energy availability, an STES (Seasonal Thermal Energy Storage) system can be used to store thermal energy, maximizing solar power utilization when sunlight is accessible. Figure 1 show the basic scheme of the SCF system primary circuit.

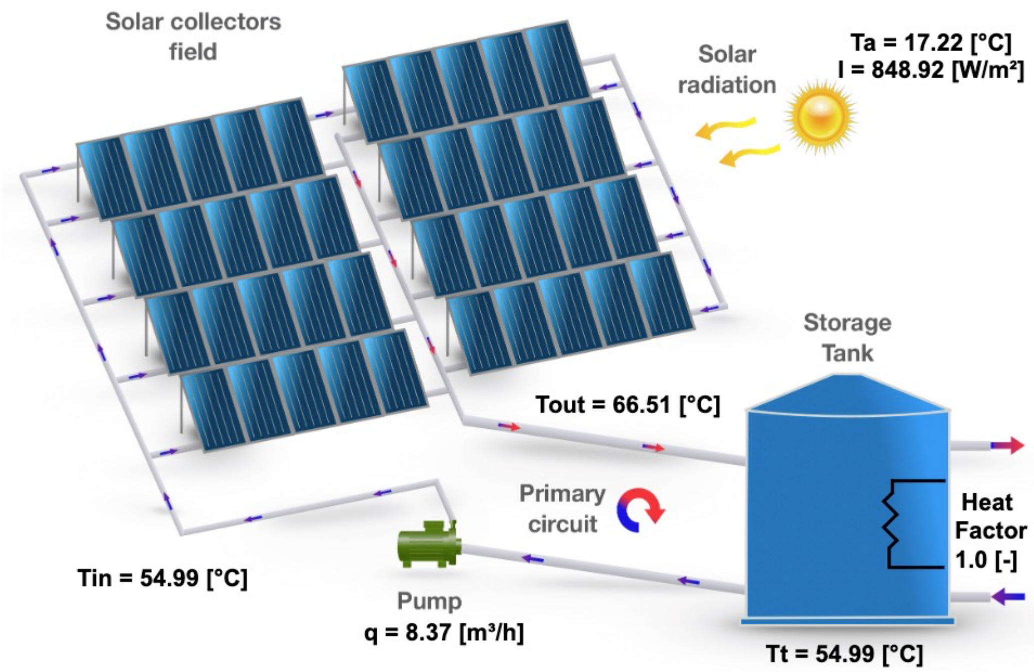


Figure 1 - Primary circuit scheme of a solar collector field system

To improve the efficiency of solar thermal plants, automatic control is essential for managing the HTF outlet temperature in SCFs. It optimizes SCF performance by capturing and transferring maximum solar energy to the load system, enhancing the plant's energy output. Effective control strategies also allow the SCF to handle disturbances, like cloudy weather, and maintain precise temperature control across varying conditions. This prevents overheating or underheating, protecting the equipment and extending its lifespan.

Controlling an SCF system is challenging due to its frequent disturbances and nonlinear behavior. The SCF outlet temperature (T_{sc}) serves as the process variable (PV), while the HTF flow rate (q) is the manipulated variable (MV). However, other non-manipulated inputs, such as ambient temperature (T_a), SCF inlet temperature (T_{in}), and irradiance (I), also influence the system. These external factors frequently disrupt the system, requiring an effective control strategy to offset their effects. Additionally, the outlet temperature sensor’s position introduces a transport delay related to the HTF flow rate, which can affect considerably the process control.

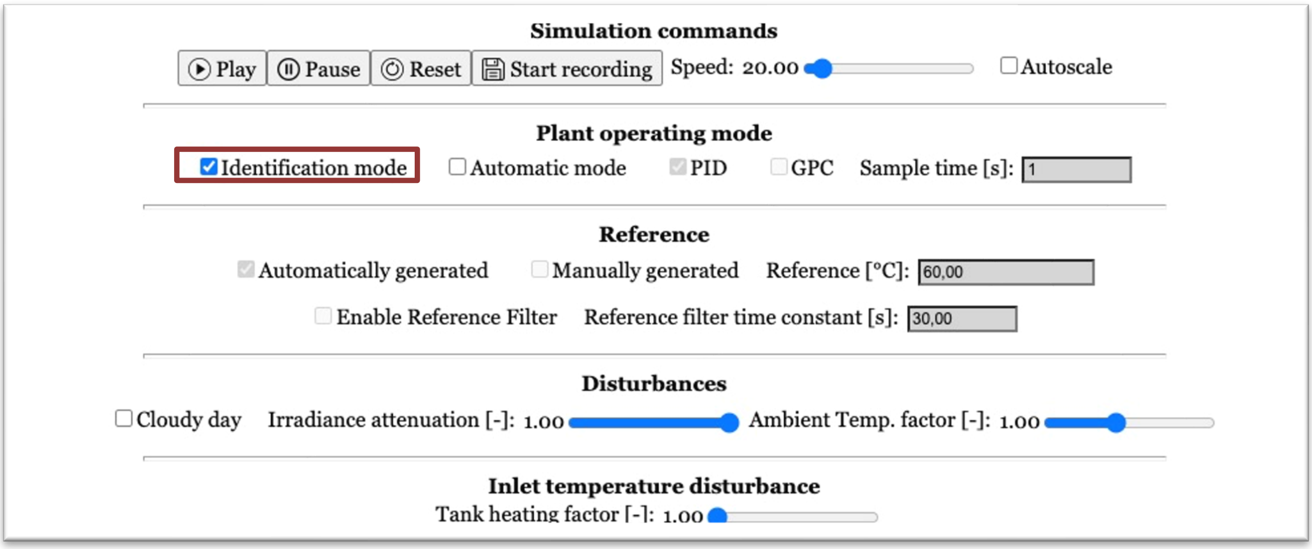
The following activities offer a step-by-step approach to effectively control an SCF. By progressing through each step, you will gain the necessary tools to properly control the system. The SCF Virtual Lab will assist you in the task, emulating an actual solar thermal facility.

Block A.0 – System identification

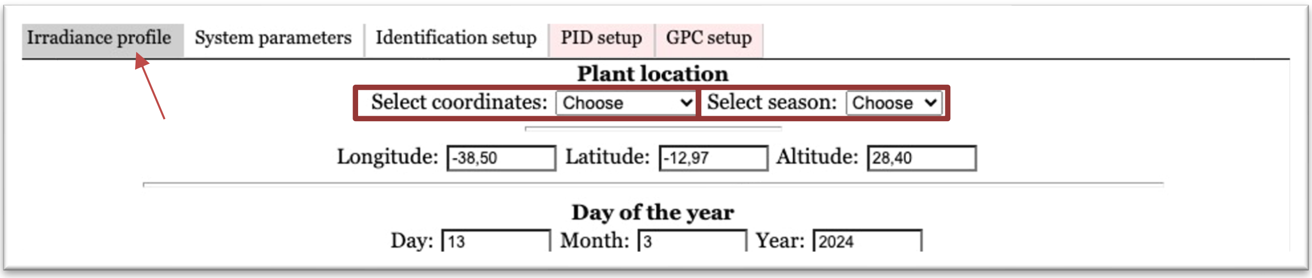
To initiate the SCF Virtual Lab, open your browser (recommended Google Chrome) and access: http://...

SCF Virtual Lab setup – Setup experiment and plant configuration

In the middle panel, keep the **Plant operating mode** in [Identification mode].

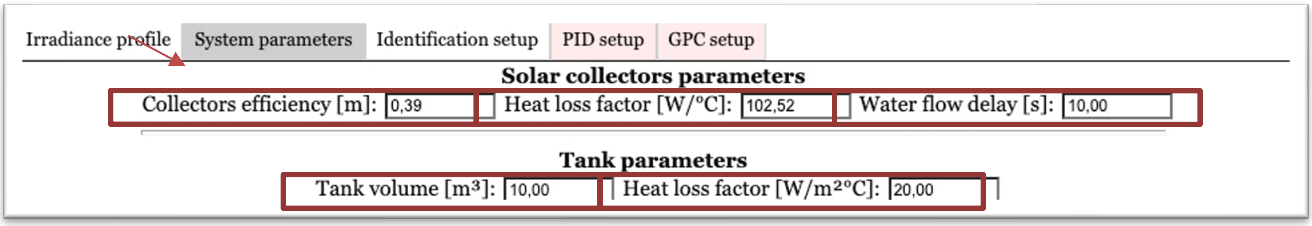


In the bottom panel, choose the first panel **Irradiance profile**. Then, define the Plant location and the year period: **Select coordinates:** [Almería] and **Selected Season:** [Spring]



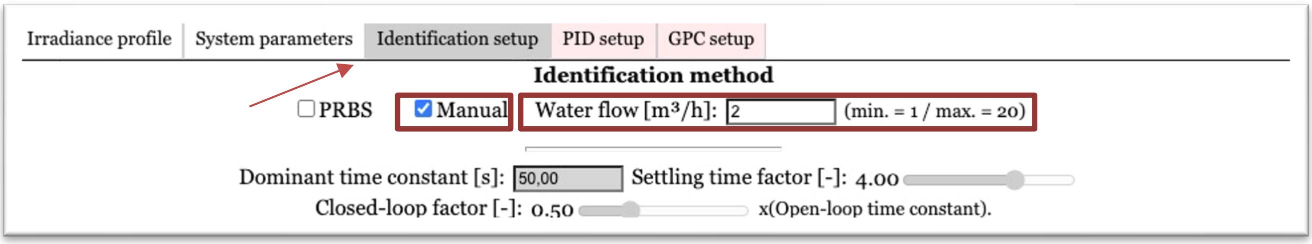
In the bottom panel, choose the second panel **System parameters**. Then, define the **SCF model parameters** and the **Tank parameters**, as defined:

