Group 11
CH-330 (Process Control)
Dept. of Chemical Engg

Type 1 Diabetes
(Drug Delivery)

Presented by :
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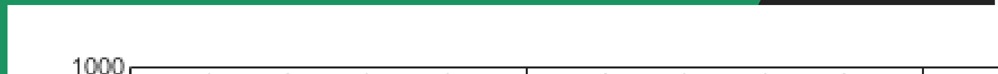


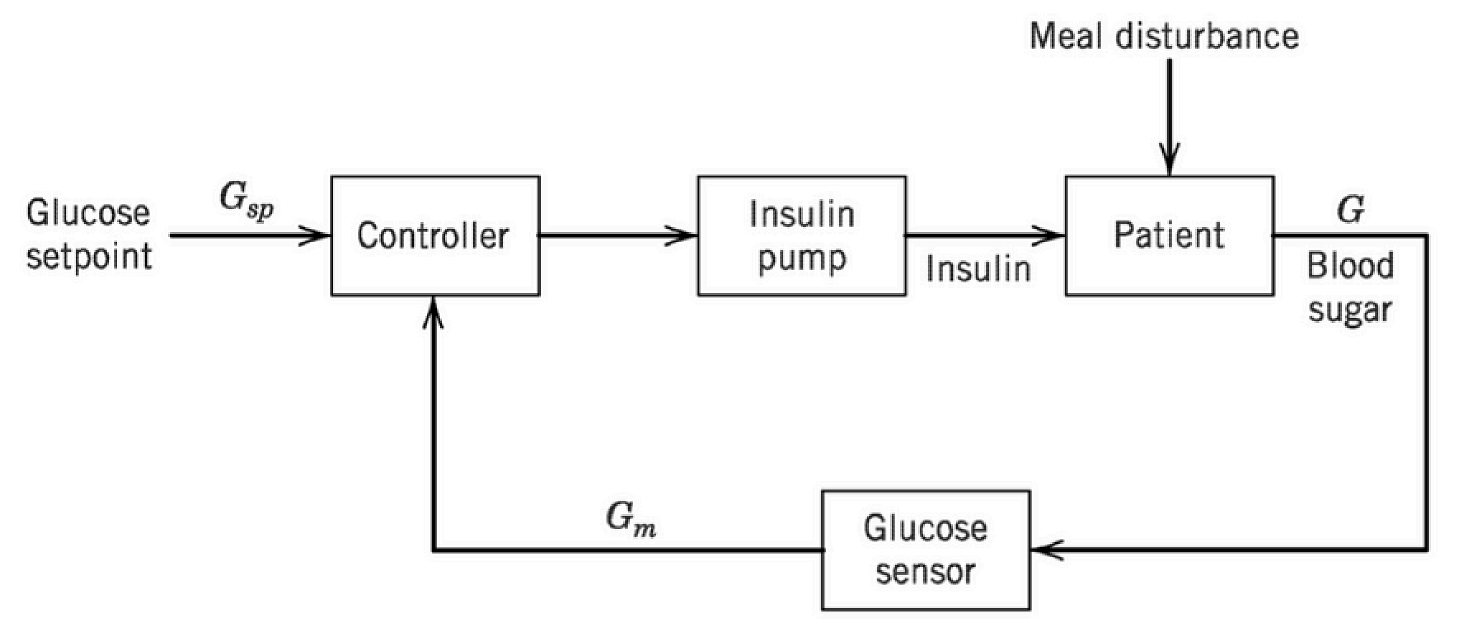
System Discription

- A patient with Type 1 diabetes needs an automated scheme to maintain her glucose within an acceptable range, . A simple model of her blood glucose level is given by

$$\frac{dG}{dt} = -p_1 G - X(G + G_{basal}) + D$$

$$\frac{dX}{dt} = -p_2 X + p_3 I$$

$$\frac{dI}{dt} = -n(I + I_{Basal}) + \frac{U}{V_1}$$



- **G** : Glucose concentration (deviation) in the blood (mg/dL)
- **X** : Insulin concentration (deviation) at the active site (mU/L)
- **I** : Blood insulin concentration

Model parameters

- Controlled Variables (CV) : Glucose concentration (G) in the blood (mg/dL)
- Manipulated variable (MV) : Insulin flow rate (U) in mU/min
- Disturbance Variables (DV) : Glucose intake rate (D) (mg/dL-min)

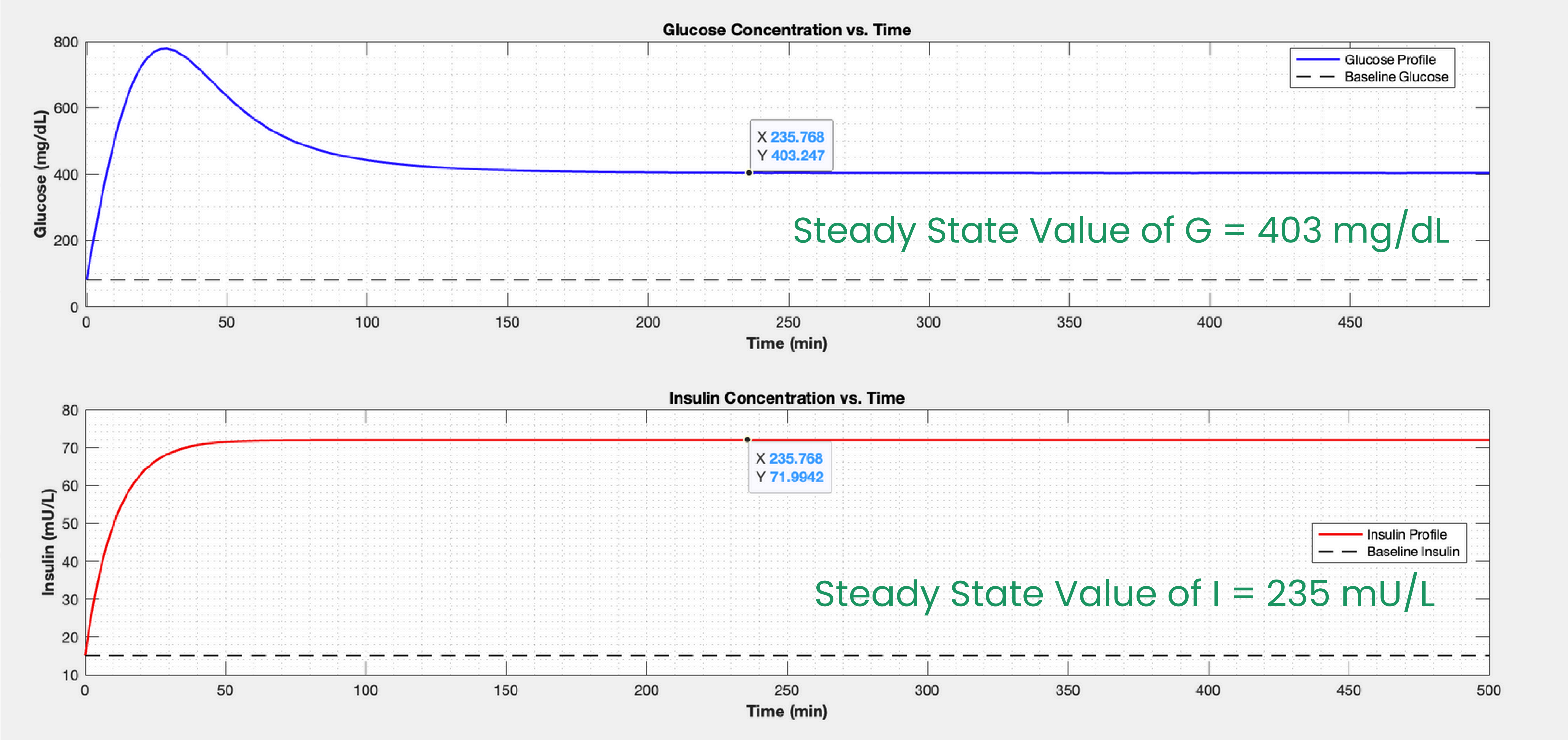
Parameters	Symbols	Units	Briefs
Rate constant 1	p1	0.028735 min−1	Rate at which glucose decreases (independent of insulin).
Rate constant 2	p2	0.028344 min−1	Rate at which insulin at the active site decreases.
Rate constant 3	p3	0.00005035	Conversion rate of blood insulin into active insulin.
Insulin decay rate	n	0.0926 min−1	Rate of blood insulin decay.
Volume of plasma	V1	12 L	Distribution volume of blood insulin.
Basal glucose	Gbasal	81 mg/dL	Baseline glucose level in the blood.
Basal insulin	Ibasal	15 mU/L	Baseline insulin level in the blood.

