# National Institute of Technology Warangal

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# Direct Synthesis scheme based controller design for Buck Converter

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# Introduction

A buck converter is a type of DC-DC converter that reduces voltage while increasing current, making it a popular choice for power supplies in various electronic devices due to its efficiency and simplicity. The performance of a buck converter can be greatly enhanced by implementing effective control strategies. This paper provides an analysis of the design and simulation of Proportional (P), Proportional-Integral (PI), and Proportional-Integral-Derivative (PID) controllers for a buck converter using the direct synthesis method. This approach enables precise control of the output voltage, ensuring stability and rapid response to variations in load and input voltage.

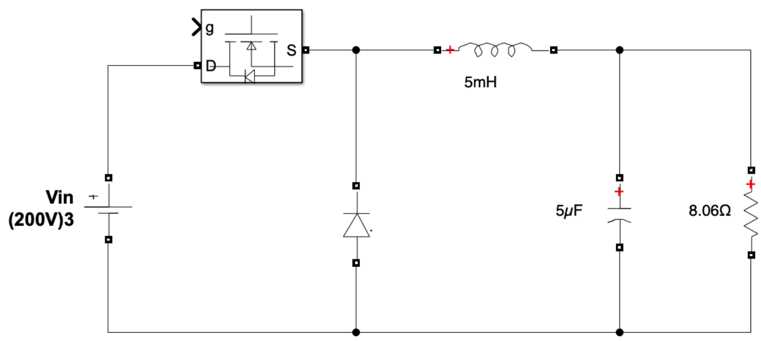
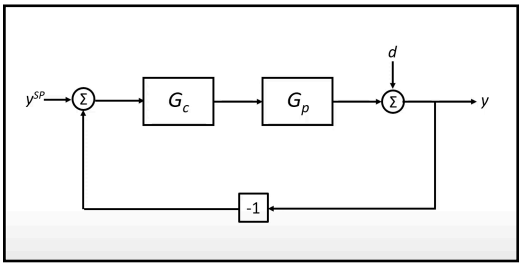



**Fig1. Buck Converter**

# Simulation Study & Controller Design

The simulation study is carried out using MATLAB/Simulink to evaluate the performance of P, PI, and PID controllers for a buck converter. The direct synthesis method involves deriving the controller parameters based on the desired closed-loop transfer function, ensuring that the system meets specific performance criteria such as overshoot, settling time, and steady-state error.

The basic idea for a closed loop system is shown in the Figure 2 and the controller gain is $G_c$ and the plant gain is $G_p$ and specified closed loop transfer function is $G_{CL}^{spec}$.




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

$G_p$ 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 2**

# P Controller Design

- For a pure integrator system plant gain is given by : $G_p = \frac{K}{s}$

and $G_{CL}{}^{spec} = \frac{1}{\lambda s + 1}$

$\lambda$ —> Tuning parameter (say 0.1 ), $G_{CL}$ spec —> Specified closed loop Gain

Substituting $G_{CL}{}^{spec}$ and $G_p$ in the above Gc equation we get the gain of proportional (P) controller i.e $G_c = K_c = \boxed{\frac{1}{K\lambda}}$

# PI Controller Design

- For a first order lag system with $G_p$ as : $G_p = \frac{K}{\tau s + 1}$

and $G_{CL}{}^{spec} = \frac{1}{\lambda s + 1}$

Substituting $G_{CL}{}^{spec}$ and $G_p$ in the first Gc equation we get the gain of proportional Integral(PI) controller i.e $G_c = K_c = \boxed{\frac{1}{K}\frac{\tau}{\lambda}\left[1+\frac{1}{\tau s}\right]}$

PI controller with

$K_c = \frac{1}{K}\frac{\tau}{\lambda} \qquad \tau_I = \tau$

$\tau_I$ —> Integral time constant

## PID Controller Design

- For a second order lag system with $G_p$ as : $\boxed{G_p = \frac{K}{(\tau_1 s+1)(\tau_1 s+1)}}$

and $G_{CL}^{spec} = \frac{1}{\lambda s + 1}$

Substituting $G_{CL}^{spec}$ and $G_p$ in the above Gc equation we get the gain of PID controller i.e $G_c = K_c = \boxed{G_c = \frac{1}{K}\frac{(\tau_1+\tau_2)}{\lambda}\left[1+\frac{1}{(\tau_1+\tau_2)s}+\frac{\tau_1\tau_2}{(\tau_1+\tau_2)}s\right]}$

PID controller with

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

$\tau_I$ —> Integral time constant

$\tau_D$ —> Derivative time constant

From figure 1 $V_{in}$ = 200v = K, L = 5mH, C = 5µF, R = 8.06Ω , $\tau_1 = \frac{L}{R}$ =6.1x10$^{-6}$, $\tau_2$ = RC= 4.03x10$^{-5}$ by substituting and comparing these values with the above standard PID controller gain obtained gains of P, PI, PID controllers are