Collectors efficiency: [0.39] , **Heat loss:** [102.52], **Water flow delay:** [10]
Tank volume: [10] , **Heat loss:** [20]

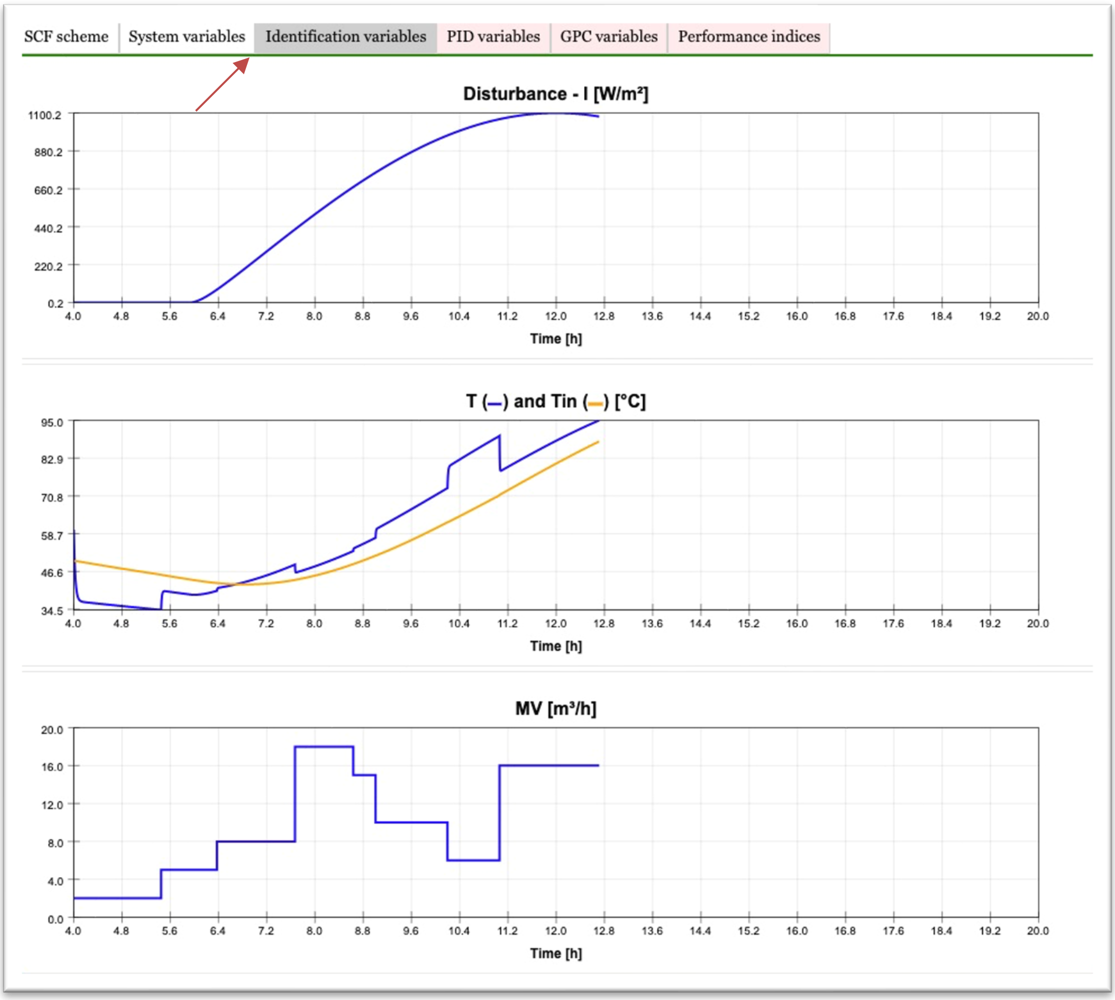


After setup the plant configuration, you are able to start the Identification experiment. Initiate the experiment by first pressing **Start Recording** and then the **Play** button in the middle panel**.**

Go to the **Identification setup** panel and operate manually the HTF flow rate, keeping the selector in **[Manual]** and varying the **[Water flow]** value in the correspondent field.



You can follow the process variables in the top panel **Identification variables.**



By the end of the experiment, save the data by pressing **Stop Recording.**

Block A.0 questions

Q.A0.i) Using the collected data and the concepts worked in class, for each step in the HTF, identify the linear system model in the Laplace domain that relates the HTF and the SCF outlet temperature.

$$G(s) = \frac{T_{sc}(s)}{q(s)}$$

What can you observe from the parameters obtain? Does the parameters are consistent throughout the experiment? What is the relation between the irradiance magnitude and the linear model parameters? Verify the model adjust through quantitative metrics and provide the validation results indicating the model parameters in each HTF flow change.

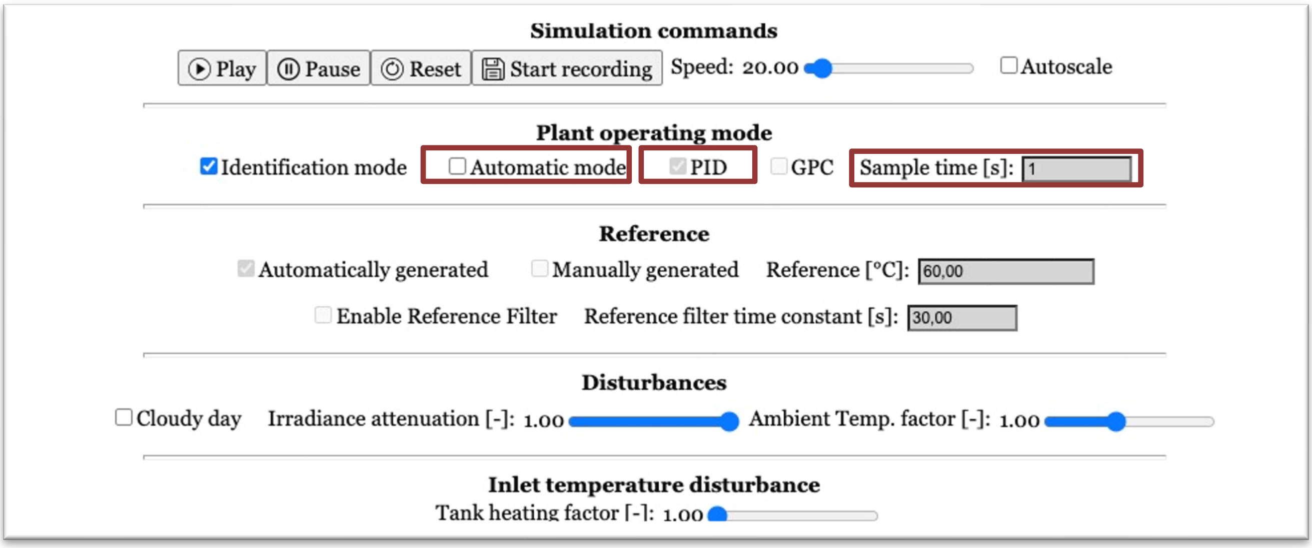
Q.A0.ii) Define the dominant and the faster open-loop time constant.

Block A.1 – PID Controller

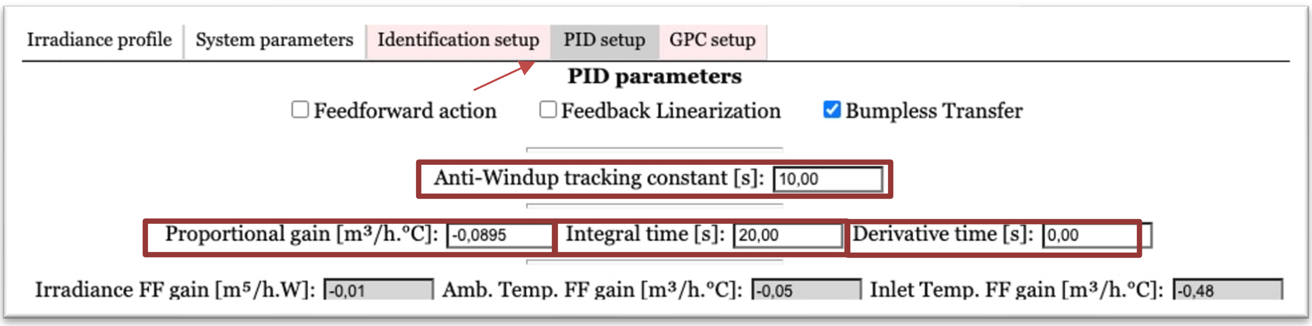
SCF Virtual Lab setup – Testing the PID Controller

Based on the previous experiment, design a proper PID controller using as reference the model validation results. The sample time used to implement the controller is **Ts = 4**. Use the proper tuning methods detailed in class considering the Anti-Windup scheme. Justify your choices.

In the SCF Virtual Lab middle panel, chose the option [Automatic mode] in Plant Operation mode panel. Keep the [PID] selector on and define the corresponding sample time define in question Q.A1.i in the field [Sample time].