Steady state identification

Initial Conditions

State Variable	Symbol	Initial Value	Description
Glucose deviation	G(0)	0.1 mg/dL	Initial deviation from the basal glucose level.
Active insulin deviation	X(0)	0.1	Initial deviation of insulin at the active site.
Blood insulin deviation	I(0)	0.1 mU/L	Initial deviation from the basal blood insulin level.
Initial disturbance	D	50 mg/dL	Initial disturbance magnitude in glucose.
Manipulated input	U	50 mU/min	Rate of insulin injection (manipulated variable).

Steady state identification



Steady State Value of G = 403 mg/dL

Steady State Value of I = 235 mU/L

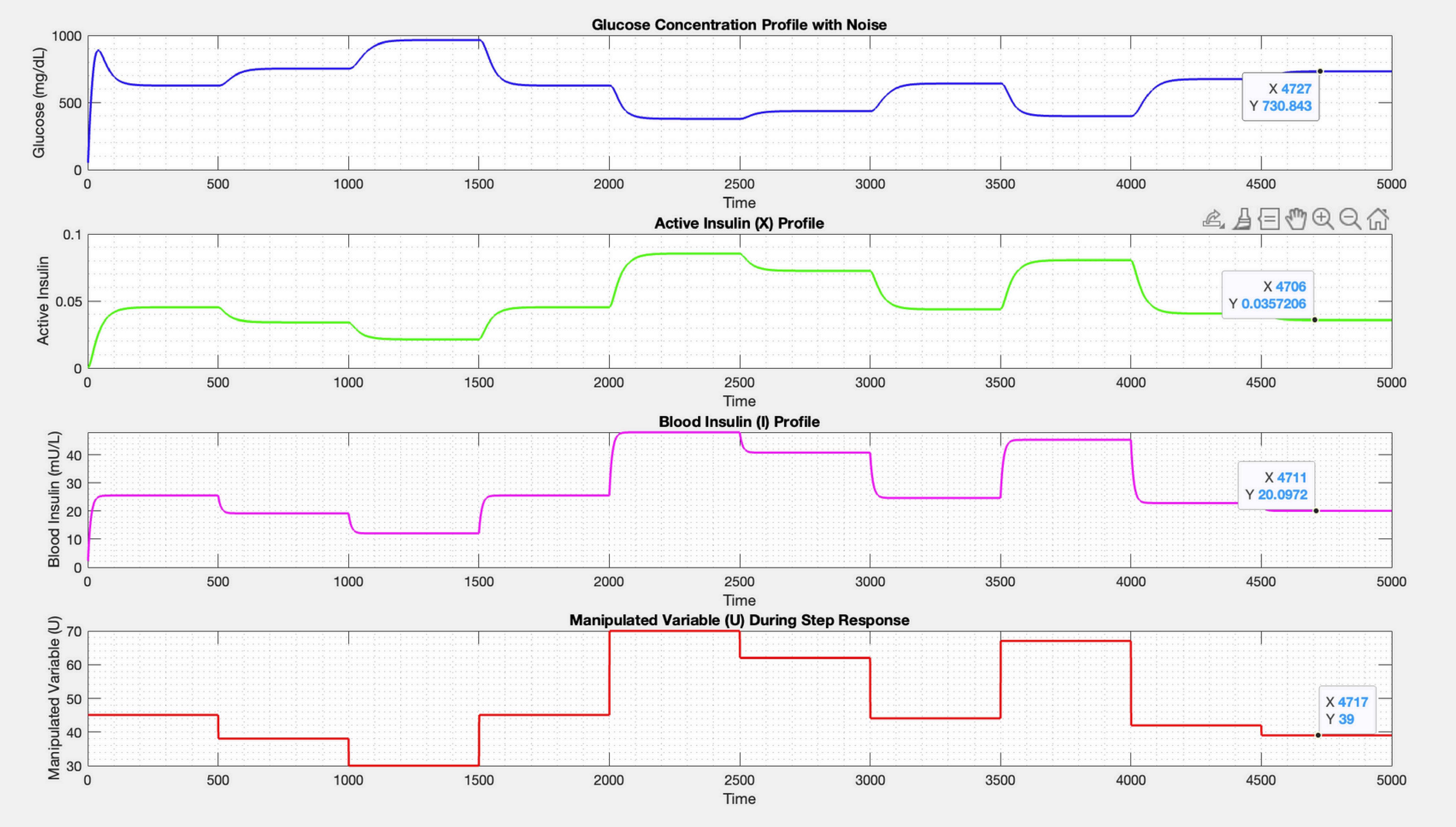
Open loop dynamic simulation

We Gave step changes to MV at intervals of 500 mins.

The Glucose Conc (G) changes inversely with U.

The Active Insulin (X) changes directly with U.

The Insulin Conc (I) changes directly with U.



First Order Model

- First Order Transfer Function model:

$$G(s) = \frac{K_p}{\tau s + 1}$$

$$y(t) = K_p\left(1 - e^{-\frac{t}{\tau}}\right)M$$

M = Step change in the manipulated variable.

- Unknown parameters : θ=(K,τ)
- We will use error function in regression to predict θ.

