Design of P, PI, PID Controllers for Buck Converter using Direct Synthesis Method

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Overview

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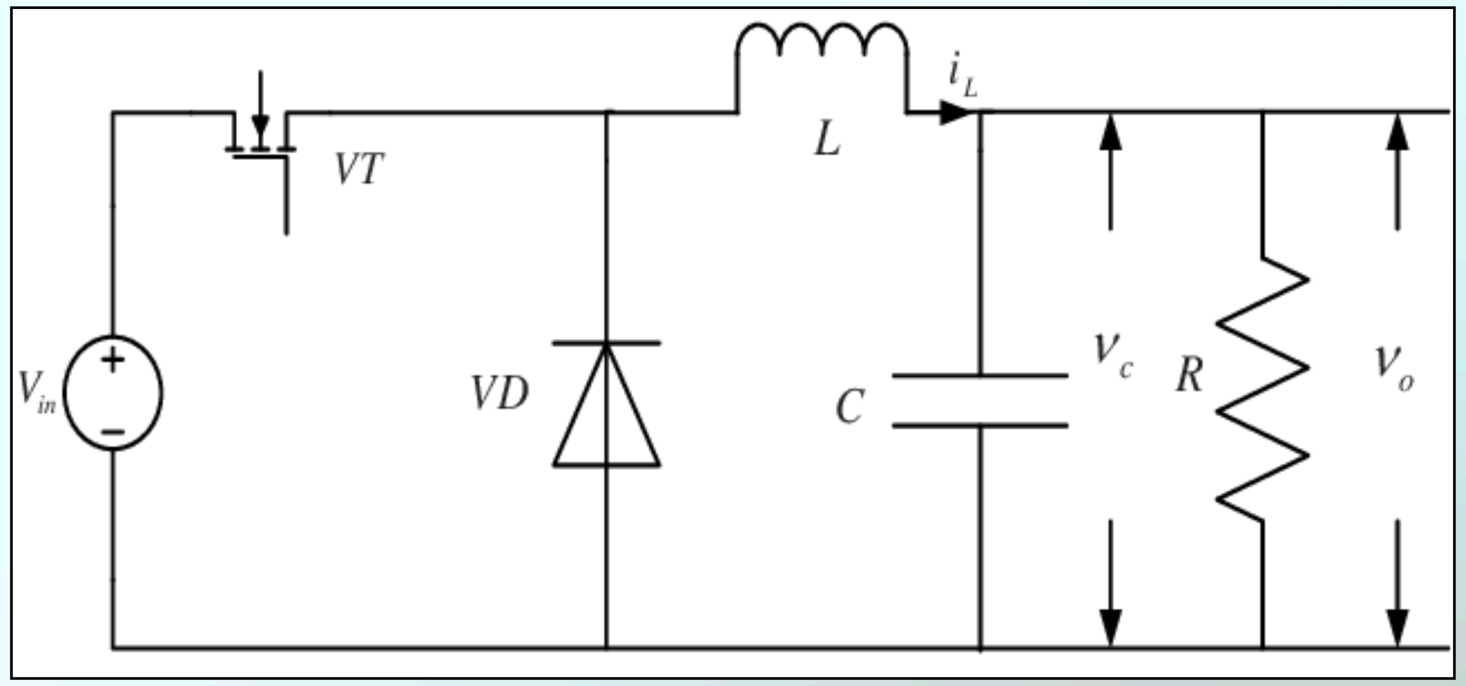
Introduction

- A buck converter is a type of DC-DC converter that steps down voltage while stepping up current. This makes it highly efficient for use in power supplies for various electronic devices. The converter operates by switching elements (like transistors) on and off, controlling the amount of energy transferred to the output load.
- Efficient control of buck converters is crucial for stability, efficiency, response time, minimised overshoot and steady state error.
- Control strategies are essential to ensure the buck converter operates efficiently and effectively. The three common types of controllers are: P, PI,PID controllers.
- P controller provides a control signal proportional to the error signal, helping to reduce the error. However, it may not eliminate steady-state error completely.
- PI controller Combines proportional control with an integral term to eliminate steady-state error, ensuring the output voltage matches the desired value over time.
- PID controller adds a derivative term to the PI controller to improve transient response, reduce overshoot, and enhance overall stability.