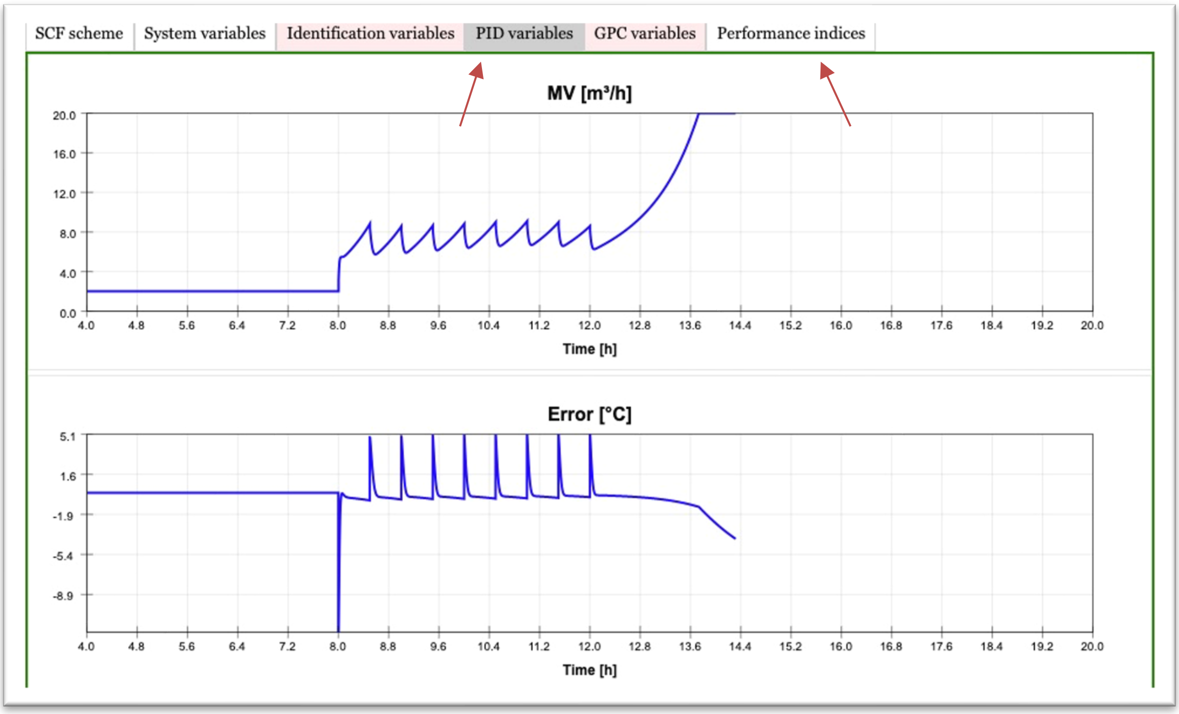


Go to the bottom panel and select **PID Setup** and insert the PID controller parameters, [Proportional gain], [Integral Time], [Derivative Time], and [Tracking time]. Keep the [Feedforward] and the [Feedback Linearization] selectors **unchecked** and [Bumpless Transfer] **checked.**



After setup the PID configuration, start the experiment clicking the **Play** button in the middle panel**.**

You can follow the simulation evolution in the top panel **PID Variables**. At the end of the experiment, check the control performance in the top panel **Performance indices.**



Block A.1. Questions

Q.A1.i) Did the controller obtain an acceptable result? Comment your answer.

Q.A1.ii) What could be done to improve the PID controller performance?

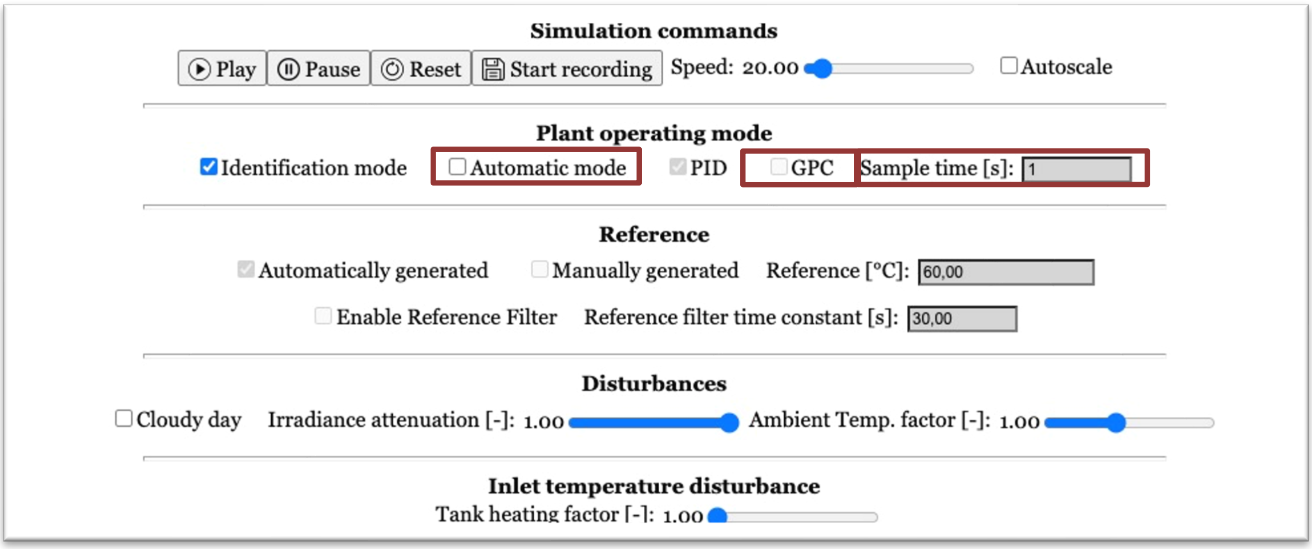
Q.A1.iii) Did the Anti-Windup is well designed? How it can be demonstrated?

Block A.2 – GPC Controller

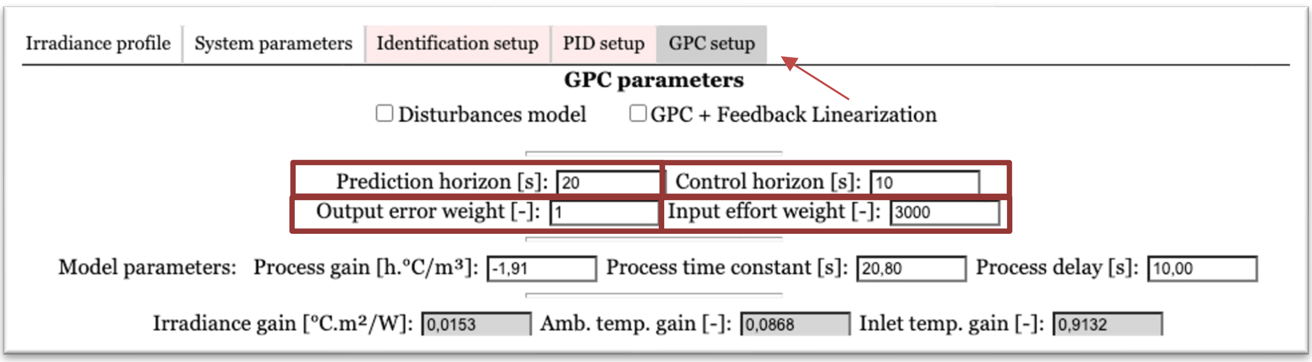
SCF Virtual Lab setup – Testing the GPC Controller

Based on the model identification experiment, design a proper GPC controller using the model validation results. The sample time used to implement the controller is [Ts = 4]. Use adequate methodology to tune the GPC weight matrices and the prediction and control horizons.

In the SCF Virtual Lab middle panel, chose the option [Automatic mode] in Plant Operation mode panel. Keep the [GPC] selector on and define the corresponding sample time define in question Q.A2.i in the field [Sample time].