Error : ε(t)=Y(t)_plant - Y(t)_model

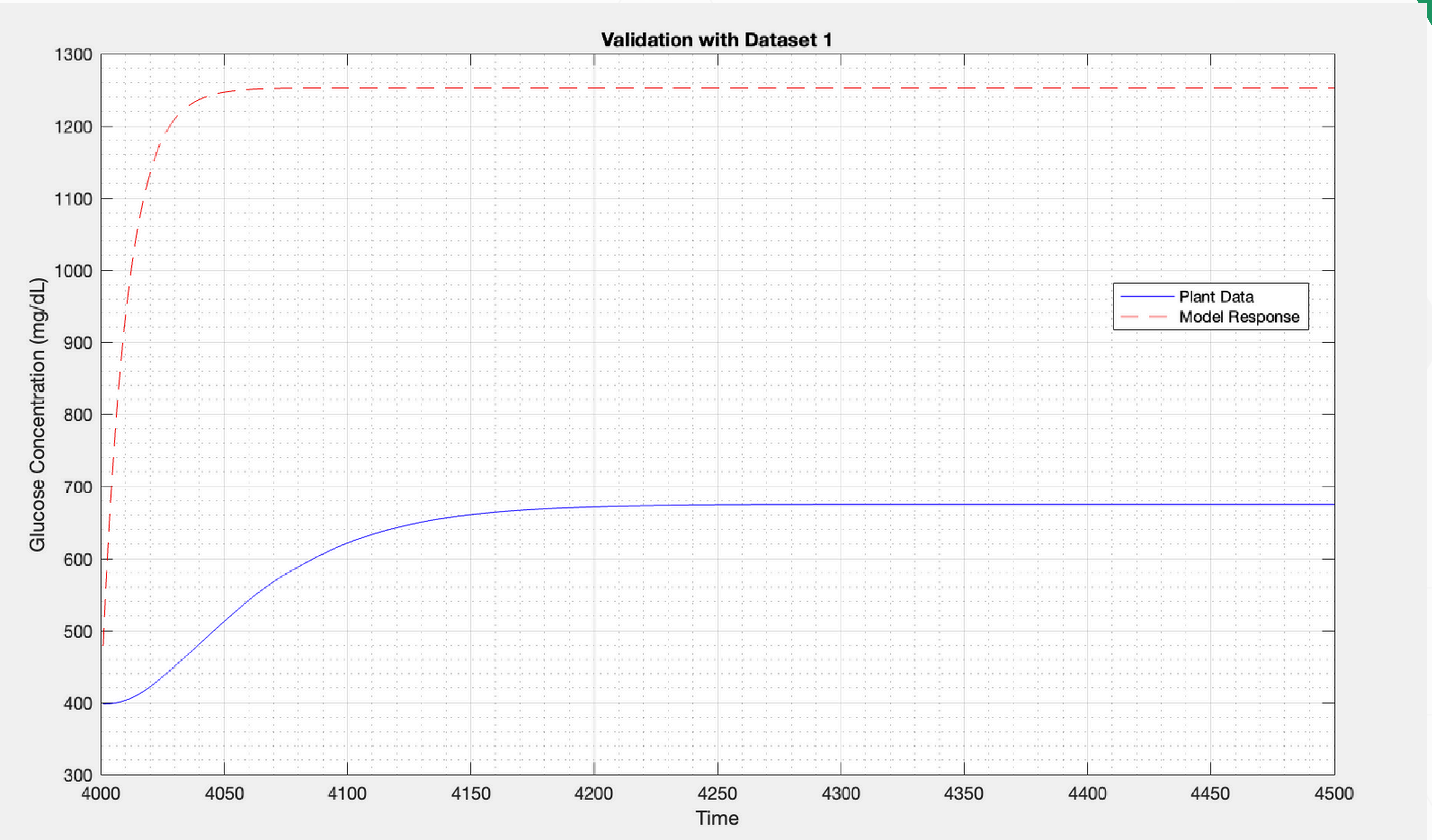
- Optimal values after regression via Fmincon :

Process gain (Kp) : 14.1755

Time constant (τ) : 10.046478

Validation Performance

- The validation we obtained is very vague the error might be coming due to the non linear relation between rate of insulin Decomposition and Change in Glucose Concentration.



FOPTD Model

- First Order Transfer Function model:

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

$$y(t) = \begin{cases} 0 & \text{if } t < \theta, \\ M K_p \left(1 - e^{-\frac{t-\theta}{\tau}}\right) & \text{if } t \geq \theta. \end{cases}$$

- Unknown parameters : θ'=(K,τ,θ)
- We will use error function in regression to predict θ.

Error : ε(t)=Y(t)_plant - Y(t)_model

- Optimal values after regression via Fmincon :

