MATLAB Based Graphical User Interface for Parameter Computation of Type II and Type III Controllers for DC DC Converters

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Abstract: A MATLAB-based graphical user interface (GUI) is presented for the optimal design of Type II and Type III controllers for DC-DC converters, including buck, boost, and buck-boost types. This GUI combines traditional design methods with computational algorithms, allowing users to automatically calculate and display the required parameter values for both controller types. It simplifies the design process while, at the same time making sure that the converters operate with enhanced stability, faster transient response, and reduced steady-state error. This interface thereby supports optimization under various conditions of operation, thus facilitating the gap between theoretical analyses and practical implementation, making it easier for engineers to achieve optimal.

1 INTRODUCTION

This study focuses on the development of an advanced and user-friendly boundary breaker for both Type II and Type III controllers in DC -In DC converters. These converters are essential components of power management systems in all modern electronics and require precision to ensure robustness and efficiency. The design boundary grid implemented in MATLAB is mainly designed to allow the calculation of compensator parameters, thereby simplifying, and simplifying the design process for engineers and researchers. This paper aims to improve the stability and performance of DC-DC converters on different topologies, including buck, boost and buck-boost configurations. The core of this paper is to determine a MATLAB-based design boundary that lets users input specific parameters for the DC-DC converters.

Once this information is obtained, the bounding unit determines compensator parameter values with traditional methods and computation algorithms both for Type II and Type III compensators. This automated process not only speeds up the design process but reduces the risk of errors, something which ensures timely and careful planning. The heat socket further improves the design by generating various frequency curves for the DC-DC converter, providing visual insight into the frequency response of the system and aiding in the analysis of stability and yield. The primary goal of this paper is to analyze and optimize stability for DC-DC converters using type II and type III controllers. By analyzing the performance of these two types, the paper intends to identify the optimal conditions under which each controller and converter makes itself manifest.

The ability to easily switch between Type II and Type III controllers within the interface gives the engineers enough flexibility to address various

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operational scenarios and performance demands. Adaptability is actually very important because different topologies of DC-DC converters and load conditions necessarily require different control strategies to acquire optimal performance. In this regard, the interface allows for a more tailored approach to design with the incorporation of both types of controllers; hence, each converter achieves the highest level of stability and efficiency regardless of the specifics of the application or environment. The paper further explores how these controllers impact the transient and steady-state error of DC-DC converters. Using careful tuning of compensator parameters, the interface minimizes such critical metrics for the performance results in faster response times and stable operations.

2 LITERATURE REVIEW

The vast literature provides various strategies to control and optimize DC-DC converters, which continue to advance in this field. There is one innovation introduced through a tri- state buck-boost converter with an optimized Type-3 controller using Particle Swarm Optimization (PSO), which effectively removes the RHP zero of conventional buck- boost converters, providing greatly improved control-to-output stability and dynamic parameters and open-loop gain visualization for various topologies like buck, boost, or buck-boost converters. The result is a streamlined design for controllers that ensures better transient and steady-state responses. In addition, the robustness and flexibility of PID controllers on DC-DC converters are highlighted. On voltage-mode buck converters, digital PID controllers have shown much higher phase margins and better stability and overall performance with such digital control elements as ADCs and digital PWM

Another detailed investigation regarding Type-II and Type- III controllers is that the controllers have transient responses and also achieve a good steady state in high-order converters, such as fourth-order systems. Models like these were tested for the practical case with the help of MATLAB-Simulink simulations. The studies on the application of classical PID controllers to boost converters emphasize the ability to maintain voltage regulation, even in the presence of variations due to input and load conditions, with some minimizing harmonic distortion, improving power factors, and maximizing efficiency. However, Type-II controllers provide easier implementations and satisfactory performance for certain applications, so there is still scope to carry out a comparison. Algorithmic developments, incorporating PSO and hybrid techniques, have been routinely applied to fine-tune the controller parameters for best performance, tackling challenges such as reduced settling time and better dynamic response. Relative studies also express the need for controller selection to enhance the reliability of power conversion systems used in critical applications, such as renewable energy, power grids, and telecommunications. This also proved that practical challenges in achieving consistent control of DC-DC converters under varying load currents and input voltage conditions are acknowledged by the research, especially in industrial applications. Despite these advances, the integration of generalized interfaces, unified frameworks, and broader topological applicability remains limited, indicating a fragmented research landscape that calls for consolidation.