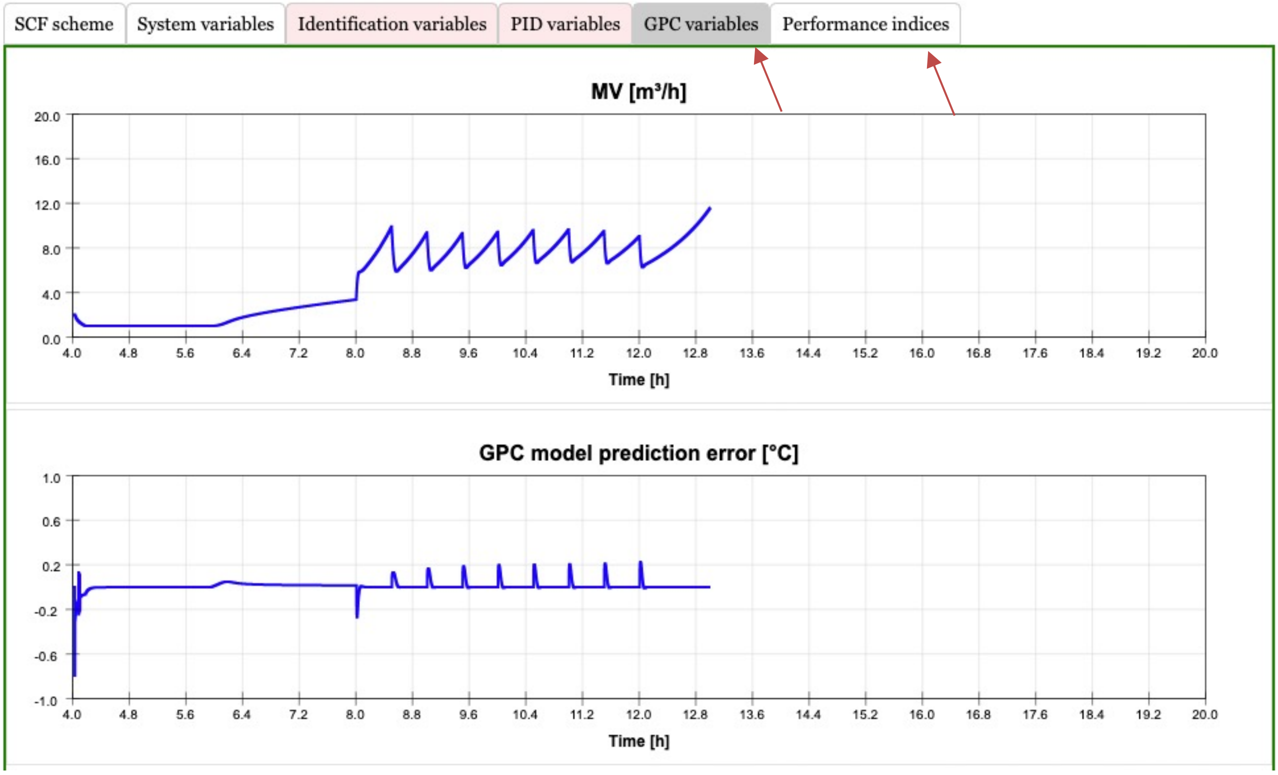


Go to the bottom panel and select **GPC Setup** and insert the GPC controller parameters, [Prediction horizon], [Control horizon], [Output error weight], and [Input effort weight]. Keep the [Disturbance model] and the [Feedback Linearization] selectors **unchecked.**



After setup the PID configuration, start the experiment clicking the **Play** button in the middle panel**.**

You can follow the simulation evolution in the top panel **GPC Variables**. Moreover, you can check the control performance in the top panel **Performance indices.**



Block A.2. Questions

Q.A2.i) Did the controller obtain an acceptable result? Comment your answer.

Q.A2.ii) What could be done to improve the GPC controller performance?

Q.A2.iii) Does the GPC model represents accurately the real plant? Comment your answer

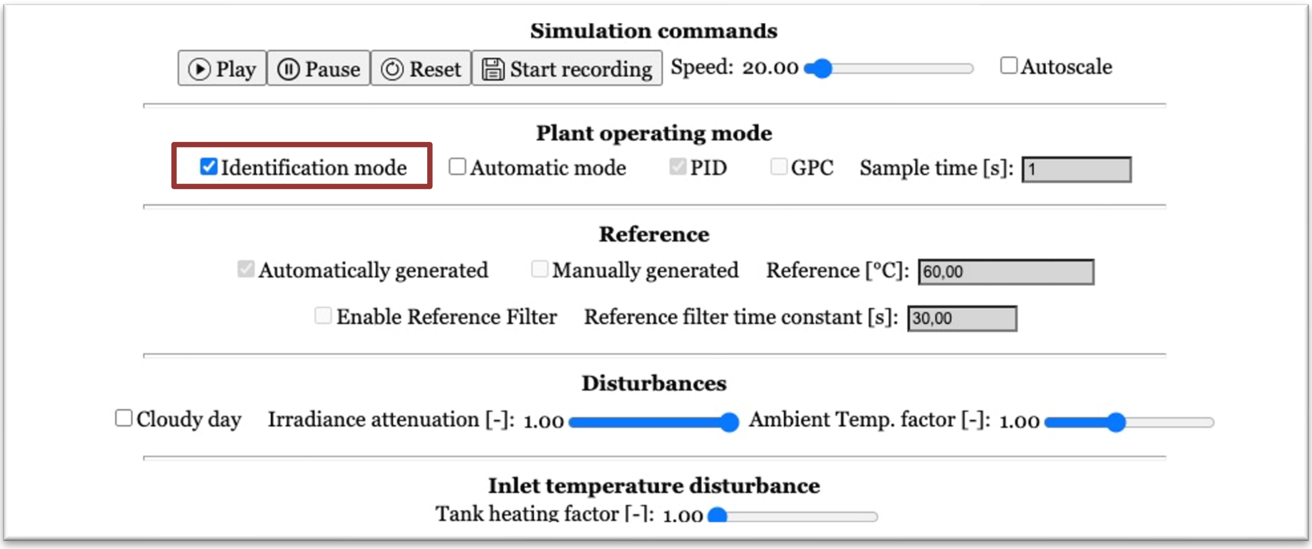
Q.A2.iv) What is the main difference between the GPC and the PID control signals? Why the GPC does not need any Anti-windup scheme?

SCF Virtual Lab setup – Identifying the nonlinear model parameters

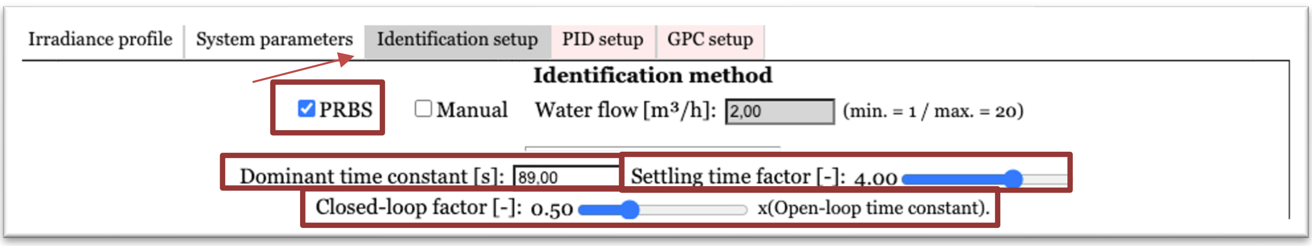
Use the same plant configuration as defined in Block A.0, including plant location, system parameters, and date. Based on the open-loop model information collected earlier, define the parameters for the PRBS (Pseudorandom Binary Sequence) identification stage.

Design the PRBS signal to achieve the desired closed-loop response of the controllers. Additionally, consider the estimated dominant time constant of the system obtained previously.

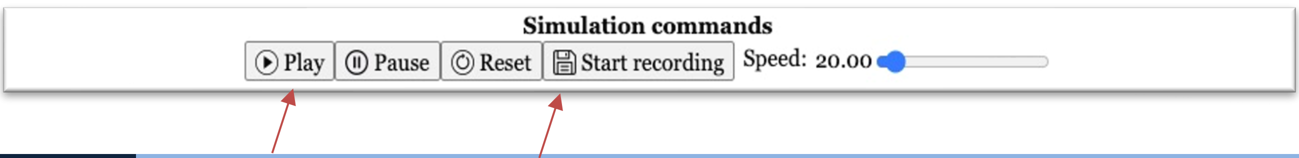
Now, set the PRBS parameters. First, select the Identification mode in the middle panel.



Then, select the PRBS check box and define the corresponding signal parameters, [Dominant time constant], [Settling time factor], and [Closed-loop factor].



After setup the PRBS signal parameters, start the Identification experiment. Initiate the experiment by first pressing **Start Recording** and then the **Play** button in the middle panel.



By the end of the experiment, save the data by pressing **Stop Recording.**

Block B.0. Questions

Q.B0.i) Using the collected data, apply the linear model system identification method to develop a complete model that relates inputs and disturbances to the output. Is this model a good representation of the system? What information can be obtained from the identification method?

Q.B0.ii) Next, apply an identification method discussed in class to estimate the system parameters β and H H based on the nonlinear model, as represented below.

$$\frac{dT_{sc}}{dt} = \frac{\beta}{\rho \cdot C_p \cdot A_{sc}} \cdot I(t) - \frac{H}{\rho \cdot C_p \cdot A_{sc} \cdot L} \cdot \left(\frac{T_{sc}(t) + T_{in}(t)}{2} - T_a(t) \right) - \frac{q(t - t_{dq})}{A_{sc} \cdot c_f} \cdot \frac{T_{sc}(t) - T_{in}(t)}{L},$$

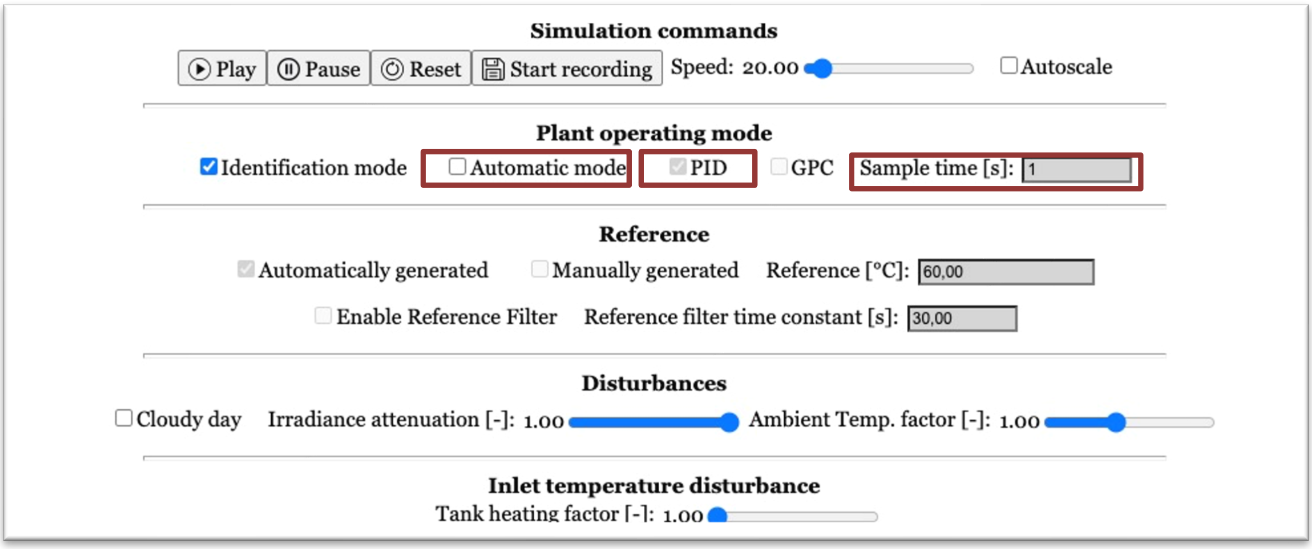
Q.B0.iii) Derive the linearized equation from the previously presented nonlinear model. Define the analytical relationship between the model's gain and time constant with respect to the system's operating point.