Buck Converter

- A buck converter is a type of DC-DC converter used to step down voltage from a higher level to a lower level while increasing the current.
- It has high efficiency, compact size, can be used in a variety of applications, from low-power portable devices to high-power industrial systems.
- Used in power supplies for computers, laptops, and smartphones, voltage regulation in renewable energy systems, providing stable voltage for sensitive components.



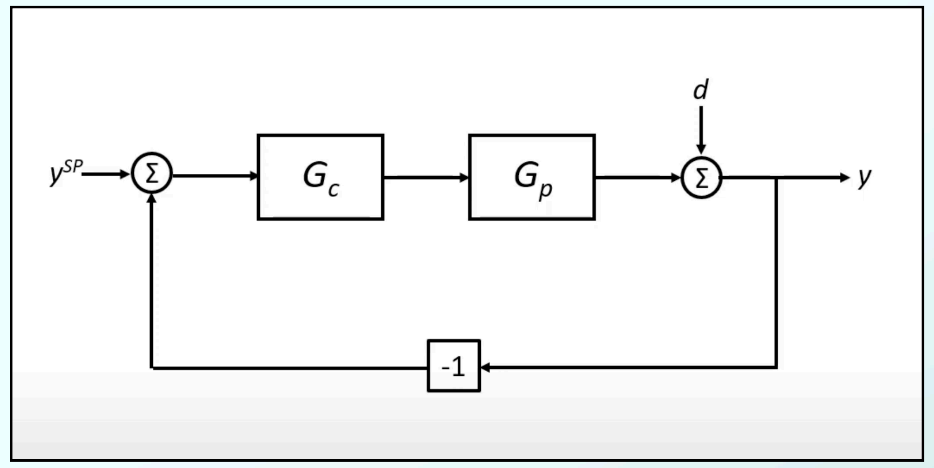
Buck Converter Circuit

Direct Synthesis Method

- The direct synthesis method is a control strategy design technique used to directly specify the desired closed-loop transfer function. It allows designers to achieve specific performance criteria by shaping the system's response directly.

- This method is particularly useful for designing controllers for dynamic systems like buck converters.

- Benefits of direct synthesis method are precise control, flexibility, simplified design process.



$$\left[\frac{y}{y^{SP}}\right]_{spec} = G_{CL}^{spec} = \frac{G_c G_p}{1 + G_c G_p}$$

G_p and G_{CL}^{spec} are known

So G_c can be back-calculated as

$$G_c = \frac{1}{G_p}\left[\frac{G_{CL}^{spec}}{1 - G_{CL}^{spec}}\right]$$

Figure 1

- Consider the system in Figure 1 the G_c controller gain for P, PI, PID controllers can be obtained by appropriate G_p i.e plant gain (for pure integrator, first order lag and second order lag systems)

- G_{CL}^{spec} specified closed loop gain is given by $\frac{1}{\lambda s + 1}$

- So by computing the G_p, G_{CL}^{spec} with appropriate values G_c is obtained.

Controller Design

- For pure integrator system with $G_p = \frac{K}{s}$, $G_C = K_C = \frac{1}{K\lambda}$ which is P controller gain.

- For first order lag system with $G_p = \frac{K}{\tau s + 1}$, $G_C = K_C = \frac{1}{K}\frac{\tau}{\lambda}\left[1 + \frac{1}{\tau s}\right]$ which is PI controller gain.

PI controller with
$K_c = \frac{1}{K}\frac{\tau}{\lambda} \quad \tau_I = \tau$

τ_I —> Integral time constant

- For second order lag with $G_p = \frac{K}{(\tau_1 s + 1)(\tau_1 s + 1)}$ $G_C = K_C =$ $G_c = \frac{1}{K}\frac{(\tau_1 + \tau_2)}{\lambda}\left[1 + \frac{1}{(\tau_1 + \tau_2)s} + \frac{\tau_1\tau_2}{(\tau_1 + \tau_2)}s\right]$ which is a standard PID controller gain.