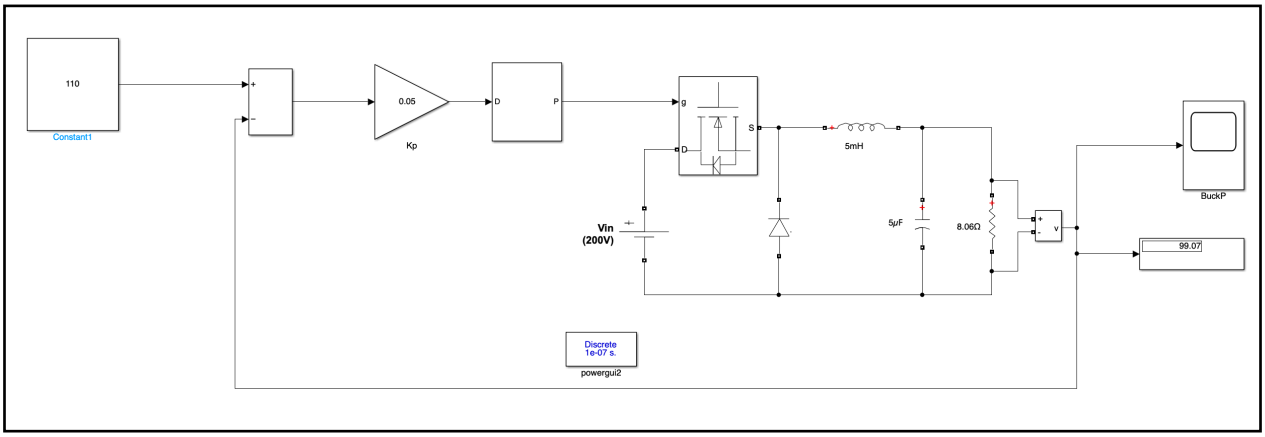
1. $K_c = K_p = 0.05$ for P controller

2. $K_c = K_p = 3.1\times10^{-5}$, $K_I = K_c/\tau_I = 0.05$ for PI controller

3. $K_c = K_p = 6.603\times10^{-5}$, $\tau_1 = 6.603\times10^{-4}$, $K_I = K_c/\tau_1 = 0.05$,

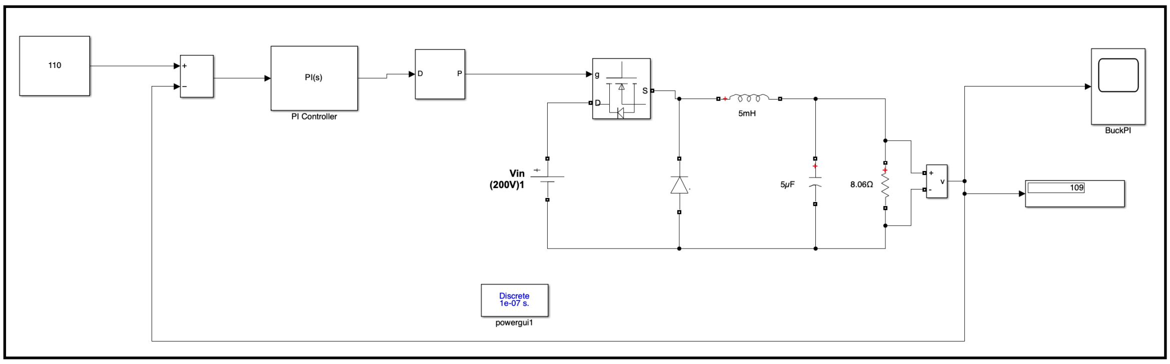
   $K_D = K_c/\tau_D = 1.25\times10^{-9}$

The **P controller** is the simplest form of control, which adjusts the output based on the proportional gain (Kp). The simulation results for the P controller are shown in Figure 3.