Process gain (Kp) : -16.6243

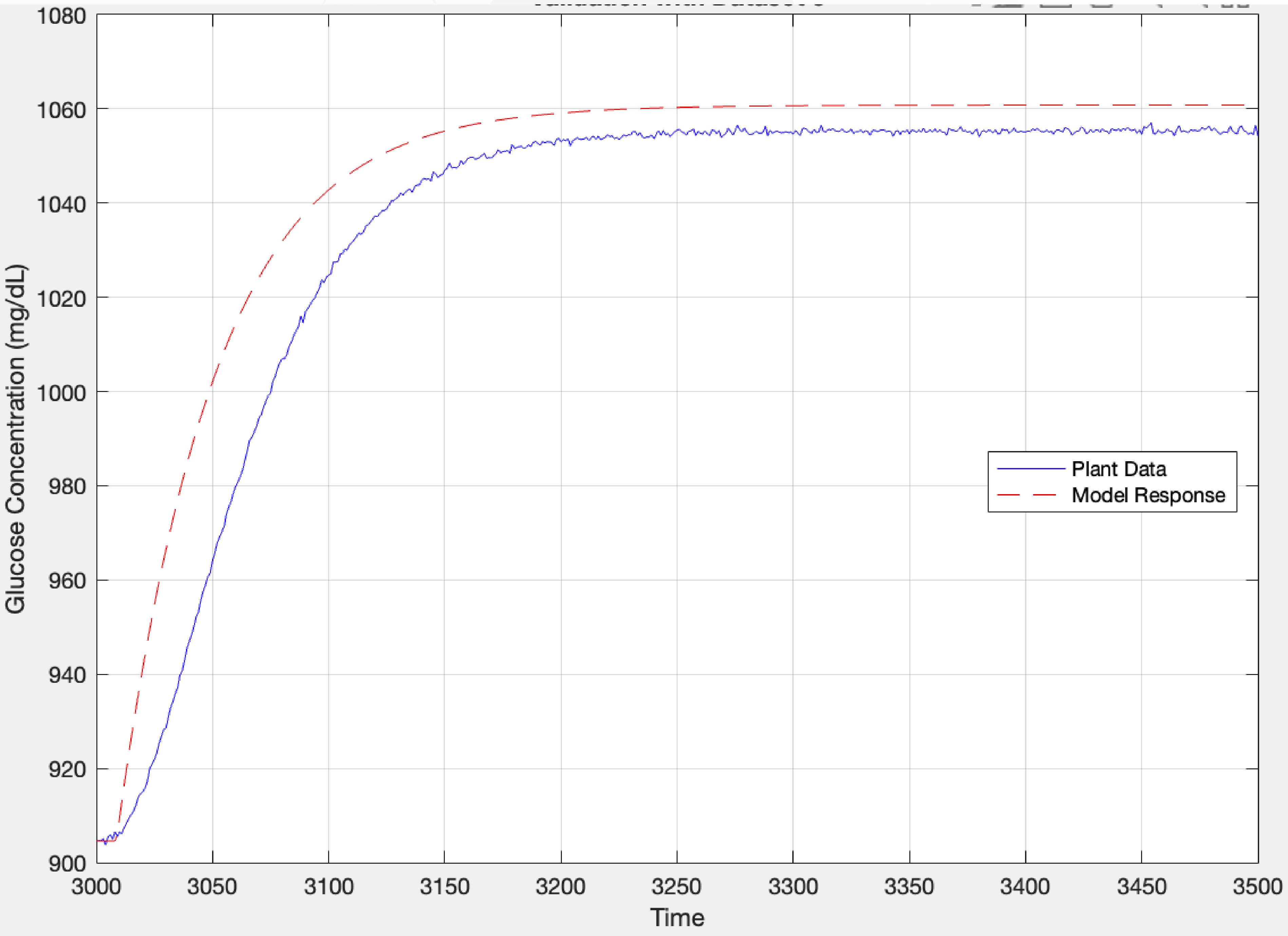
Time constant (τ) : 42.3034

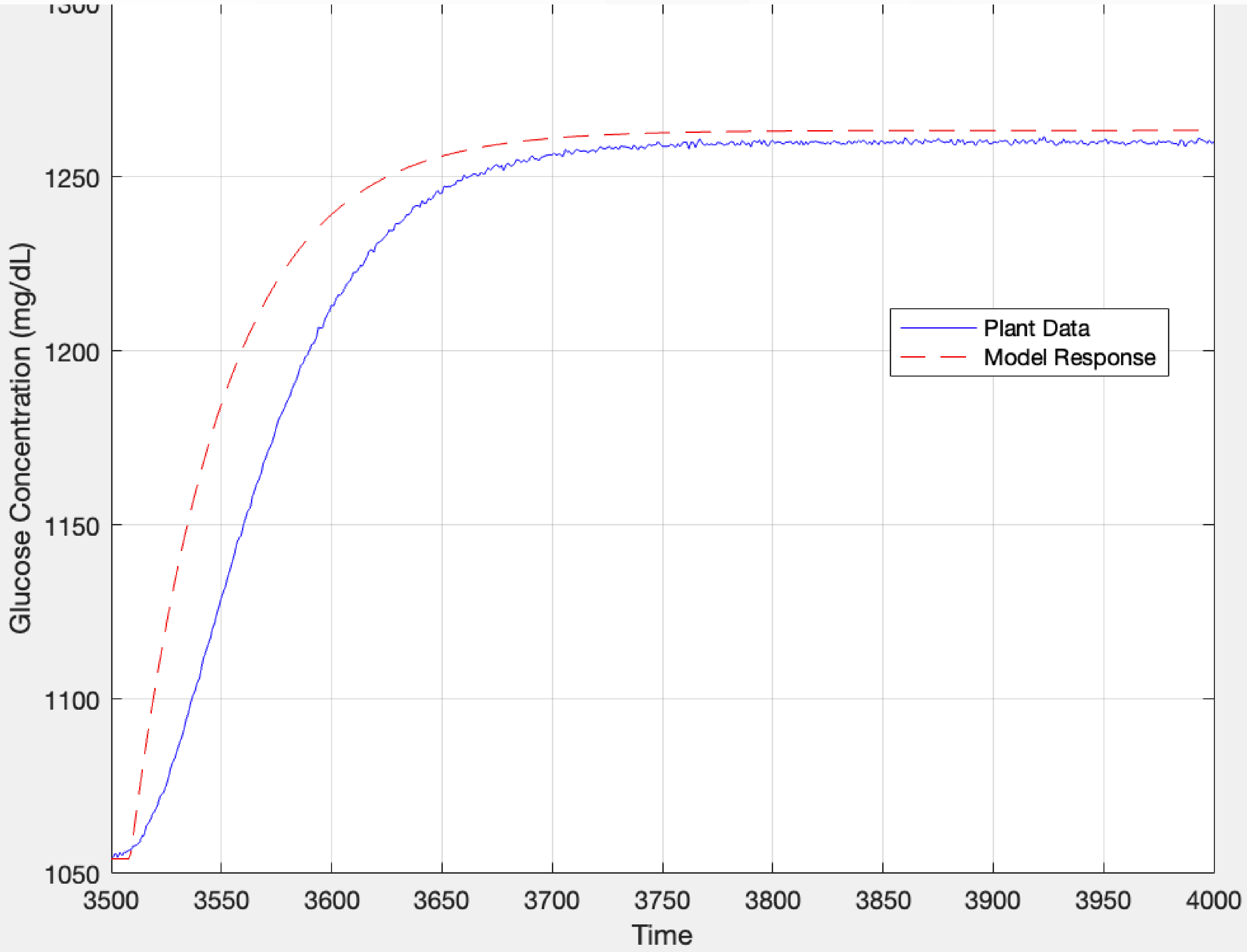
Time delay: 8.6397

Validation Performance of FOPTD

The validation we obtained is decent , the error might be coming due to the non linear relation between rate of insulin decomposition and Change in Glucose Concentration.

The validation is done on time stamp of 3000-3500 with M = -8 and On 3500-4000 with M = -18





Closed-Loop Stability Analysis

- The **Routh-Hurwitz criterion** is used to determine the stability of the system. For this analysis, we focus exclusively on the Proportional Controller to calculate the stability range for Kc.

For a First-Order Process (FOPTD Model):

The closed-loop transfer function for the FOPTD model is given as:

$$G(s) = \frac{K_p K_c}{\tau\theta s^2 + (\tau + \theta)s + K_p K_c + 1}$$

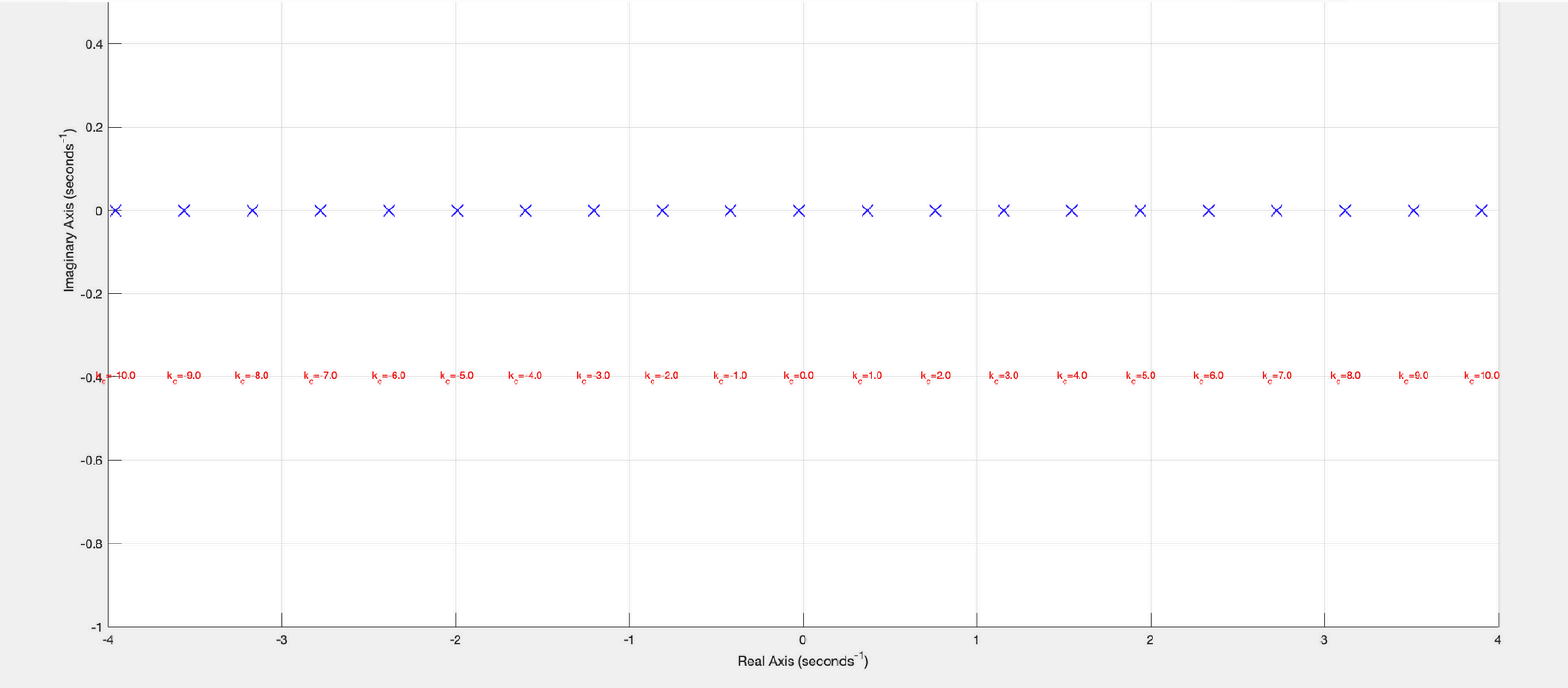
For the **Routh-Hurwitz criterion** to determine the stability of the closed-loop system, we analyze the characteristic equation of the system's denominator:

$$\tau\theta s^2 + (\tau + \theta)s + K_p K_c + 1 = 0$$

For the FOPTD model, the stability condition for the controller gain is:

Kc < 0.06

Root Locus



Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-4
-3
-2
-1
0
1
2
3
4
k_c=-10.0
k_c=-9.0
k_c=-8.0
k_c=-7.0
k_c=-6.0
k_c=-5.0
k_c=-4.0
k_c=-3.0
k_c=-2.0
k_c=-1.0
k_c=0.0
k_c=1.0
k_c=2.0
k_c=3.0
k_c=4.0
k_c=5.0
k_c=6.0
k_c=7.0
k_c=8.0
k_c=9.0
k_c=10.0

Closed-Loop Analysis

For a First-Order Process (FOPTD Model):

The closed-loop transfer function for the FOPTD model is given as:

$$\frac{Y_m}{Y_{sp}} = \frac{G_c G_v G_p}{1 + G_c G_v G_p}$$

After rearranging we get

$$G_c(s) = \frac{1}{G_p(s)} \left(\frac{Y_m(s)}{Y_{sp}(s)} \right) \left(\frac{1}{1 - \frac{Y_m(s)}{Y_{sp}(s)}} \right)$$

After substituting we get:

$$K_c = \frac{1}{K_p} \left(\frac{\tau_p}{\tau_p + \theta} \right) \qquad \tau_I = \tau_p, \qquad \tau_c = \frac{\tau_p}{2} \text{ or } \tau_c = \frac{\tau_p}{3}$$

. Kc =-0.05 and τ_c = 21.15

Root Locus Analysis

From the root locus graph, we can conclude that the system is stable for the values of Kc for which the roots lie on the left half plane

- From the Root Locus graph we conclude that for:

$$K_c < 0$$

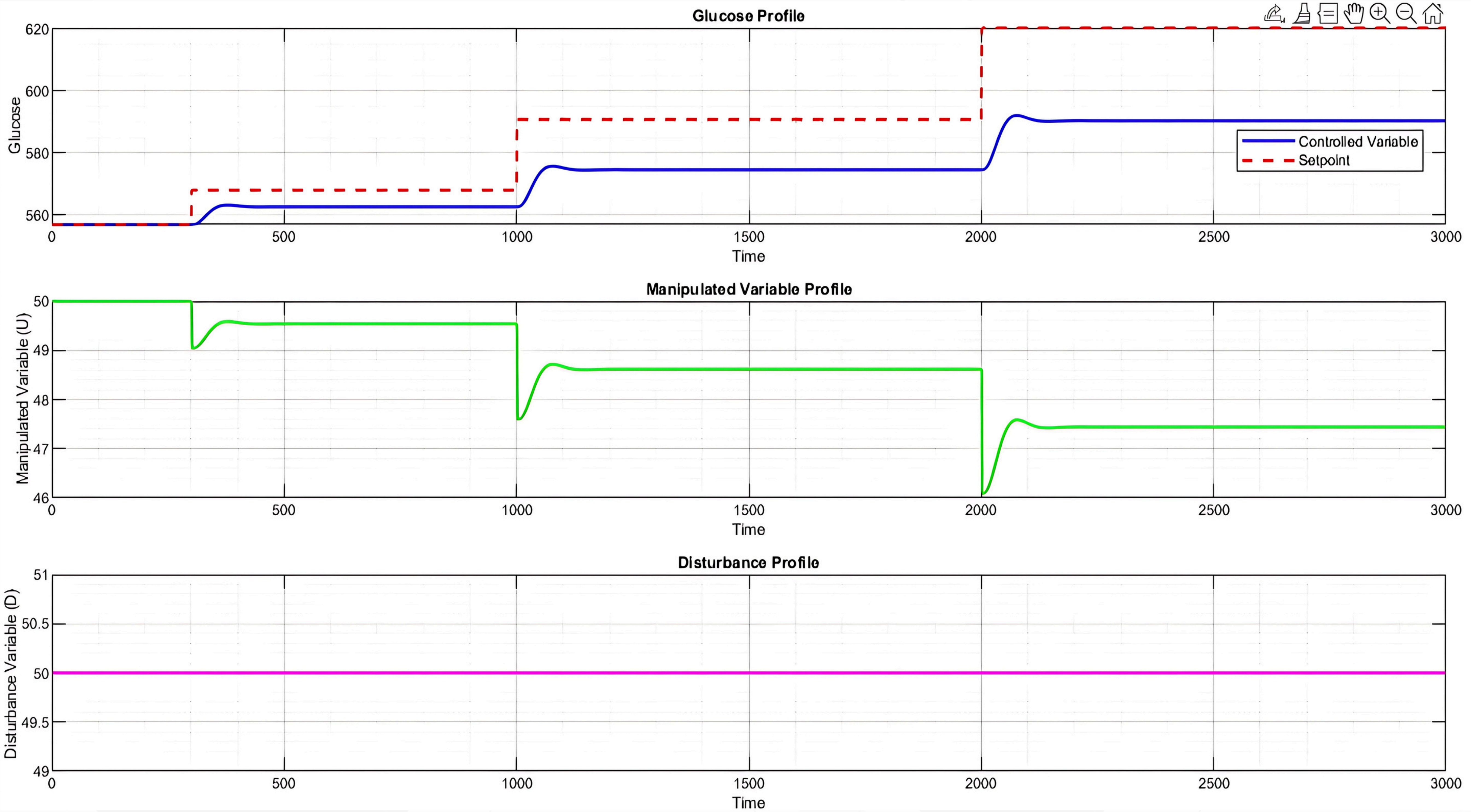
- Our system will be a stable close loop system if at least one of the roots lies on the right half plane, then for that value of Kc the system is unstable