Reviewing the presented studies reveals significant results but also some significant gaps. Present work has been much focused on Type-III controllers and their application on the different types of converters while the focus on Type-II controllers is less. This creates a comparative gap in understanding applications that could be linked with this. Most works concentrate on specific converters, for instance, on a buck or boost and do not present generalized design interfaces that may accommodate a broader range of converters, like buck-boost. While techniques such as PSO and advanced algorithms are applied for controller tuning in the techniques used are highly scenario-specific and cannot be generalized to multiple controllers or different topologies optimization techniques, and comparative evaluations of diverse controller types.

3 METHODOLOGY

The methodology in this paper is understood to be an organized and detailed approach towards the designing of a Graphical User Interface (GUI) aimed at the optimization of the design and analysis of the Type II and Type III controllers for DC-DC converters. The first stage consisted of meticulous literature reviews and theoretical analysis to lay down the understanding from a fundamental point of control strategies for DC-DC converters, primarily Type II and Type III compensators. This stage incorporates a detailed study of mathematical modelling and transfer functions relevant to various types of converters, such as buck, boost, and buck-boost. Ideally, the goal is to create a fundamental basis for the subsequent stages. Following the theoretical foundations, system modelling and simulation is the next step, where the selected DC-DC converters are modelled using MATLAB/Simulink. In the discussion that follows, building small-signal models and derivation of transfer functions for each converter type permits an accurate simulation of the converters' open-loop behavior, thus gaining insight into their inherent system dynamics. In the controller design and parameter selection phase, Type II and Type III compensators are designed based on the previously derived transfer functions. This involves employing Bode plot analysis to fine-tune the compensator parameters—such as gain, poles, and zeros—to achieve the desired stability and performance criteria. The goal of this step is to ensure an adequate transient response and steady-state performance, enhancing the controller's overall efficiency and robustness.

3.1 K-Factor Method

K Factor was created primarily to assist in the determination of amplifier R and C values. This is defined as the root of the ratio of the pole to the zero frequency in Type 2 controllers and the ratio of double pole frequency over double zero in Type 3 amplifiers. Choose a cross-over frequency, desired phase margin, determine the required amplifier gain and calculate the required phase boost. Calculate the Phase boost using Eq. 1 (Prokopev et al., 2019).

$$Boost = M - P - 90 \tag{1}$$

Where, M = desired phase margin (degrees) and p = modulator phase shift (degrees). The mentioned expressions apply to Type 2 amplifiers only.

$$K = Tan\,[(\frac{Boost}{2}) + 45] \tag{2}$$

converters and not applicable to a wide range of variations in input-output conditions for scalable solutions or interfaces. Overall, the research is fragmented, and there is a need for a unified framework that integrates generalized interfaces,

$$C_2 = \frac{1}{2\pi f G K R_1} \tag{3}$$

$$C_1 = C_2(K_2 - 1) \tag{4}$$

$$R_2 = \frac{K}{2\pi f G} \tag{5}$$

$$K = \left\{T_a\left[\left(\frac{\boldsymbol{Boost}}{2}\right) + 45\right]\right\}2 \tag{6}$$

$$C_2 = \frac{1}{2\pi f G R_1} \tag{7}$$

$$C_1 = C_2(K - 1) \tag{8}$$

$$R_2 = \frac{\sqrt{K}}{2\pi f G} \tag{9}$$

$$R_3 = \frac{R_1}{K-1} \tag{10}$$

$$C_3 = \frac{1}{2\pi f G\sqrt{K R_3}} \tag{11}$$

These parametric equations allow the precise calculation and error analysis of loop performance without the iterative process normally associated with stability analysis.

3.2 PSO Algorithm

Particle Swarm Optimization (PSO) is an evolutionary algorithm that optimizes the continuous or discrete, linear or nonlinear, constrained or unconstrained, and non- differentiable functions by trying iteratively to improve the solutions with respect to different parameter values (Chan et al., 2015). The key components of PSO include:

Particles: These are individual candidate solutions represented as vectors in a multidimensional space, where each vector corresponds to a set of parameters (in this case, compensator values R and C).

Position and Velocity: Each particle has a position in the search space and a velocity that determines how it moves within that space. The position of the particle represents a potential solution (e.g., a set of values for R and C), while the velocity determines how the particle updates its position in subsequent iterations.

Best Positions:

Personal best (pBest): Each particle tracks its best solution found so far in terms of the objective function.

Global best (gBest): The best solution found by any particle in the entire swarm.

Update Rules: The position and velocity of each particle are updated according to the following equations:

$$V_i^{(K+1)} = W.V_i^{(K)} + C_1 r_1\left(P_{Besti} - x_i^{(K)}\right) + C_2 r_2\left(g_{Besti} - x_i^{(K)}\right) \tag{12}$$

$$x_i^{(K+1)} = x_i^{(K)} + V_i^{(K+1)} \tag{13}$$

Where: v $^{(k)}$ is the velocity of particle i at iteration k, x $^{(k)}$ is the position of particle i at iteration k, w is the inertia weight controlling the influence of the previous velocity, c1 and c2 are acceleration coefficients that control the attraction to personal and global best positions, r1 and r2 are random numbers between 0 and 1, pBest and gBest are the personal and global best positions, respectively. The flowchart of the PSO algorithm is shown in Fig. 1.

