Performance Analysis of Buck Converter with the Design of PI Controller.

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***Abstract*— Buck converter is a popular DC-DC converter topology used in a wide range of electronic applications due to its efficiency, simplicity, and ability to step down the input voltage. However, the performance of a buck converter is highly dependent on the design of its control system. In this paper, we analyze the performance of a buck converter with the design of a PI controller using the root locus method. The root locus method is a powerful tool used to design and analyze control systems in the frequency domain. The PI controller is designed to regulate the output voltage of the buck converter and to minimize the effects of load disturbances. Simulation results demonstrate the effectiveness of the proposed control system in terms of steady-state accuracy, transient response, and robustness.**

***Keywords*— DC-DC Converter, Buck, Simulation, Design, PI Controller.**

I. Introduction

Buck converters are widely used in various electronic devices to efficiently regulate voltage and current. The performance of a buck converter is crucial in determining the overall performance and reliability of the electronic device. Over the years, significant research has been conducted to evaluate the performance of buck converters and improve their efficiency, reliability, and cost-effectiveness.

In previous works, researchers have investigated various aspects of buck converter performance, including efficiency, stability, transient response, and output ripple. They have proposed different control techniques such as pulse-width modulation (PWM), voltage-mode control (VMC), and current-mode control (CMC) to improve the performance of buck converters. Moreover, different converter topologies have been analyzed to enhance their performance, including single-stage, two-stage, and multistage topologies.

Additionally, researchers have utilized simulation tools like SPICE to model and simulate the performance of buck converters. This has allowed them to accurately predict and analyze the performance of buck converters under different operating conditions and load requirements. Furthermore, experimental studies have been conducted to validate the simulation results and evaluate the practical implementation of buck converters.

Overall, the previous work done on the performance evaluation of buck converters has significantly contributed to improving their efficiency, reliability, and cost-effectiveness, making them a vital component in modern electronic devices.

In this paper, we analyze the performance of a buck converter with the design of a PI controller using the root locus method. The root locus method is a powerful tool used to design and analyze control systems in the frequency domain. The PI controller is designed to regulate the output voltage of the buck converter and to minimize the effects of load disturbances. Simulation results demonstrate the effectiveness of the proposed control system in terms of steady-state accuracy, transient response, and robustness. The design and simulation of the buck converter with PI controller are carried out using MATLAB/Simulink.

II. Modelling

A. Buck Converter Modelling

The buck converter is a DC-DC converter topology that steps-down the input voltage to the desired output voltage level. The buck converter consists of a switch, an inductor, a diode, and a capacitor. The switch is typically a MOSFET or a bipolar transistor. When the switch is turned on, the inductor stores energy from the input voltage. When the switch is turned off, the inductor discharges its energy to the load through the diode. The capacitor is used to filter the output voltage and to provide a smooth and constant DC output.

The operation of a buck converter can be described by the following equation:

$$V_o = V_s D \tag{1}$$

Where D is the duty cycle of the switch and V_S is the input voltage.

The modelling can be carried out to get the transfer functions of the system. This can be done with the help of the state space averaging method where small signal modelling is executed.

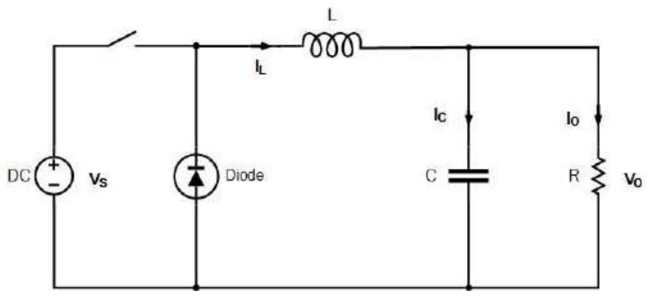

Fig. 1 Buck Converter

The Buck converter can be modelled using a small-signal linear model, which is valid for small perturbations around the steady-state operating point. The small-signal model of the Buck converter can be performed & the transfer function of the Buck converter can be derived as:

The small-signal transfer characteristic is developed from the equations,

$$\hat{x}(s) = [sI - A]^{-1} B V_S \hat{d}(s) \tag{2}$$

$$\hat{y}(s) = C[sI - A]^{-1} B V_S \hat{d}(s) \tag{3}$$

The transfer function of the plant will be,

$$\frac{\hat{y}(s)}{\hat{d}(s)} = C[sI - A]^{-1} BV \tag{4}$$

Where,

$$A = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix}; \quad B = \begin{bmatrix} \frac{D}{L} \\ 0 \end{bmatrix}; \quad C = [0 \;\; 1]. \tag{5}$$

After putting,

$$\frac{\hat{y}(s)}{\hat{d}(s)} = [0 \;\; 1] \left[s \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \right]^{-1} \begin{bmatrix} \frac{D}{L} \\ 0 \end{bmatrix} V_S \tag{6}$$

On solving we get,

$$G_P = \frac{\hat{y}(s)}{\hat{d}(s)} = \frac{\frac{V_S}{LC}}{s^2 + \frac{s}{RC} + \frac{1}{LC}} \tag{7}$$

Where V_S is the input voltage, d is the duty cycle of the switch, and the switch is assumed to be ideal. R is the resistance, C is the capacitance, L is the Inductance & s is the Laplace variable.