- From the Routh Hurwitz Criteria we Concluded that:

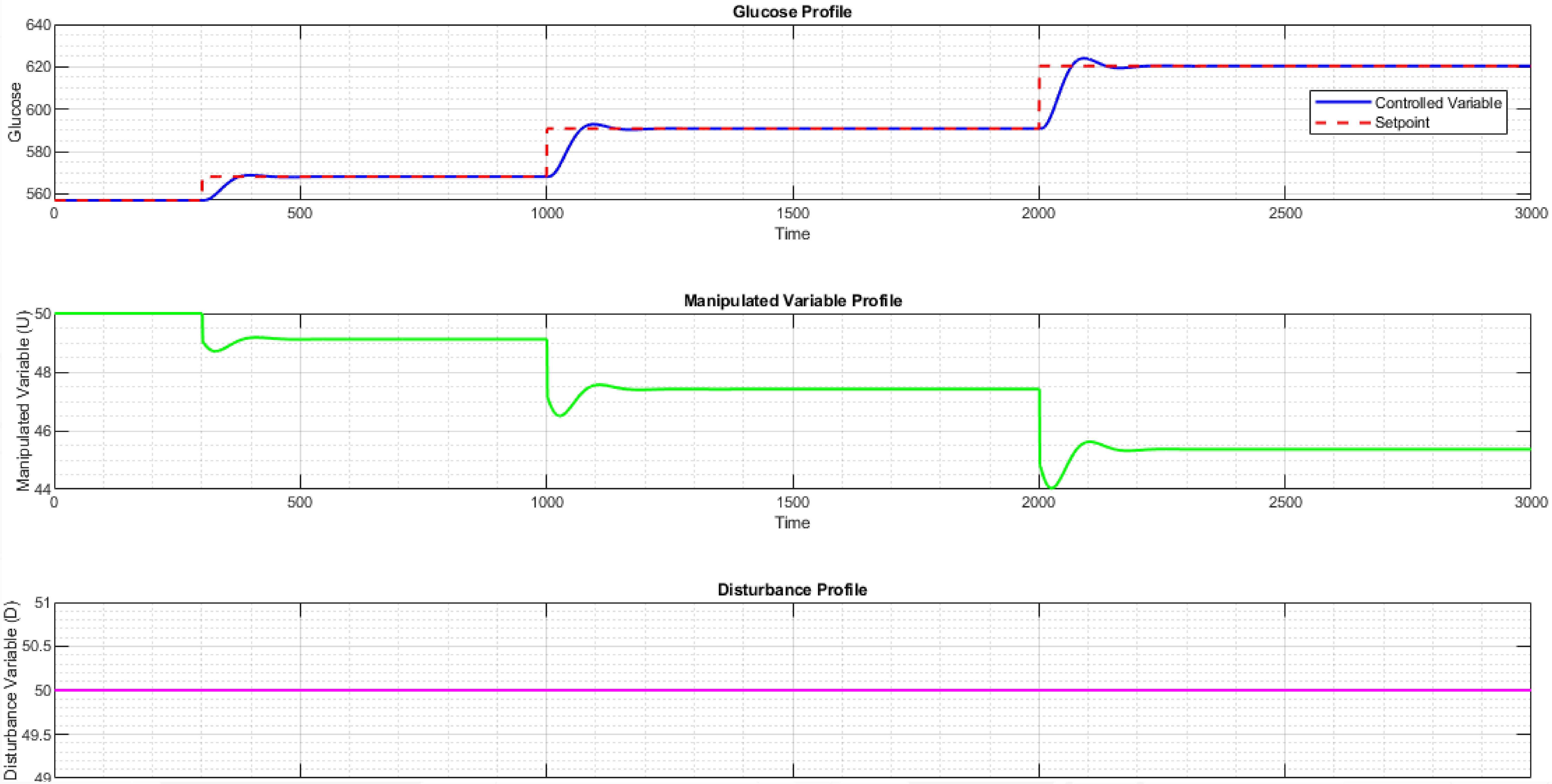
$$K_c < 0.06$$

From the root locus graph we can conclude that after a certain value of Kc the system becomes unstable which can be verified from the Routh Hurwitz criteria