Particle Swarm Optimization is one viable optimization technique to use in fine-tuning the parameters of control compensators, such as resistance and capacitance, to optimize system performance. Because such behavior of particles finds optimal/near-optimal solutions in the parameter space within reasonable computational time, it is, therefore, efficient in search. This places PSO as a valuable tool in compensator design to optimize system performance in any application. Then comes the simulation stage of the paper, wherein the closed-loop system would be simulated with all the designed compensators put in place. At this stage, the performance based on stability, transient response, and steady-state error is evaluated with iteration of the tuning of compensator parameters for better performance. Through this iteration, there is a refining of the compensator design to meet desired specifications in real applications. Finally, a frequency response analysis and visualization are carried out to understand and interpret the system's frequency response characteristics. With tools like Bode plots, the paper visually examines the effects of variations in parameters on system stability and performance. This stage helps us understand the trade-offs available for controller design and how decisions are made, and modifications are done to achieve an optimal balance in competing performance metrics. This approach attempts to achieve a robust, user-friendly GUI by efficiently guiding users through the intricate process of designing and analyzing Type-II and Type-III controllers for DC- DC converters.

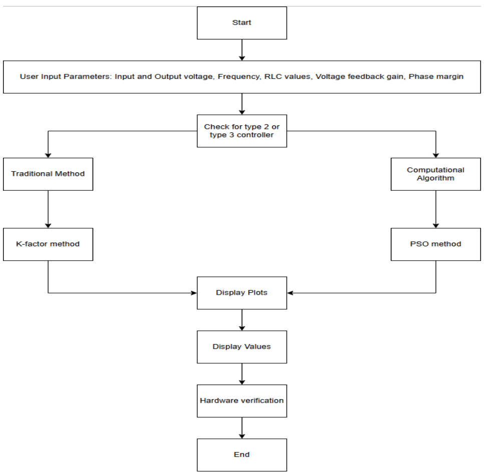


Figure 3.1: Flowchart

4 RESULTS AND DISCUSSIONS

The proposed method successfully integrates a MATLAB-based GUI for the design and analysis of Type II and Type III controllers for DC-DC converters, as shown in Fig. 2. The GUI is user-friendly and incorporates robust computational algorithms to automate the calculation of compensator parameters such as resistors and capacitors. These parameters are directly derived from the transfer functions of various converter topologies, such as buck, boost, and buck-boost, and have been seamlessly integrated into MATLAB Simulink simulations.

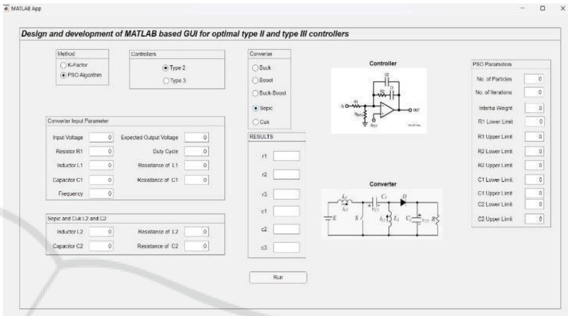


Figure 4.1: GUI

Simulation of the closed-loop behavior of DC-DC converters by the designed compensators provided a good validation of the system performance. The interface between the GUI and Simulink provides real-time visualization and analysis of the system dynamics, frequency response, and stability margins. Such analysis tools as Bode plots are very useful in giving some insight into gain and phase margins and aid in the fine-tuning of the parameters of the compensators to optimal performance. Key results achieved include:

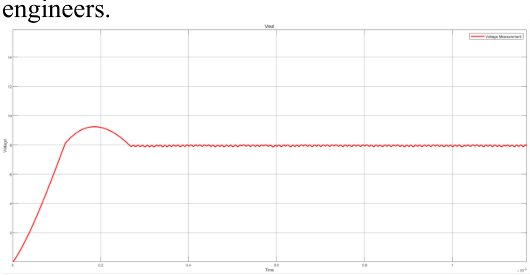
Automated Parameter Integration: The GUI successfully calculated and transferred compensator parameters to MATLAB Simulink, streamlining the design and simulation process.

Improved Converter Stability: The controllers designed via the GUI enhanced the stability of the converters, maintaining steady operation across varying load and input conditions.