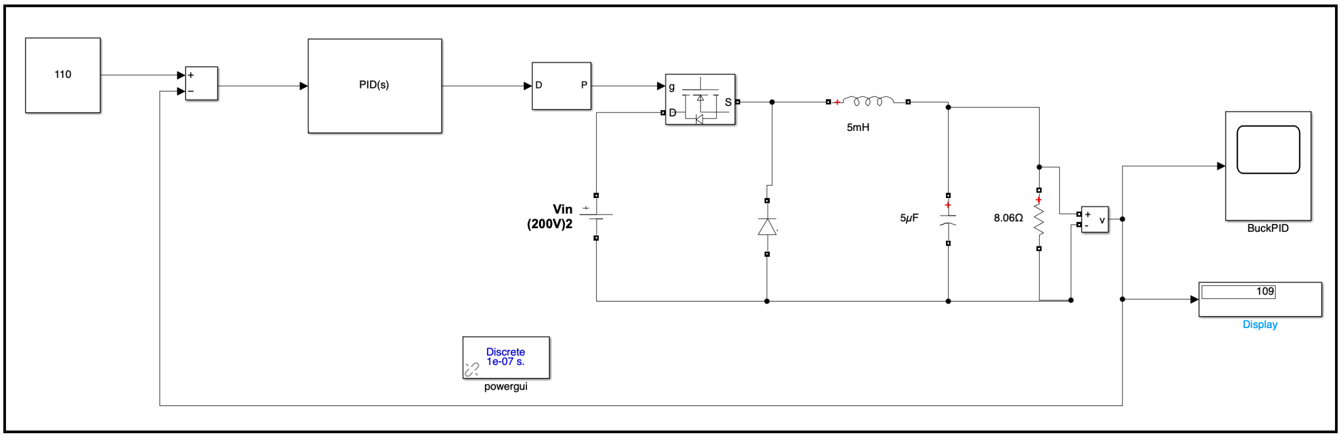

**P Controller Circuit**

The **PI controller** adds an integral component to the P controller, which helps eliminate the steady-state error by integrating the error over time. The simulation results for the PI controller are shown in Figure 3.




**PI Controller Circuit**

The **PID controller** incorporates a derivative component, which predicts future errors and improves the overall response. The simulation results for the PID controller are shown in Figure 3.