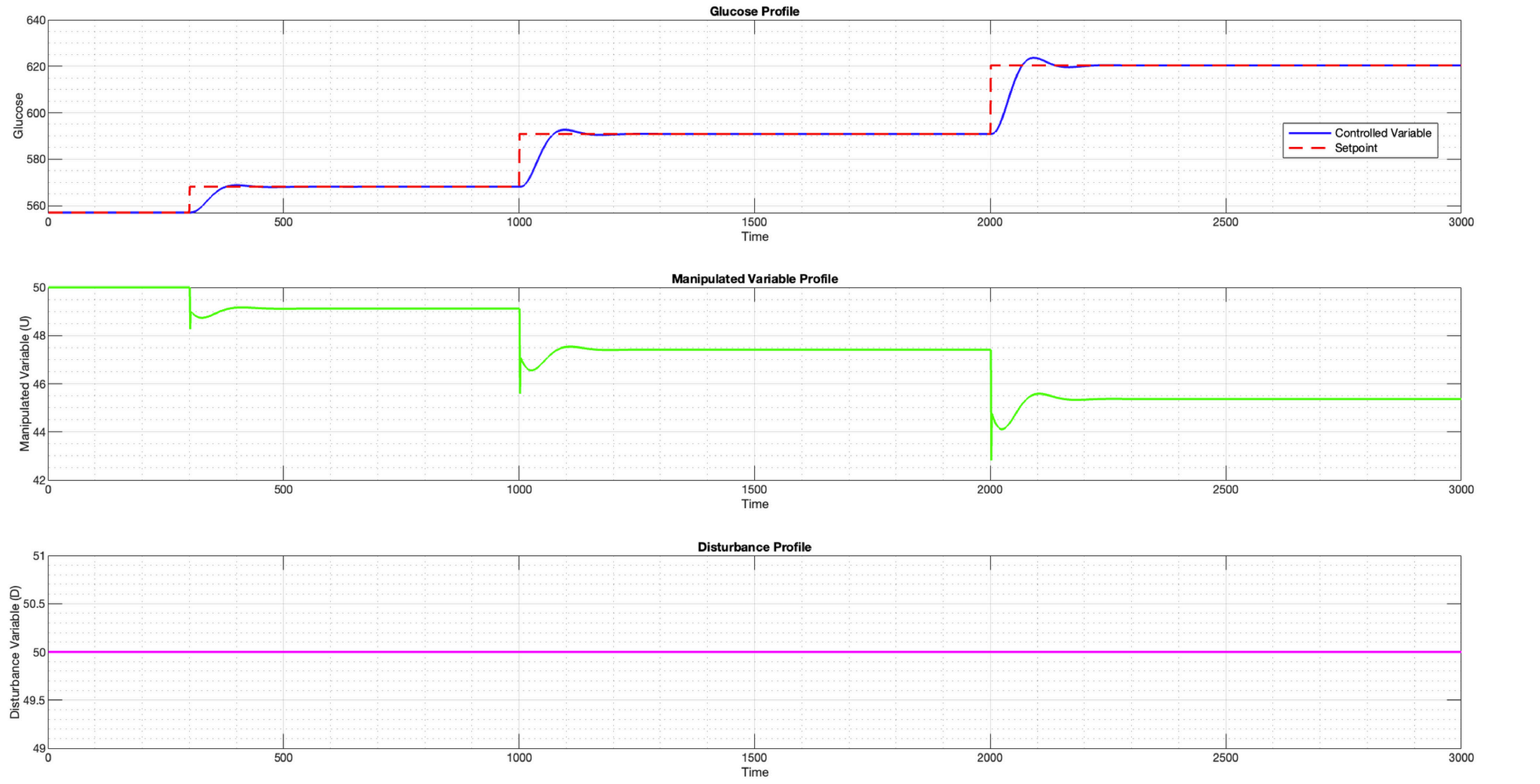
Servo Control-Proportional



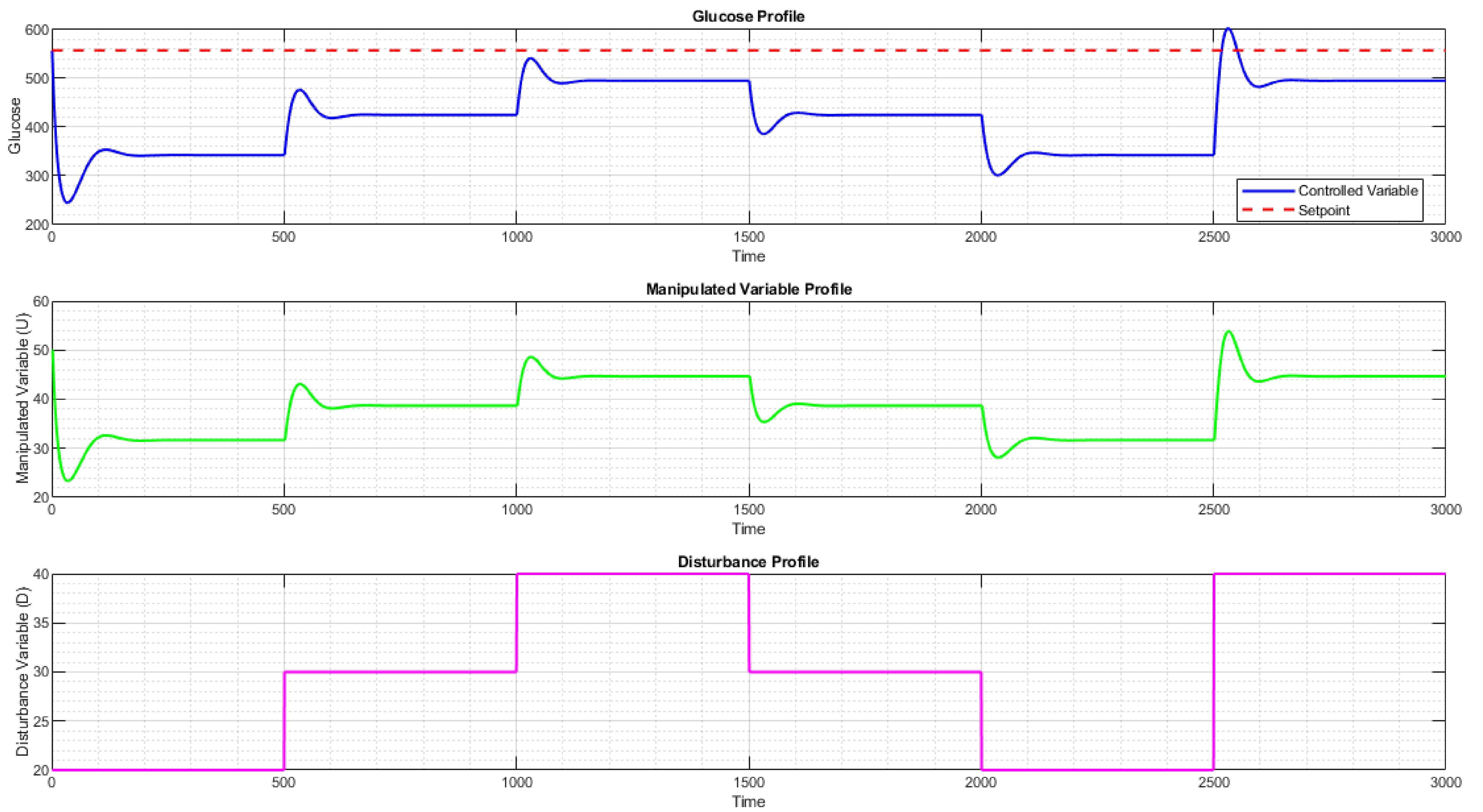
Servo Control-PI Controller



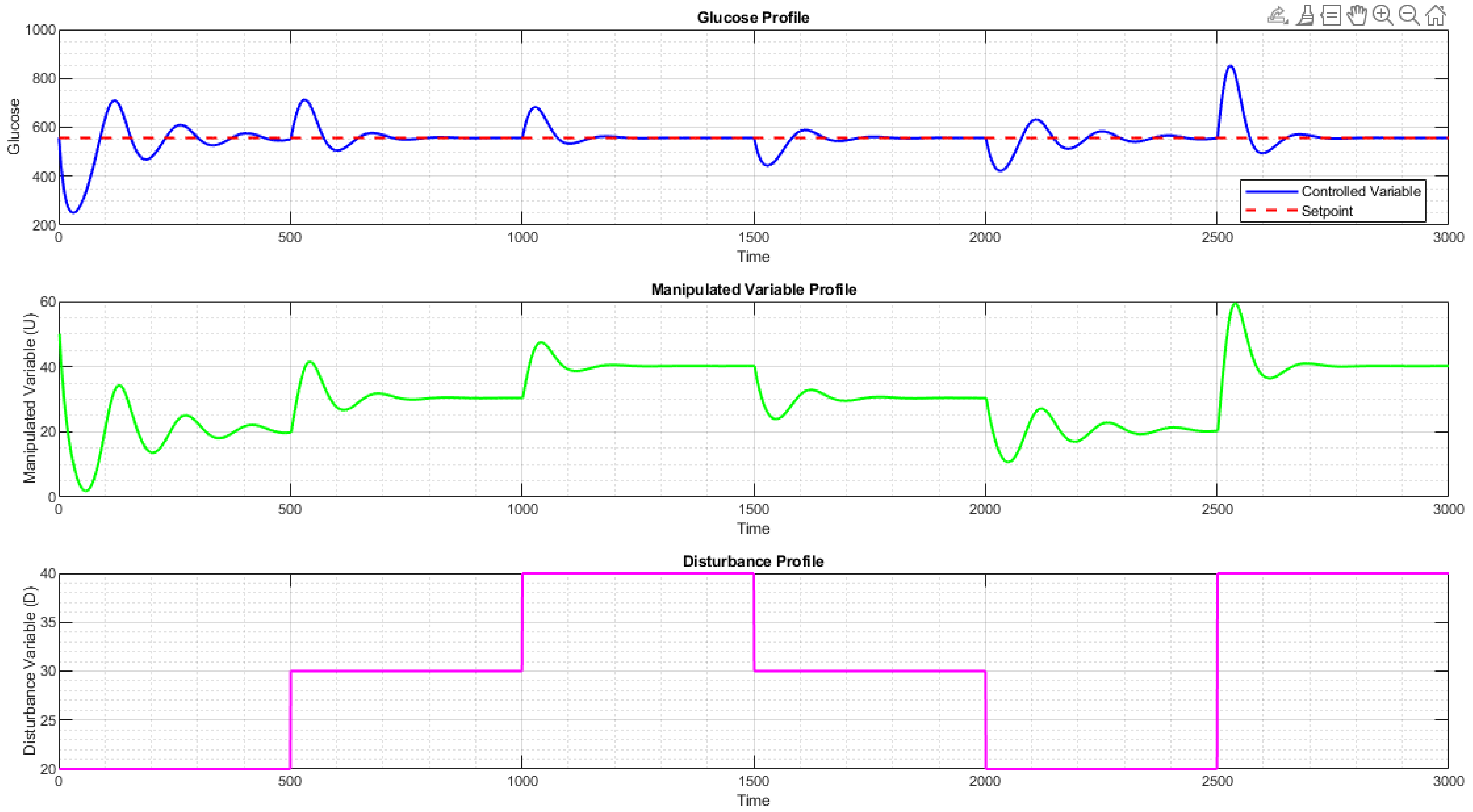
Servo Control-PID type



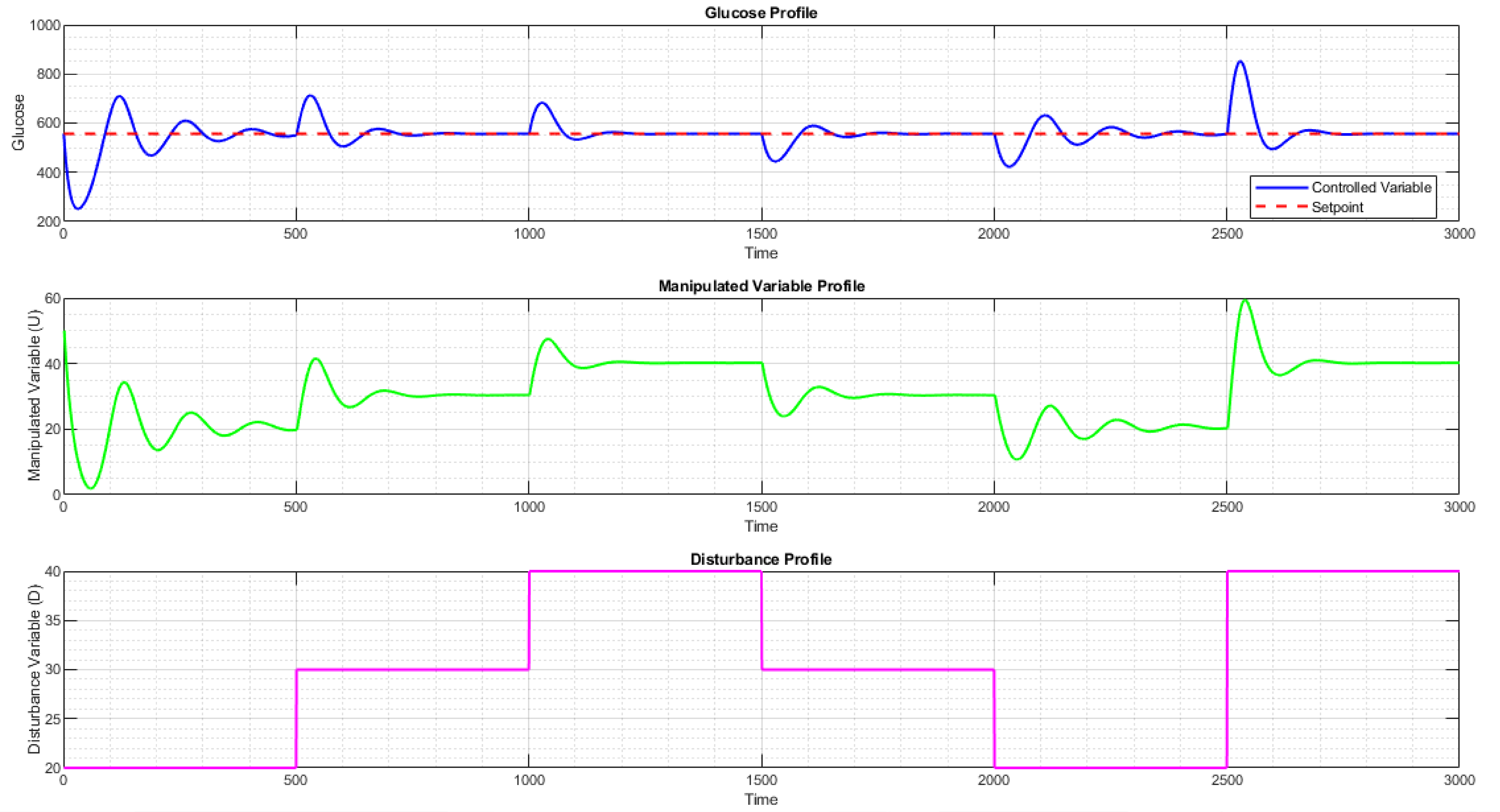
Regulatory Control-P type



Regulatory Control-PI type



Regulatory Control-PID type



Lession Learned

1. Understanding Nonlinear Dynamics
    - Techniques to identify steady states and initial conditions for nonlinear chemical processes, ensuring the selection of operating points.
    - Gained a strong understanding of nonlinear system behavior through open-loop simulations, enabling predictions of system responses under diverse scenarios.
2. Empirical Modeling with FOPTD Models
    - Developed idea in approximating nonlinear systems using First Order and First-Order Plus Time Delay (FOPTD) models.
    - Acquired expertise in extracting critical parameters such as process gain, time constant, and time delay, foundational for designing effective control systems.
3. Stability Analysis Techniques
    - Utilized the Routh-Hurwitz Criterion and root locus plots to analyze closed-loop stability.
    - Enhanced ability to interpret stability insights for control system optimization.
4. Feedback Control Design
    - Designed and tuned P, PI, and PID controllers to achieve objectives like precise setpoint tracking and robust disturbance rejection.

Thank You