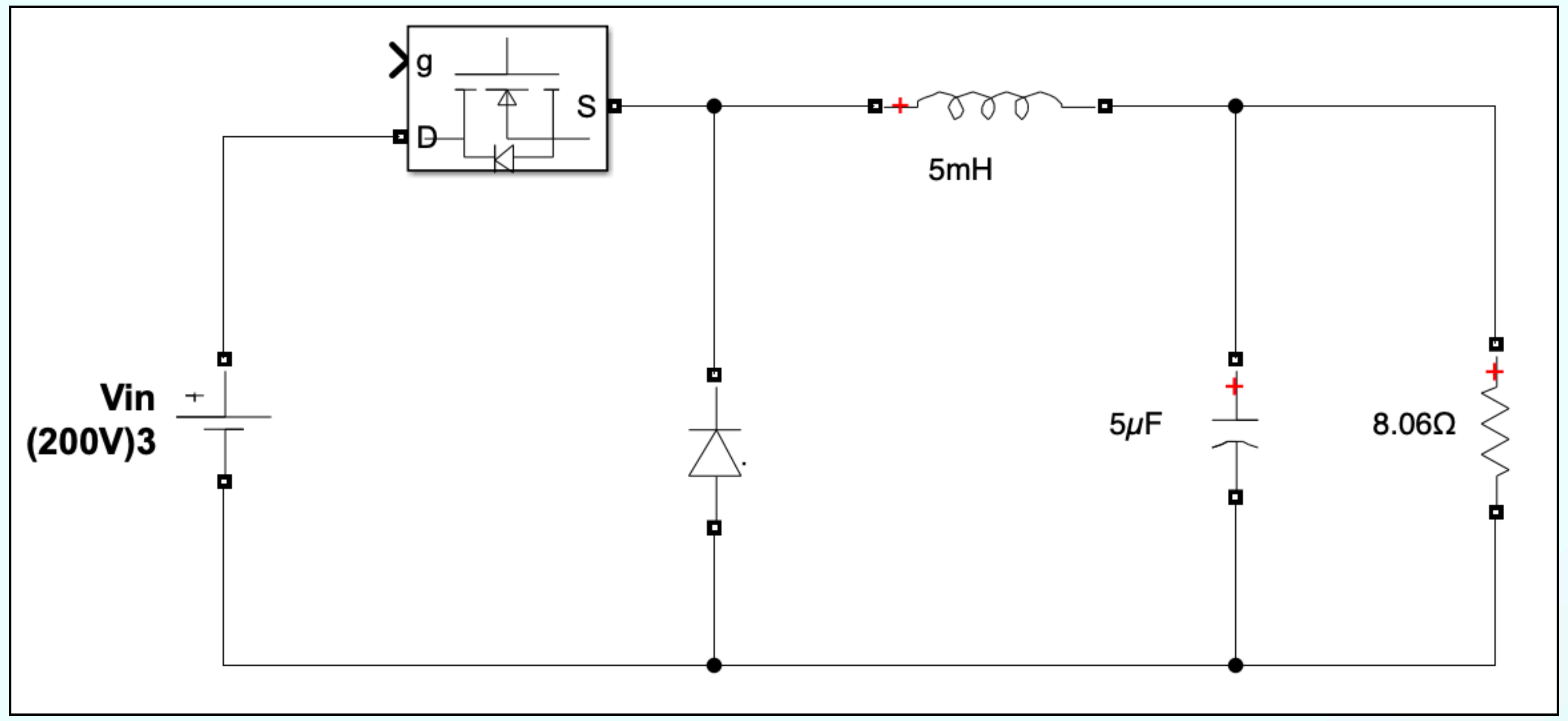
PID controller with
$K_c = \frac{1}{K}\frac{(\tau_1+\tau_2)}{\lambda} \qquad \tau_I = \tau_1 + \tau_2 \qquad \tau_D = \frac{\tau_1\tau_2}{(\tau_1+\tau_2)}$