Block B.1 – PID + FF controller

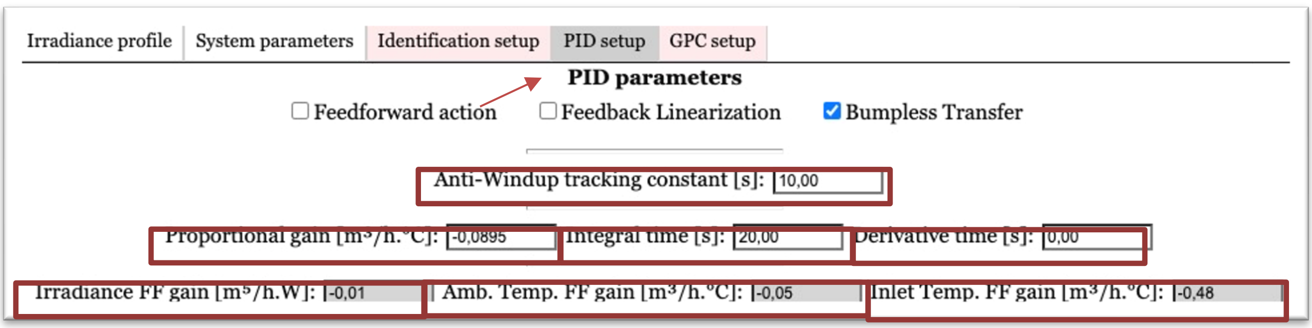
SCF Virtual Lab setup – Testing the PID+FF Controller

Based on the nonlinear model identification experiment, design again a proper PID controller now employing the FF control actions for the measured disturbances. The sample time used to implement the controller is the same as defined in **Block A.1** [Ts = 4]. Use adequate methodology to tune the PID parameters.

In the SCF Virtual Lab middle panel, chose the option [Automatic mode] in Plant Operation mode panel. Keep the [PID] selector on and define the corresponding sample time in the field [Sample time].



Go to the bottom panel and select **PID Setup** and check the [Feedforward action] checkbox. Then, insert the PID controller parameters, [Proportional gain], [Integral Time], [Derivative Time], and [Tracking time] and the computed FF static gains for the disturbances, in the fields [Irradiance FF gain], [Amb. Temp. FF gain], and [Inlet. Temp. FF gain]. Keep the the [Feedback Linearization] selector **unchecked** and [Bumpless Transfer] **checked.**



After setup the PID configuration, start the experiment clicking the **Play** button in the middle panel**.**

You can follow the simulation evolution in the top panel **PID Variables**. At the end of the experiment, check the control performance in the top panel **Performance indices.**

Repeat the same experiment two more times. First consider the cloud day scenario. Set the plant configuration again and check the box [Cloudy day] in the middle panel.

Compare the performance indices of the PID with and without the FF action ([Feedforward action] unchecked).

Block B.1. Questions

Q.B1.i) How does the PID+FF controller performance compare to the standard PID controller in terms of error reduction? Which controller performs better under disturbances?

Q.B1.ii) Analyze the control effort required by both the PID and PID+FF controllers. Did the addition of Feedforward improve efficiency, or did it increase control effort? Comment on the trade-off between error reduction and control effort.

Q.B1.iii) Evaluate the response time of the PID+FF controller in disturbance rejection. Did the Feedforward action lead to faster disturbance compensation compared to the standard PID controller?

Q.B1.iv) Based on the error performance index, did the PID+FF controller meet the acceptable error threshold in the disturbance scenario? If not, what adjustments could further improve the controller?

Q.B1.v) Does the Feedforward action affect the Anti-Windup mechanism's effectiveness? If so, describe how the Anti-Windup is impacted and whether it still functions as intended under disturbances.

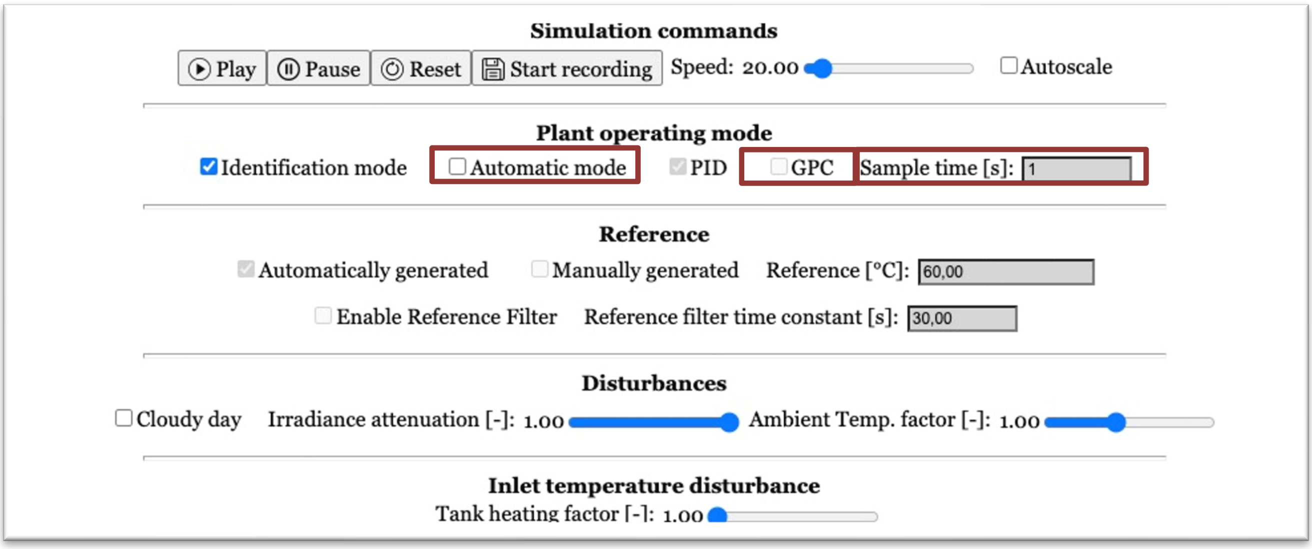
Q.B1.vi) Was there a noticeable impact of Feedforward on steady-state error in the disturbance scenario? Explain if and why the PID+FF controller achieves a lower steady-state error compared to the standard PID.

Block B.2 – GPC + FF controller

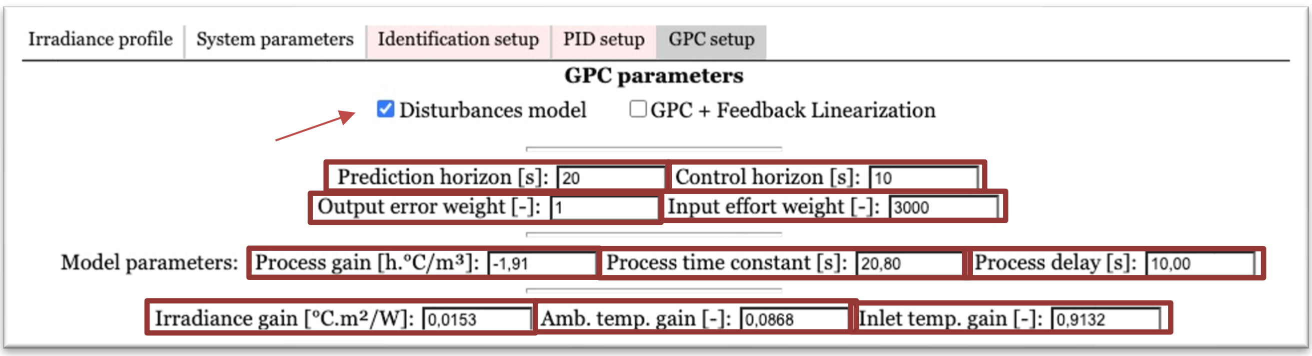
SCF Virtual Lab setup – Testing the GPC+FF Controller

Once again based on the nonlinear model identification experiment, design a proper GPC controller now employing the disturbances model to account for the implicit FF action in the predictive controller. The sample time used to implement the controller is the same as defined in **Block A.2** [Ts = 4]. Use adequate methodology to tune the GPC parameters.

In the SCF Virtual Lab middle panel, chose the option [Automatic mode] in Plant Operation mode panel. Keep the [GPC] selector on and define the corresponding sample time define in question Q.A2.i in the field [Sample time].