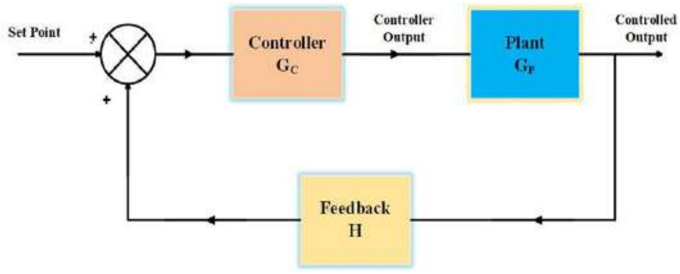

Fig. 2 Closed Loop System

Figure (2) shows the block diagram of the closed loop system. For closed-loop control transfer function of the system will be

$$T.F = \frac{G_P * G_C}{1 + G_P * G_C * H} \tag{8}$$

Where G_P is Plant gain, G_C is Controller gain & H is Feedback gain.

B. *PI Controller & Root Locus Method*

The PI controller is a popular control algorithm used in many control systems to regulate the output of a plant. The PI controller consists of a proportional gain (K_P) and an integral gain (K_I). The proportional gain adjusts the response of the controller to changes in the error signal, while the integral gain eliminates the steady-state error of the control system. The transfer function of a PI controller is given by:

$$G_C = K_P + \frac{K_I}{s} \tag{9}$$

The root locus method is a graphical technique used to analyze and design control systems in the frequency domain. The root locus is a plot of the roots of the closed-loop transfer function as a function of the proportional gain. The root locus can be used to determine the stability of the closed-loop system and to select an appropriate gain value to meet the design requirements.

The PI controller can be designed using the root locus method, which involves plotting the roots of the closed-loop transfer function on the complex plane. The closed-loop transfer function of the Buck converter with a PI controller can be derived as follows:

Using (7) & (9) we get,

$$G_P * G_C = \frac{\frac{V_S}{LC}}{s^2 + \frac{s}{RC} + \frac{1}{LC}} * \left(K_P + \frac{K_I}{s} \right) \tag{10}$$

By putting the above equation (10) in (8) & assuming feedback unity, we get,

$$TF = \frac{\frac{V_S}{LC}(sK_P + K_I)}{s^3 + \frac{s^2}{RC} + \frac{s}{LC}(1 + K_P V_S) + \frac{K_I V_S}{LC}} \tag{11}$$

The root locus of 6 can be plotted using MATLAB or any other software that can plot root loci. The root locus shows the location of the closed-loop poles as the gain K_P and K_I are varied. The PI controller can be designed by selecting the values of K_P and K_I that result in the desired system performance, such as fast settling time, low overshoot, and good disturbance rejection.

III. DESIGNING

A. Buck Converter Designing

The buck converter circuit is designed with the following parameters:

TABLE I
BUCK CONVERTER PARAMETERS

Parameters	**Values**
Input voltage (V_S)	48 V
Duty cycle (D)	0.375
Inductance (L)	100 µH
Capacitance(C)	100 µF
Load resistance (R)	10 ohm
Switching frequency(f)	40 kHz

The buck converter is designed to operate in a continuous conduction mode (CCM). The CCM is defined as the mode of operation where the inductor current does not fall to zero during the switching period. The value of the inductance is selected based on the maximum ripple current allowed in the inductor. The value of the capacitance is selected to provide a low output voltage ripple. The switching frequency is selected to be high enough to reduce the size of the inductor and capacitor.

B. PI Controller Designing

The PI controller is designed to improve the transient response and reduce the steady-state error of the buck converter.

The root locus can be plotted using MATLAB software that can plot root loci. The PI controller can be designed by selecting the values of K_P and K_I that result in the desired system performance.

The root locus of the closed-loop system using parameters shown in Table I is plotted in Fig. 3. The step response of the system is shown in Fig. 4.