τ_I —> Integral time constant

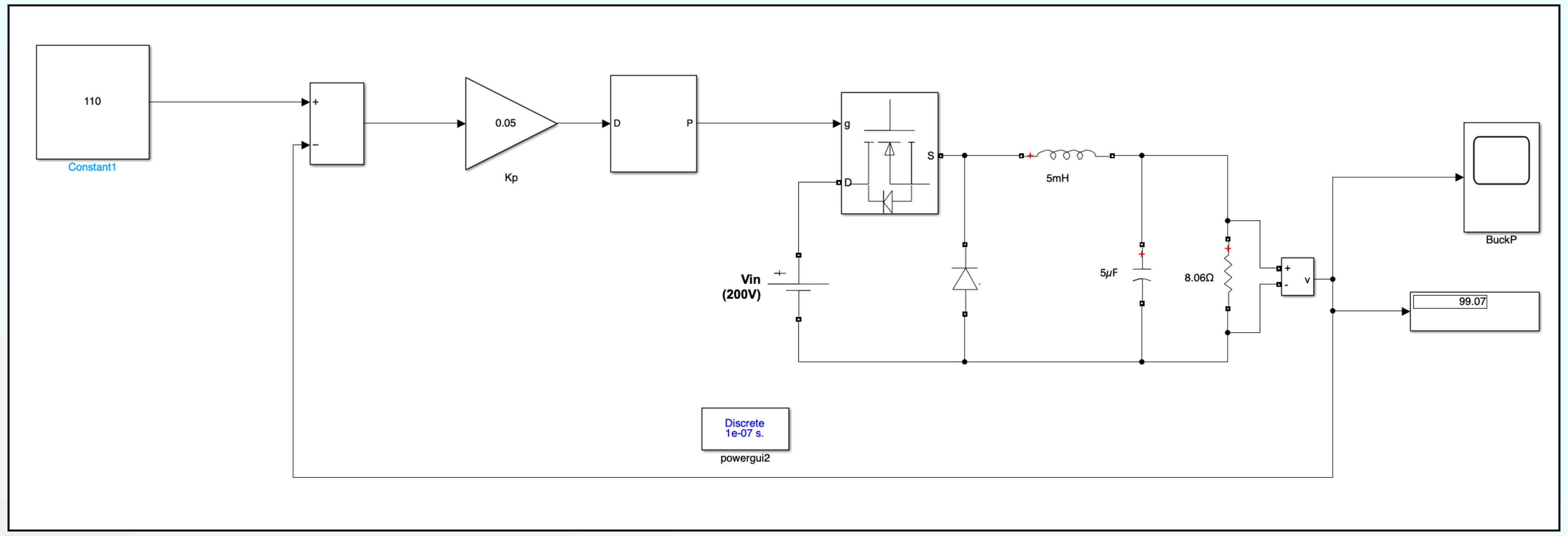
τ_D —> Derivative time constant

λ —> Tuning parameter (0.1)

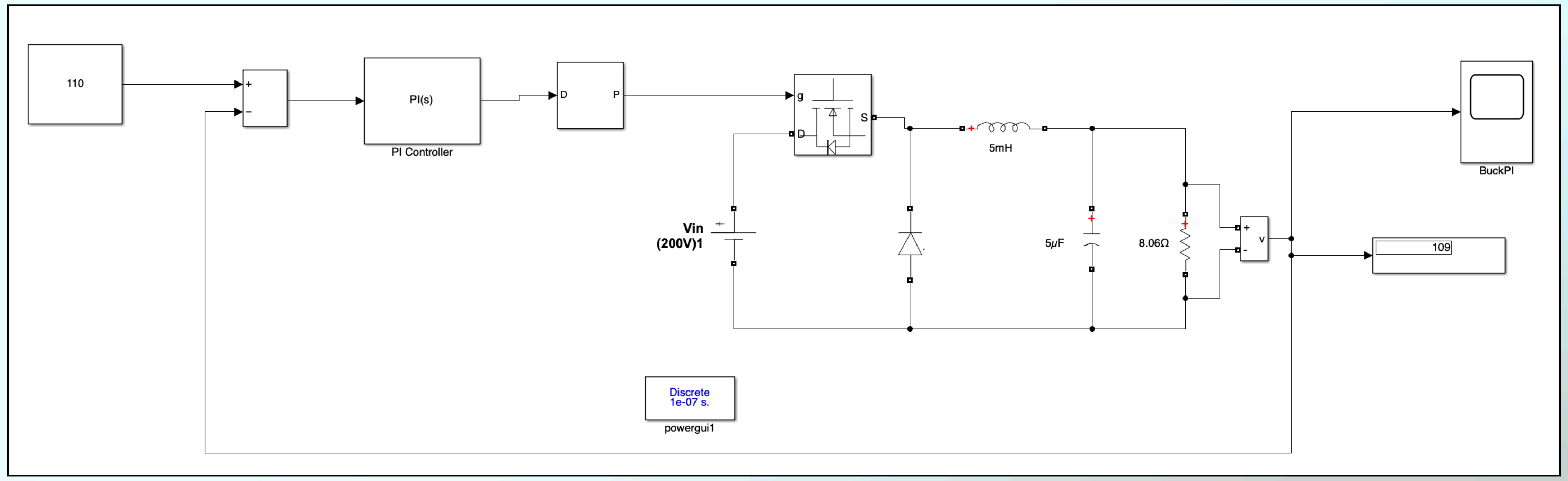
- With the values of the parameters from the buck converter diagram and the simulation circuit diagrams the respective values of controller gains are obtained.