Go to the bottom panel and select **GPC Setup** and insert the GPC controller parameters, [Prediction horizon], [Control horizon], [Output error weight], and [Input effort weight]. Moreover, define the proper disturbances model gains, [Irradiance gain], [Amb. temp. gain], and [Inlet. temp. gain]. Keep the [Feedback Linearization] selectors **unchecked.**



After setup the GPC configuration, start the experiment clicking the **Play** button in the middle panel**.** You can follow the simulation evolution in the top panel **GPC Variables**. At the end of the experiment, check the control performance in the top panel **Performance indices.**

Repeat the same experiment two more times. First consider the cloud day scenario. Set the plant configuration again and check the box [Cloudy day] in the middle panel.

Compare the performance indices of the GPC with and without the FF action ([Disturbance model] unchecked).

Block B.2. Questions

Q.B2.i) How does the performance of GPC compare to the PID controller in terms of tracking accuracy and disturbance rejection? Is the GPC controller more effective at handling model uncertainties?

Q.B2.ii) When using GPC+FF, did the Feedforward action improve the controller's performance during disturbances? Evaluate its effect on both error and control effort compared to the standard GPC.

Q.B2.iii) How does model accuracy impact GPC performance? Was the model accurate enough to provide satisfactory control results, or are there areas where inaccuracies affected the GPC's performance (compared to the Block A2) ?

Q.B2.iv) Compare the control effort required by GPC and GPC+FF with that of the PID controller. Did the predictive nature of GPC reduce control effort, or did it require more effort to achieve similar results?

Q.B2.v) Analyze the effect of the prediction horizon on GPC performance. Does increasing the prediction horizon lead to better error reduction, or does it increase control effort unnecessarily?

Q.B1.vi) Discuss the influence of the control horizon on the GPC response. What tuning adjustments could improve the GPC's ability to reject disturbances while minimizing control effort?

Q.B1.vii) Evaluate the impact of the output error weight and input effort weight on GPC performance. How did tuning these weights affect the balance between control precision and effort?

Q.B1.viii) In terms of response time and disturbance handling, does GPC+FF achieve faster stabilization compared to the PID+FF and standard GPC? Explain how the predictive component affects response time under disturbances.

Design the Feedback Linearization scheme

To implement a feedback linearization control scheme in series with a PID or GPC controller, use the nonlinear model provided previously to design a feedback law that cancels out the complete system dynamic, including its nonlinearity.

$$\frac{dT_{sc}}{dt} = \frac{\beta}{\rho \cdot C_p \cdot A_{sc}} \cdot I(t) - \frac{H}{\rho \cdot C_p \cdot A_{sc} \cdot L} \cdot \left(\frac{T_{sc}(t) + T_{in}(t)}{2} - T_a(t) \right) - \frac{q(t - t_{d_q})}{A_{sc} \cdot c_f} \cdot \frac{T_{sc}(t) - T_{in}(t)}{L},$$

As a result, the FBL scheme must be employed in series with the primary controller, PID or GPC. The primary controllers must provide a control signal considering that the system dynamic is now a integrator. The control signal is used as a virtual signal $v(t)$ that linearly affects the output $T_{sc}(t)$.

With the nonlinearities cancelled out, the PID or GPC controller can now be implemented to regulate the simplified system. This approach also simplifies tuning, as the controller no longer has to account for complex, nonlinear behaviors in the system.

Block C.0. Questions

Q.C0.i) In the context of feedback linearization, is integral action necessary in the outer-loop controller to achieve zero steady-state error? Analyze how the addition of integral action affects system performance and stability in the linearized framework.

Q.C0.ii) How sensitive is the feedback linearization scheme to model uncertainties? If there are inaccuracies in the model used for linearization, how would this affect the controller's ability to track setpoints and reject disturbances? Propose potential adjustments to improve robustness against these uncertainties.

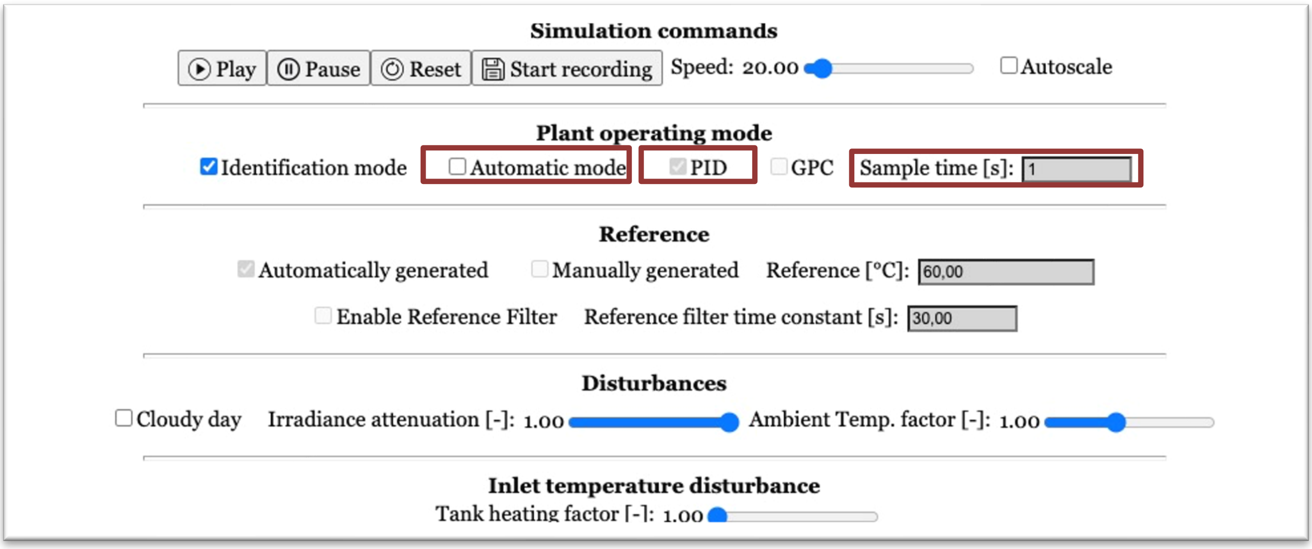
Q.C0.iii) In a disturbance scenario, does feedback linearization alone provide sufficient disturbance rejection, or would adding a feedforward (FF) control enhance performance?

Block C.1 – PID + FBL controller

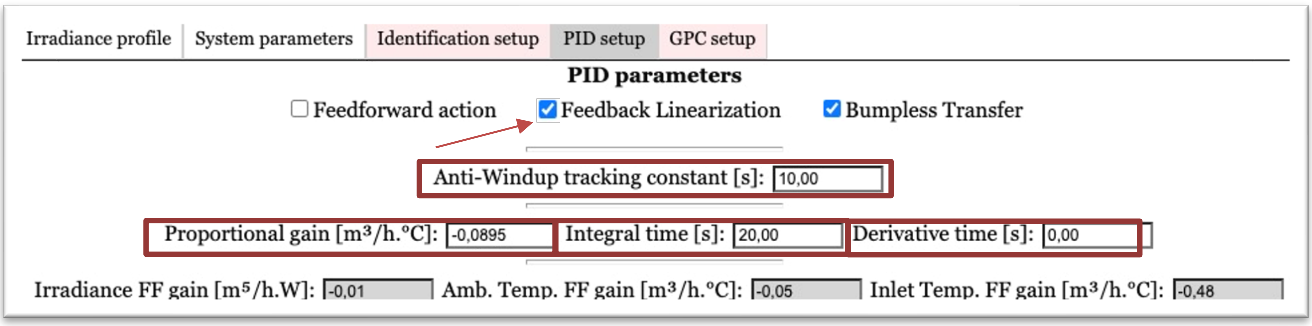
SCF Virtual Lab setup – Testing the PID+FBL Controller

Based on the desgined FBL control scheme, derive a proper PID controller to provide the virtual signal for the FBL block. The sample time used to implement the controller is the same as defined in **Block A.1** [Ts = 4]. Use adequate methodology to tune the PID parameters.

In the SCF Virtual Lab middle panel, chose the option [Automatic mode] in Plant Operation mode panel. Keep the [PID] selector on and define the corresponding sample time in the field [Sample time].



Go to the bottom panel and select **PID Setup** and check the [Feedback Linearization] checkbox. Then, insert the PID controller parameters, [Proportional gain], [Integral Time], [Derivative Time], and [Tracking time].



After setup the PID configuration, start the experiment clicking the **Play** button in the middle panel**.**

You can follow the simulation evolution in the top panel **PID Variables**. At the end of the experiment, check the control performance in the top panel **Performance indices.**

Repeat the same experiment two more times. First consider the cloud day scenario. Set the plant configuration again and check the box [Cloudy day] in the middle panel.

Compare the performance indices of the PID with and without the FBL action. In addition, compare the performances regarding the results obtained with the PID, PID+FF with and without clouds.

Block C.1. Questions

Q.C1.i) Does the PID+FBL scheme improve the system's responsiveness compared to the standard PID and PID+FF controllers? How effective is this approach in reducing nonlinearity-induced errors?

Q.C1.ii) Compare the control performance of PID, PID+FF, and PID+FBL under similar disturbance conditions. Does the PID+FBL scheme achieve better disturbance rejection than PID+FF, and how does each approach can overcome the disturbance effects?

Q.C1.iii) Evaluate the control effort required by each controller setup: PID, PID+FF, and PID+FBL. Does the Feedback Linearization scheme reduce control effort by simplifying the system dynamics, or does it introduce new challenges in terms of control signal requirements?