**PID Controller Circuit**

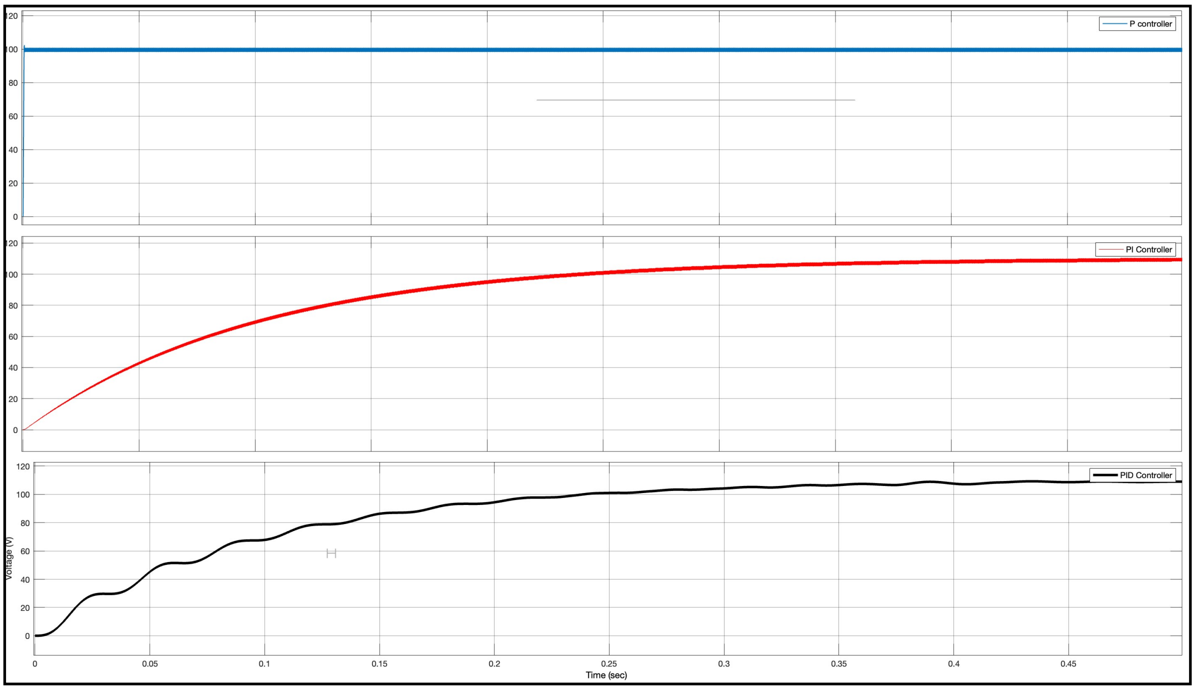



**Figure 3**

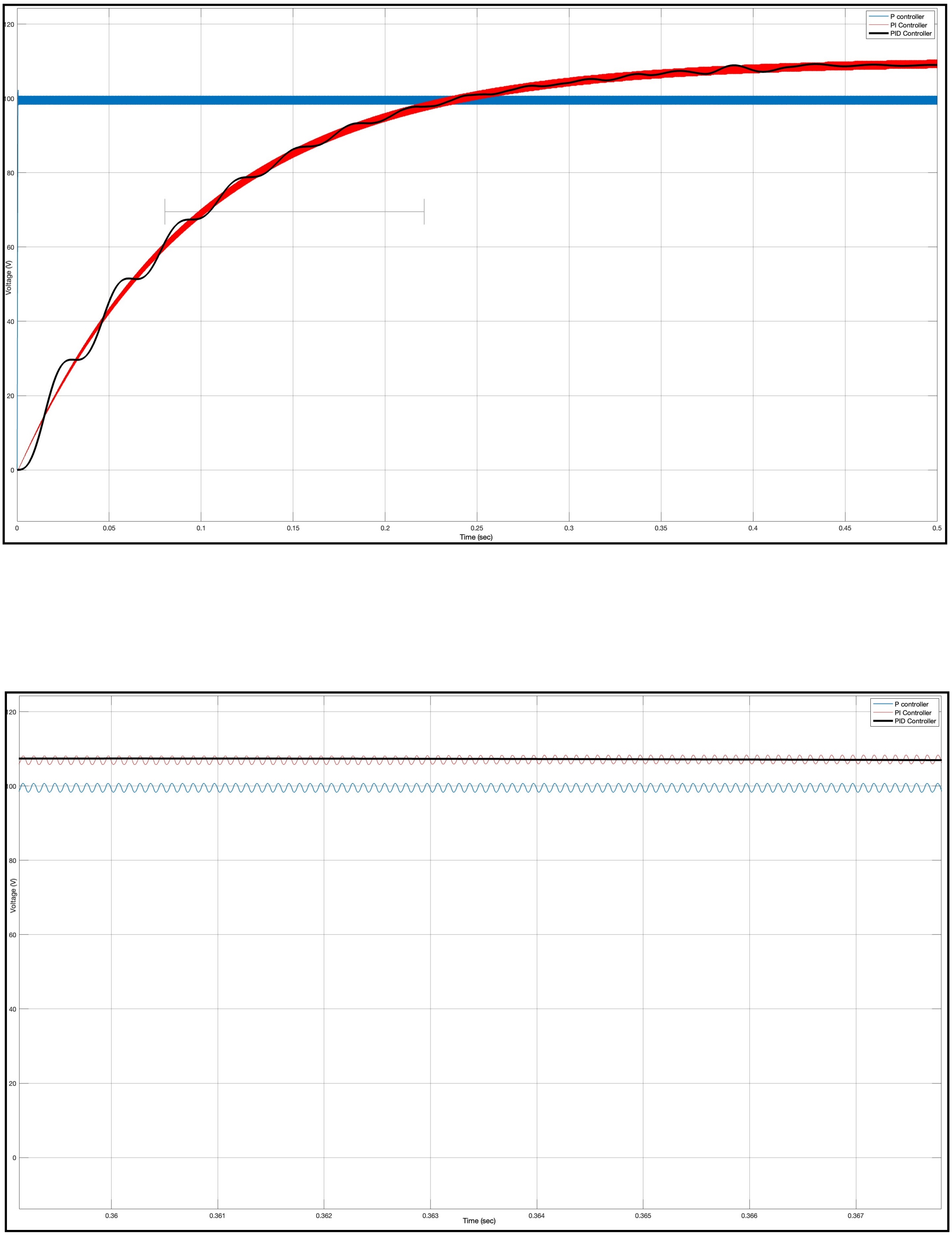

P controller
PI Controller
PID Controller
Voltage (V)
Time (sec)
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.36
0.361
0.362
0.363
0.364
0.365
0.366
0.367

**Figure 4**

## Conclusion

From Figure 4 it is known which controller is best suited for the buck converter. In conclusion, the direct synthesis method offers a powerful and systematic approach to designing controllers for buck converters, ensuring precise control and optimal performance. By defining a desired closed-loop transfer function and deriving the corresponding controller transfer function, this method allows for precise shaping of the system's response. The benefits of the direct synthesis method include improved stability, flexibility, and simplified design process, making it ideal for a wide range of applications.Through the design and simulation of P, PI, and PID controllers, it has been demonstrated that each controller type offers unique advantages. The **P controller** provides straightforward proportional control, the **PI controller** eliminates steady-state error for enhanced accuracy, and The **PID controller** offers the best performance among the three, with minimal overshoot, fast settling time, and negligible steady-state error.The simulations show that employing the right controller can significantly enhance the performance of a buck converter, ensuring stable and efficient voltage regulation.

Overall, the direct synthesis method proves to be an effective tool for controller design, offering a clear path to achieving desired performance criteria in buck converters and other dynamic systems. By leveraging this method, designers can ensure that their power supply systems are both efficient and reliable, meeting the demands of modern electronic applications.