Buck Converter



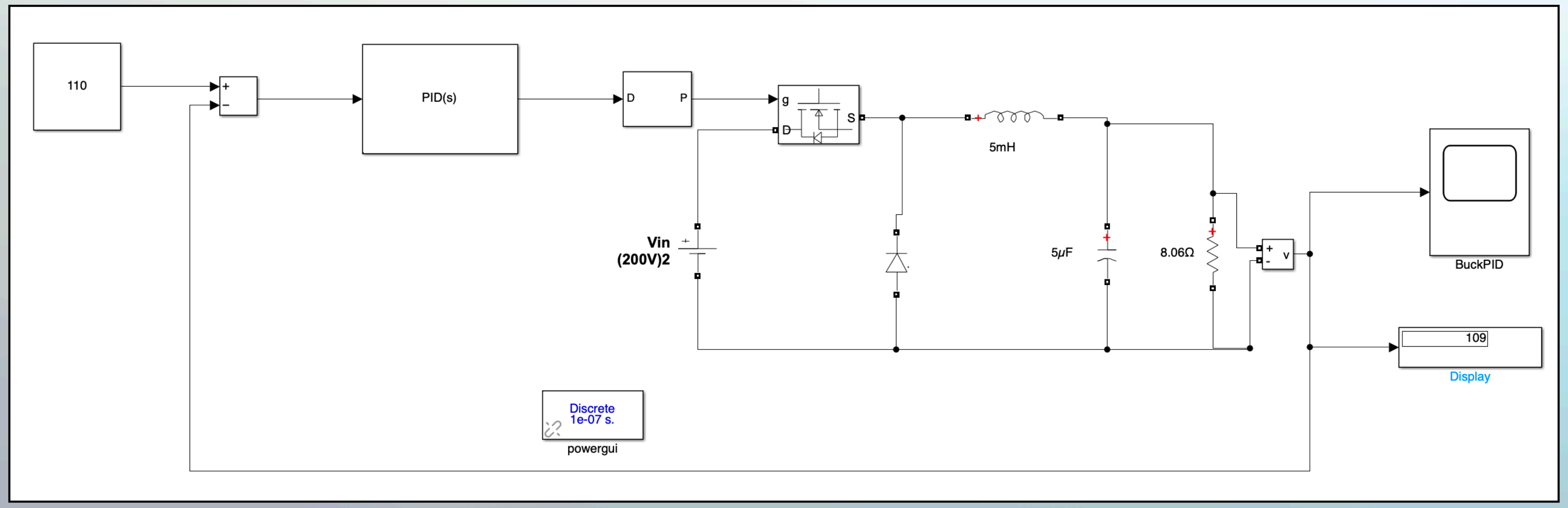
P Controller Circuit



PI Controller Circuit

From buck converter circuit V_{in} = 200v = K, L = 5mH, C = 5μF, R = 8.06Ω ,

$\tau_1 = \frac{L}{R}$ =6.1x10^{-6}, τ_2 = RC= 4.03x10^{-5}



PID Controller Circuit

1. $K_c = K_p = 0.05$ for P controller

2. $K_c = K_p = 3.1 \times 10^{-5}$, $K_I = K_c/\tau_I = 0.05$ for PI controller

3. $K_c = K_p = 6.603 \times 10^{-5}$, $\tau_1 = 6.603 \times 10^{-4}$, $K_I = K_c/\tau_1 = 0.05$,