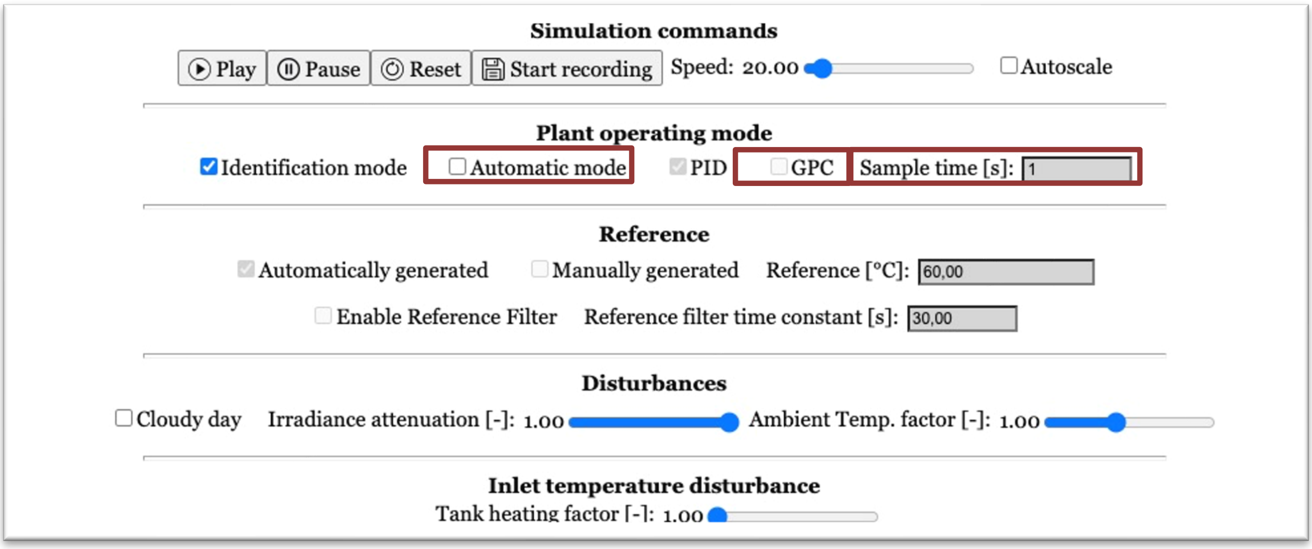
Q.C1.iv) What is the dynamic of the PID virtual signal? Is similar to the PID or PID+FF? Comment your response

Block C.2 – GPC + FBL controller

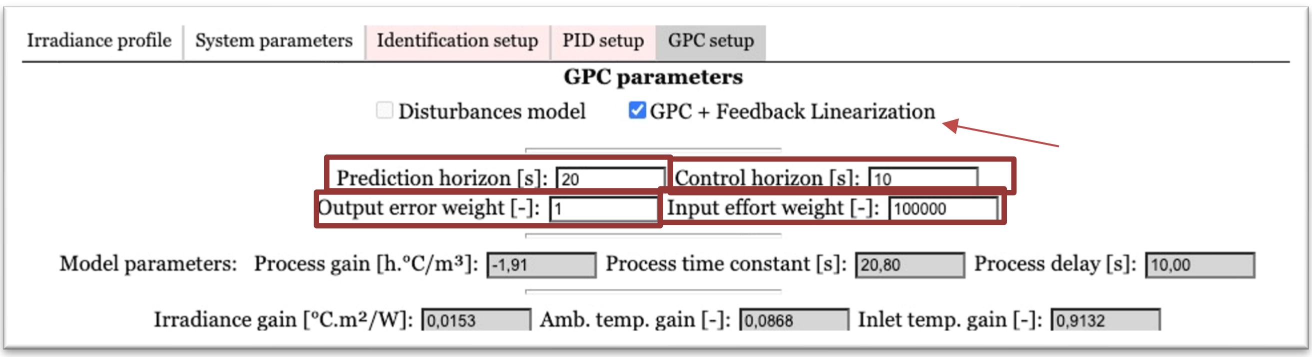
SCF Virtual Lab setup – Testing the GPC+FBL Controller

Design a proper GPC controller now employing the FBLdeveloped in **Block C.0**. The sample time used to implement the controller is the same as defined in **Block A.2** [Ts = 4]. Use adequate methodology to tune the GPC parameters.

In the SCF Virtual Lab middle panel, chose the option [Automatic mode] in Plant Operation mode panel. Keep the [GPC] selector on and define the corresponding sample time define in question Q.A2.i in the field [Sample time].



Go to the bottom panel and select **GPC Setup** and insert the GPC controller parameters, [Prediction horizon], [Control horizon], [Output error weight], and [Input effort weight].



After setup the GPC configuration, start the experiment clicking the **Play** button in the middle panel**.** You can follow the simulation evolution in the top panel **GPC Variables**. At the end of the experiment, check the control performance in the top panel **Performance indices.**

Repeat the same experiment two more times. First consider the cloud day scenario. Set the plant configuration again and check the box [Cloudy day] in the middle panel.

Compare the performance indices of the GPC with and without the FBL and with the FF action.

Block C.2. Questions

Q.C2.i) How does the GPC+FBL scheme compare to GPC alone in terms of tracking accuracy and disturbance rejection? Does Feedback Linearization improve GPC's performance in managing system nonlinearities?

Q.C2.ii) Evaluate the control effort required by the GPC+FBL controller compared to standard GPC. Does the Feedback Linearization reduce the overall control effort by simplifying system dynamics, or does it increase complexity in terms of tuning or computational demand?

Q.C2.iii) When using Feedback Linearization in conjunction with GPC, how should the force matrix in the GPC output model prediction? Explain how the choice of the FBL scheme facilitates the GPCcontrol design.

Appendix – SCF Virtual Lab variables and description

Process variables:

$I(t)$	Global irradiance	[W/m^2]
$T_{sc}(t)$	SCF outlet temperature	[ºC]
$T_{in}(t)$	SCF inlet temperature	[ºC]
$T_t(t)$	Tanque temperature	[ºC]
$q(t)$	HTF water flow rate	[m^3/h]
$T_a(t)$	Ambient temperature	[ºC]

Nonlinear model parameters:

β	Irradiance efficiency and conversion factor related to the dimension of the collectors	- [m]
H	global heat losses coefficient per equivalent tube length (L)	- [W/ºC]
A_{sc}	Collectors pipe cross-section area	1.13x10^{-4} [m^2]
C_p	Specific heat capacity of the water	4186 [J/kgºC]
ρ	Water density	972 [kg/m^3]
L	Equivalent absorber tube length	46.6 [m]
c_f	Conversion factor	36000 [-]

Control variables:

T_s	Sample time	[s]
PV	Process variable ($T_{sc}(t)$)	[ºC]
SP	Set-point	[ºC]
MV	Manipulated variable (q(t))	[m^3/h]
PID	PID control signal (from stationary point)	[m^3/h]
PID+FBL	Virtual PID control signal for the FBL block	[ºC/s]
GPC	GPC control signal	[m^3/h]
GPC+FBL	Virtual GPC signal for the FBL block	[ºC/s]

PID parameters:

K_p	Proportional gain	[m^3/h.ºC]
T_i	Integral time	[s]
T_d	Derivative time	[s]
T_r	Anti-windup tracking constant	[s]
FF_I	Feedforward gain for the irradiance	[m^5/h.W]
FF_{Ta}	Feedforward gain for the ambient temperature	[m^3/h.ºC]
FF_{Tin}	Feedforward gain for the inlet temperature	[m^3/h.ºC]

GPC parameters:

N_p	Prediction horizon	[s]
N_c	Control horizon	[s]
Q	Output error weight	[-]
R	Input effort weight	[-]
K	Process model gain	[h.°C / m^3]
τ	Process model time constant	[s]
d_q	Process model delay related to the input (q(t))	[s]
K_I	Irradiance model gain	[°C m^{2}/W]
K_{Ta}	Ambient temperature model gain	[-]
K_{Tin}	Inlet temperature model gain	[-]

Simulation commands:

Play	Play – Start the simulation
Pause	Pause – Pause the simulation
Reset	Reset – Restart the simulation from beginning
Start recording	Start recording – Start recording data
Stop recording	Stop recording – Stop recording data and save them in the .txt file
Speed: 20.00	Define the simulation speed (1x – 300x)
Autoscale	Autoscale – Readjust the PID and GPC graphics for zooming in.

Plant operating mode:

Identification mode	Manual operation of the system – Enable manipulating the HTF water flow rate manually of apply the PRBS method. No control works. Once the simulation starts, this selector can be switched on/off.
Automatic mode	Automatic operation of the system – Enable manipulating the controllers PID and GPC selectors. Once the simulation starts, this selector can be switched on/off.
PID	PID control enable – When the automatic mode is checked, the PID selector can be checked on/off. It will control the plant with the PID or the PID+FLB controller.

This selector switch status with the GPC selector.

Once the simulation starts, this selector can NOT be switched on/off.

☐ GPC	GPC control enable – When the automatic mode is checked, the GPC selector can be checked on/off. It will control the plant with the GPC or the GPC+FLB controller. This selector switch status with the PID selector. Once the simulation starts, this selector can NOT be switched on/off.
Sample time [s]: [1]	Controller sample time – Define the sample time in which the PID or GPC controllers will be implemented. Once the simulation starts, this selector can NOT be switched on/off.