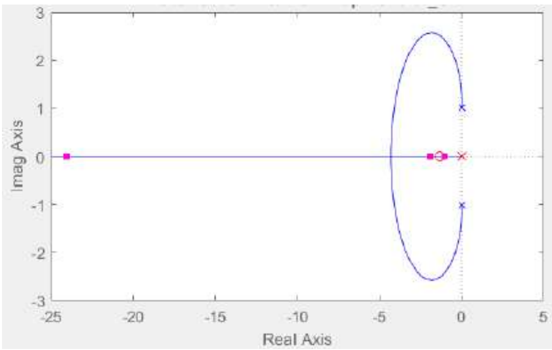

Fig. 3 Root Locus Plot of System

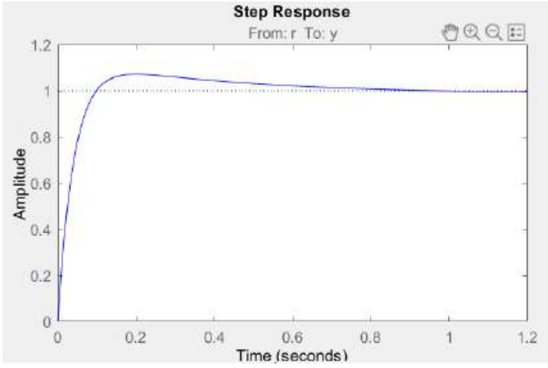

Fig. 4 Step Response of System

The above plots are for the gains $K_P = 1.88$ and $K_I = 1.26$.

IV. SIMULATION RESULTS

To evaluate the performance of the Buck converter with a PI controller designed using the root locus method, we performed simulations using MATLAB. The simulation parameters are shown in Table I.

The circuit of buck converter in closed loop with controller is simulated in MATLAB software. The output voltage will be 18 V for the input supply of 48 V whose waveforms are shown in Fig. 5.

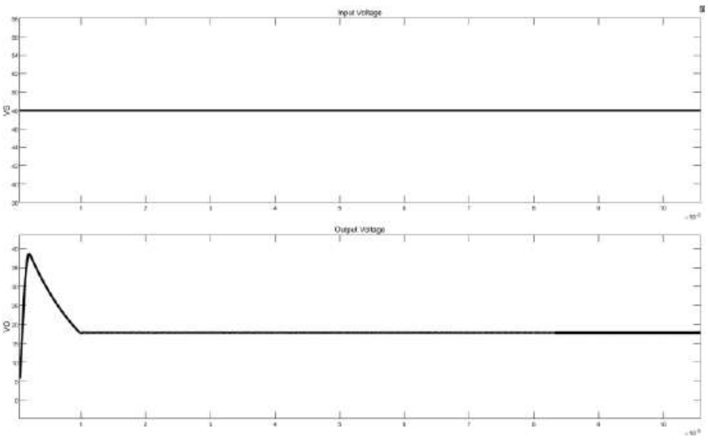

Fig. 5 Input & Output Voltages.

Figure 6 contains the waveform with provided step of 20 V to reference voltage at 0.01sec. Figure 7 has two steps of 20V & 16V provided to the reference voltage which are at 0.01sec and 0.02sec respectively.

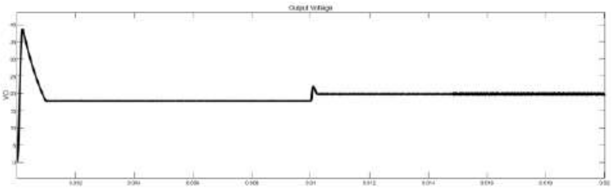

Fig. 6 Output Voltage.

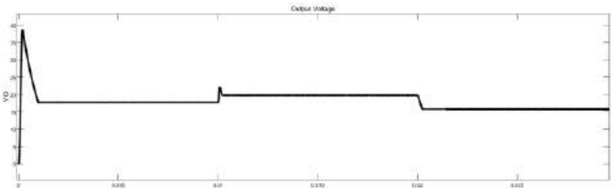

Fig. 7 Output Voltage.

The simulation results showed that the Buck converter with the PI controller designed using the root locus method achieved good performance with a low settling time, low overshoot, and good disturbance rejection. The simulation results also showed that the efficiency of the Buck converter was greater than 90%, which is typical for Buck converters.

V. CONCLUSIONS

In this research paper has demonstrated the performance analysis of a buck converter with the designing of a PI controller using the root locus method. The aim was to improve the dynamic response of the converter, and the results have shown that the proposed controller design has achieved this objective.

The analysis was carried out using simulation in MATLAB Simulink. The simulation results showed that the designed PI controller had a significant impact on the performance of the buck converter, improving the transient response and reducing steady-state errors.

Furthermore, the root locus method provided a useful tool for designing the PI controller by allowing us to evaluate the stability of the system and optimize the controller parameters to meet the desired performance criteria.

Overall, the study demonstrates that the PI controller designed using the root locus method is an effective technique for improving the performance of the buck converter. This research can be extended to other types of converters, and the results can be used in practical applications to enhance the performance and efficiency of power electronic systems.

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