   $K_D = K_c/\tau_D = 1.25 \times 10^{-9}$

Simulation Results

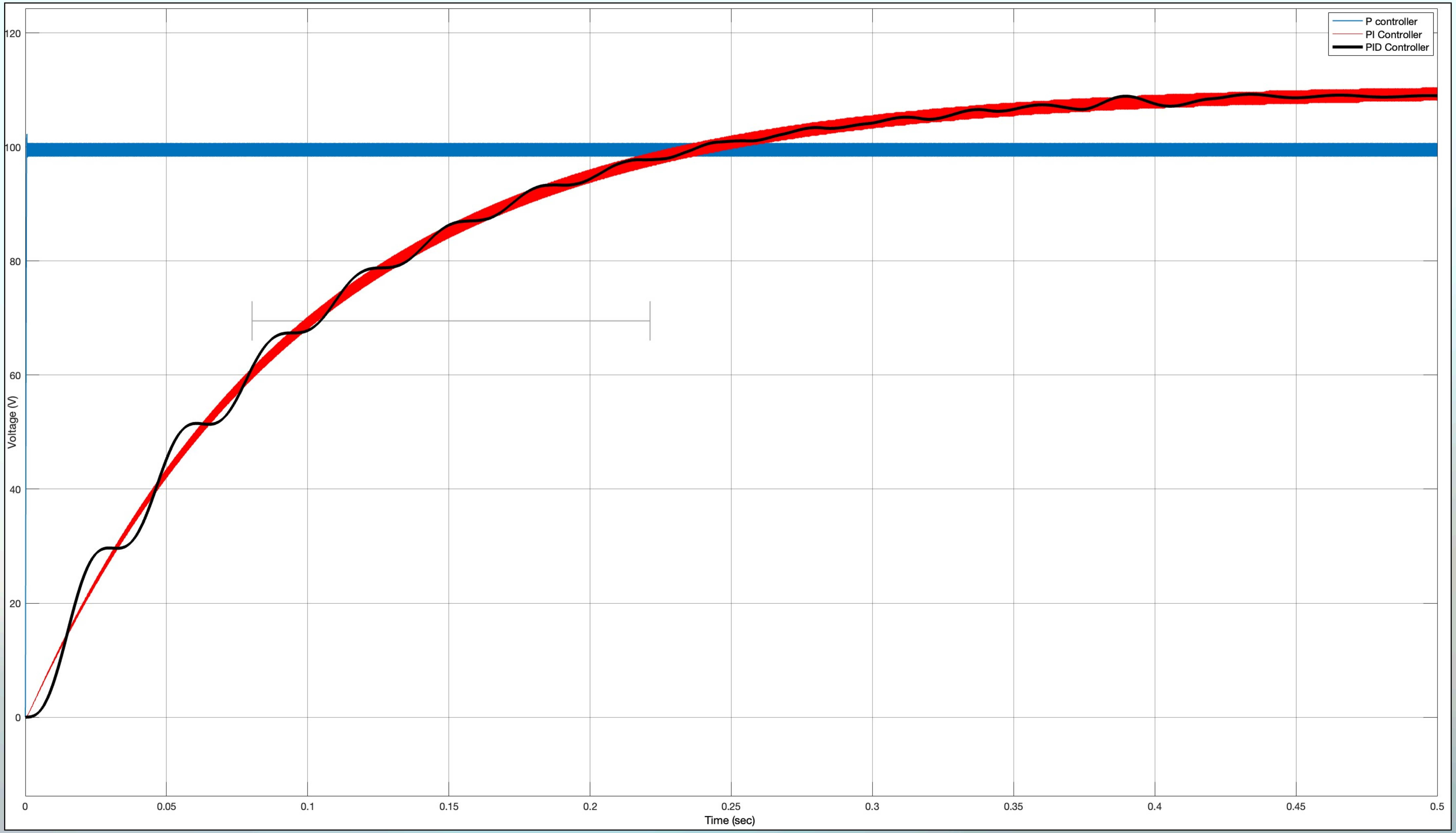


Figure 2

Comparative Results

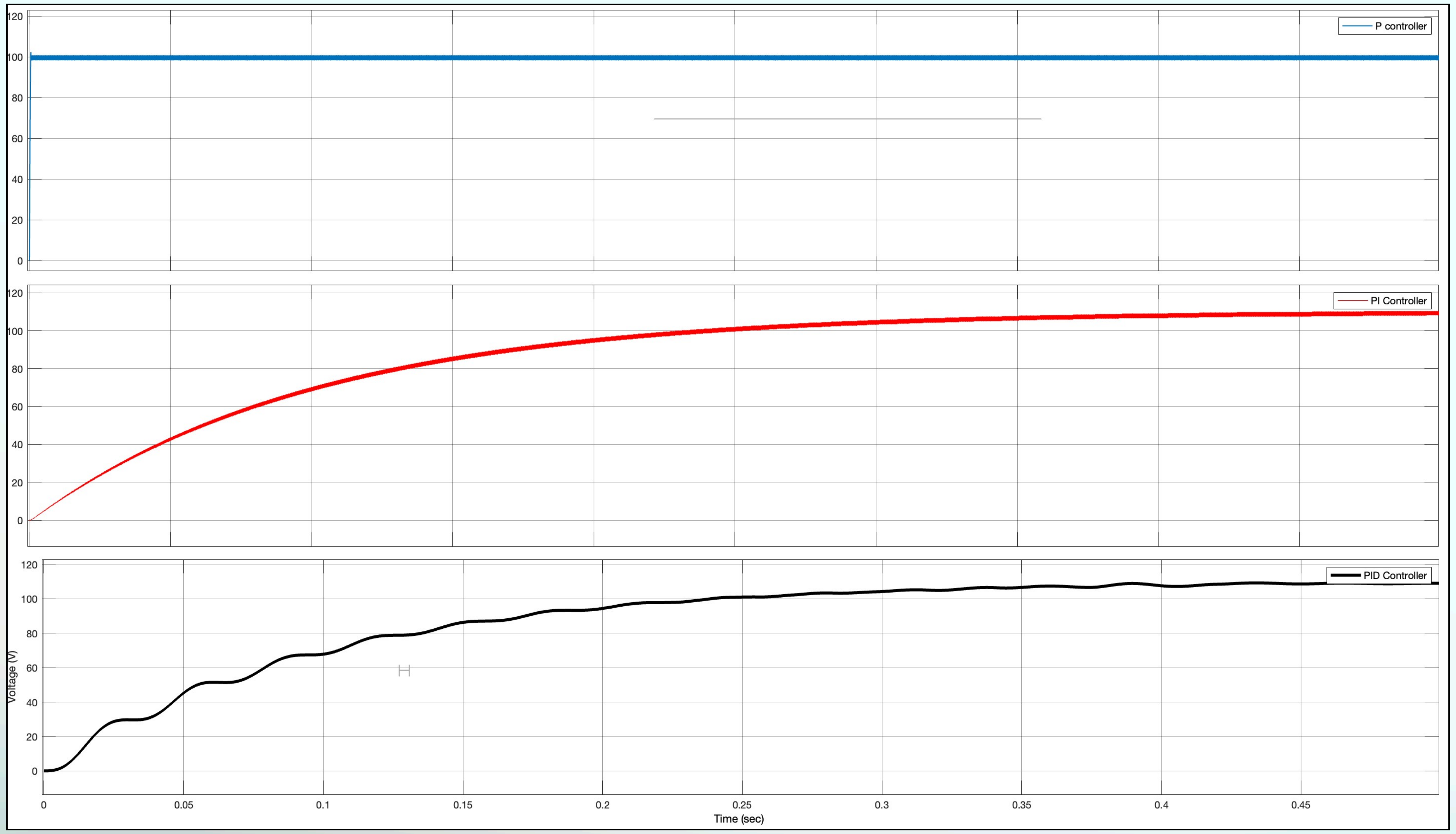


Figure 3

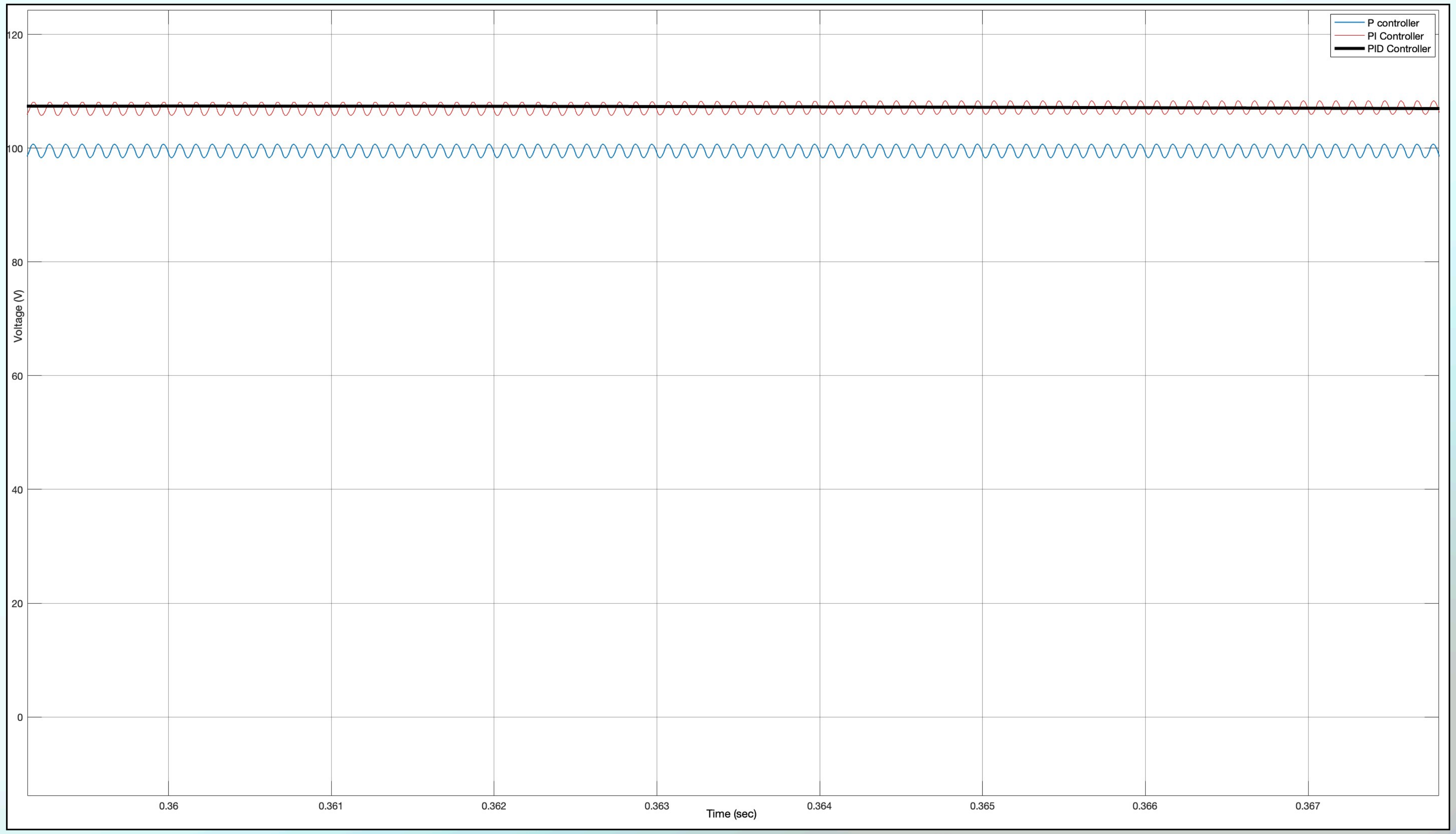


Figure 4

- From Figure 4 it is clear that which controller is best suited for the buck converter.

Conclusion

- The direct synthesis method offers a systematic and effective approach for designing P, PI, and PID controllers for buck converters, ensuring precise control and optimal performance. Each controller type—P, PI, and PID—provides unique benefits, such as improved accuracy and enhanced transient response.

- Simulations confirm that the right controller significantly boosts buck converter performance, ensuring stable and efficient voltage regulation.

- Overall, the direct synthesis method is a valuable tool for designing reliable and efficient power supply systems for modern electronics.