Reference:

Enabled when automatic mode is on.

☑ Automatically generated	Automatically generated – Automatic step changes in the SP. The steps considering the maximum irradiance level and the reachable temperature. NOTE: The imposed reference cannot be reachable depending on the process parameters and plant location the user defines. Once the simulation starts, this selector can be switched on/off.
☐ Manually generated	Manually generated – Enable the user defines the desired SP. Once the simulation starts, this selector can be switched on/off.
Reference [°C]: [60,00]	Reference – Define the desired reference for the $T_{sc}(t)$.
☐ Enable Reference Filter	Enable Reference Filter - Employ reference first order filter for the SP changes. Once the simulation starts, this selector can be switched on/off.
Reference filter time constant [s]: [30,00]	Reference filter time constant – Define the SP first order filter time constant.

Disturbances:

☐ Cloudy day

Cloudy day – Impose artificially generated variations in the global irradiance to emulate passing clouds and thus, global irradiance attenuations.
Once the simulation starts, this selector can be switched on/off.

Irradiance attenuation [-]: 1.00

Irradiance attenuation – Impose an artificial attenuation in the global irradiance, emulating dense clouds.
Once the simulation starts, this slider can be changed.

Amb. Temp. factor [-]: 1.00

Ambient Temp. factor. – It affects the intensity in which the ambient temperature varies according to the irradiance levels.
Once the simulation starts, this slider can be changed.

Tank heating factor [-]: 1.00

Tanking heating factor – Emulate a heating dynamic in the STES due to the insertion of an electric resistance. This factor increases the tank temperature.
Once the simulation starts, this slider can be changed.

Irradiance profile:

Select coordinates: Choose

Select coordinates – Choose a predefined city for the plant coordinates. If you select [Choose], the fields [Latitude], [Longitude], and [Altitude] are enabled to be changed. Otherwise, predefined cities are available: Almería, Rio de Janeiro, New York, Oslo, Tokyo, El Cairo, Quito, Sydney.
Once the simulation starts, this selector can be changed.

Select season: Choose

Select season – Choose a desired season to define the day of the year. If you select [Choose], the fields [Day], [Month] and [Year] are enabled to be changed. Otherwise, predefined season are available: Summer, Spring, Winter, Autumn.
Once the simulation starts, this selector can be changed.

Longitude: -38,50

Longitude – Define the longitude coordinate for the plant location.
Once the simulation starts, this field can be changed.

Latitude: -12,97

Latitude – Define the latitude coordinate for the plant location.
Once the simulation starts, this field can be changed.

Altitude: 28,40

Altitude – Define the altitude for the plant location.
Once the simulation starts, this field can be changed.

Day: 13
Month: 3
Year: 2024

Day, Month and Year – Define the date in which you want to simulate the irradiance profile in the specified plant location.
Once the simulation starts, this field can be changed.

System parameters:

Collectors efficiency [m]: 0,39

Collectors efficiency – Define the nonlinear model parameter for the collectors' efficiency.
Once the simulation starts, this selector can NOT be changed.

Heat loss factor [W/°C]: 102,52

Heat loss – Define the nonlinear model parameter for the collectors' heat loss to the ambient.
Once the simulation starts, this selector can NOT be changed.

Tank volume [m³]: 10,00

Tank volume – Define the STES volume.
Once the simulation starts, this field can NOT be changed.

Heat loss factor [W/m²°C]: 20,00

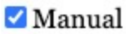
Heat loss factor – Define the STES heat loss to the ambient.
Once the simulation starts, this field can NOT be changed.

Identification method:
Enabled when Identification mode is on.

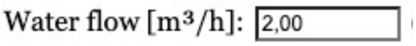
☐ PRBS

PRBS – Pseudo-random Binary Signal – Implement the PRBS signal in the HTF flow rate. Enable the corresponding fields [Dominant time constant], [Settling time factor], and

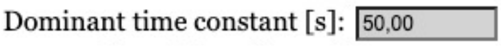
[Closed-loop factor]. This check box switches status with the [Manual] check box
Once the simulation starts, this field can be changed.



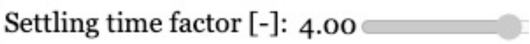
Manual – Enable change the HTF flow rate manually.
Once the simulation starts, this selector can be changed.



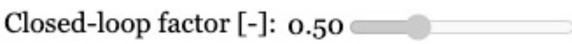
Water flow rate – Define manually the water flow rate.
Once the simulation starts, this selector can be changed.



Dominant time constant – Define dominant time const of the open-loop system model. This value is used to generate the PRBS signal
Once the simulation starts, this field can be changed.

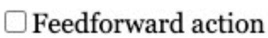


Settling time factor – Factor to define the time required for the response curve to reach and stay within a range of stationary. Define the desired factor to the system achieve the settling time when generating the PRBS. (ex: $\tau_s \approx 4.\tau$).
Once the simulation starts, this field can NOT be changed.



Closed-loop factor – Define the closed-loop time constant regarding the open-loop time constant. (ex: $\tau_{cl} \approx 0.50.\tau$).
Once the simulation starts, this field can NOT be changed.

PID setup:
Enabled when automatic mode and PID is on.



Feedforward action – Activate the static Feedforward action with the PID feedback controller. Enable the fields [Irradiance FF gain], [Amb. Temp. FF gain], and [Inlet Temp. FF gain].
Once the simulation starts, this field can NOT be changed.

☐ Feedback Linearization	Feedback Linearization – Apply the FBL control scheme with the PID controller. Disable the the fields [Irradiance FF gain], [Amb. Temp. FF gain], and [Inlet Temp. FF gain]. Once the simulation starts, this selector can NOT be changed.
☑ Bumpless Transfer	Bumpless transfer – Apply the Bumpless transfer scheme, when changing from Identification Mode to Automatic Mode. Once the simulation starts, this selector can be changed.
Anti-Windup tracking constant [s]: 10,00	Anti-Windup Tracking Constant: Input field to specify the anti-windup tracking constant for the PID controller in seconds. Once the simulation starts, this field can NOT be changed.
Proportional gain [m³/h.°C]: -0,0895	Proportional Gain: Field for setting the proportional gain of the PID controller. Once the simulation starts, this field can NOT be changed.
Integral time [s]: 20,00	Integral Time: Field to specify the integral time of the PID controller. Once the simulation starts, this field can NOT be changed.
Derivative time [s]: 0,00	Derivative Time: Field to input the derivative time of the PID controller. The Derivative action is implemented with a first of filter with a time constant 1/N, for N = 10. Once the simulation starts, this field can NOT be changed.
Irradiance FF gain [m⁵/h.W]: -0,01	Irradiance FF Gain: Field to set the feedforward gain based on irradiance effect. Only enable with the FF action. Once the simulation starts, this field can NOT be changed.
Amb. Temp. FF gain [m³/h.°C]: -0,05	Ambient Temperature FF Gain: Field for inputting the feedforward gain based on ambient temperature effect. Only enable with the FF action.

Once the simulation starts, this field can NOT be changed.

Inlet Temp. FF gain [m³/h.°C]: -0,48

Inlet Temperature FF Gain [m³/h·°C]: Field to set the feedforward gain based on inlet temperature effect.
Only enable with the FF action.
Once the simulation starts, this field can NOT be changed.

GPC setup:
Enabled when automatic mode and GPC is on.

☐ Disturbances model

Disturbances Model: When selected, enables the disturbances model in the GPC controller.
Once the simulation starts, this selector can NOT be changed.

☐ GPC + Feedback Linearization

GPC + Feedback Linearization Checkbox: Activates the GPC scheme with Feedback Linearization. It disables the fields [Irradiance gain], [Amb. Temp. gain], and [Inlet Temp. gain], as well as the [Disturbances Model] checkbox.

Prediction horizon [s]: 20

Prediction Horizon: Field to set the prediction horizon for the GPC model prediction.
Once the simulation starts, this selector can NOT be changed.

Control horizon [s]: 10

Control Horizon: Field to specify the control horizon of how far into the future the GPC controller considers control moves.
Once the simulation starts, this selector can NOT be changed.

Output error weight [-]: 1

Output error weight: Define the weight given to the output error in the GPC control optimization.
Once the simulation starts, this selector can NOT be changed.

Input effort weight [-]: 3000

Input effort weight: Set the weight on input effort in the optimization used to penalize control actions increments.
Once the simulation starts, this selector can NOT be changed.

Process gain [h.°C/m³]: -1,91

Process gain [h·°C/m³]: Define the model gain used in the GPC model prediction.
Once the simulation starts, this selector can NOT be changed.

Process time constant [s]: 20,80

Process time constant: Field for setting the model time constant in seconds used in the GPC output prediction.
Once the simulation starts, this selector can NOT be changed.

Process delay [s]: 10,00

Process delay: Field to specify the process model for the GPC output prediction.
Once the simulation starts, this selector can be changed.

Irradiance gain [°C.m²/W]: 0,0153

Irradiance Gain: Field to set the gain related to irradiance disturbance.
Once the simulation starts, this selector can NOT be changed.

Amb. temp. gain [-]: 0,0868

Ambient temperature gain [-]: Field to set the gain related to ambient temperature disturbance.
Once the simulation starts, this selector can NOT be changed.

Inlet temp. gain [-]: 0,9132

Inlet temperature gain [-]: Field to set the gain related to inlet temperature disturbance.
Once the simulation starts, this selector can NOT be changed.