Enhanced Transient Response: Simulations demonstrated faster response times and reduced overshoot, ensuring the converters' ability to handle sudden changes in input or load.

Accurate Frequency Response Visualization: Bode plots generated through the GUI provided clear insights into stability metrics and trade-offs, aiding in

iterative tuning.
Wide Applicability: The GUI's versatility in supporting multiple converter topologies validates its effectiveness as a universal tool for power electronics engineers.



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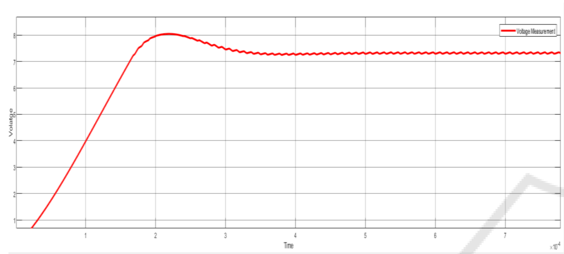


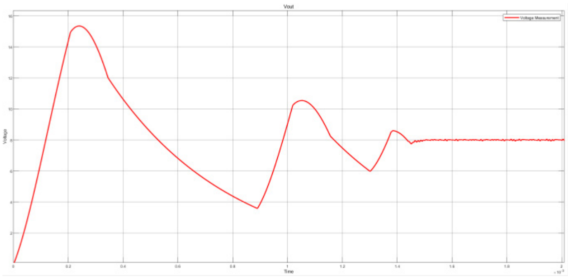
(b)

Figure 4.2.1: Output Waveform for Type -2 controller for Buck Converter; (a) K-factor, (b) PSO

From the values obtained from the GUI, it is observed that the maximum overshoot is the same for both the K-factor and PSO methods, but rise time is less in the PSO method than the K-Factor method and settling time is less in the K- Factor method than the PSO method, so it is concluded that and K-Factor and PSO method is both suitable for getting the required output for Type-III controller for the buck converter. The output voltage obtained for the buck converter with the K-factor method and PSO method is presented in Fig. 4. The time domain specifications of the buck converter with Type-II and Type-III controllers are recorded in Table I.

4.1 Type II and Type III Controller Analysis for Buck Converter

From the values obtained from the GUI, it is observed that the maximum overshoot, rise time and settling time is less in the PSO method than in the K-Factor method, so it is obvious that the PSO method is more suitable for getting the required output for Type-II controller for the buck converter. The output voltage obtained for the buck converter with the K-factor method and PSO method is presented in Fig. 3. The time domain specifications of the buck converter with Type-II and Type-III controllers are recorded in Table I.



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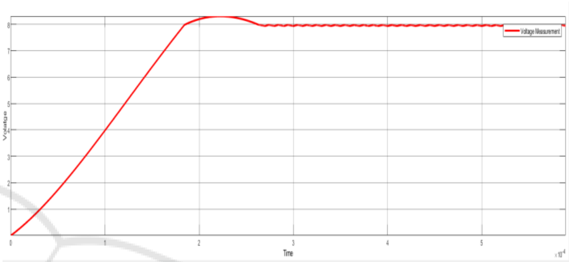


(b)

Figure 4.2.2: Output Waveform for Type -3controller for Buck Converter; (a) K-factor, (b) PSO

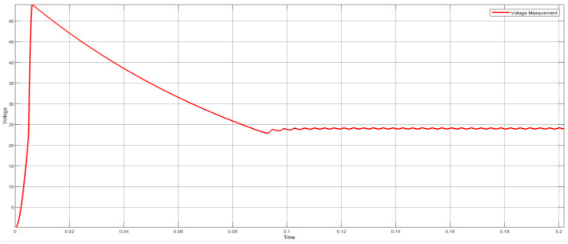
Table 1: Time Domain Specifications values for Buck converter with controllers

	Buck (Type-II)		Buck (Type-III)	
Specifications	**K-Factor**	**PSO**	**K-Factor**	**PSO**
Maximum Overshoot	15.0%	14.6%	87.5%	87.5%
Rise Time (s)	0.00118	0.00117	0.00118	0.00117
Settling Time (s)	0.00265	0.00261	0.00146	0.00196

4.2 Type II and Type III Controller Analysis for Boostconverter

From the values obtained from the GUI, it is observed that the maximum overshoot is less in the K-Factor method than the PSO method, but rise time is less in the K-Factor method than the PSO method and settling time is less in the PSO method than the K-Factor method, so it is concluded that K-Factor method is more suitable for getting the required output for Type-II controller for boost converter.

The output voltage obtained for the buck converter with the K-factor method and PSO method is presented in Fig. 5. The time domain specifications of the boost converter with Type-II and Type-III controllers are recorded in Table II.



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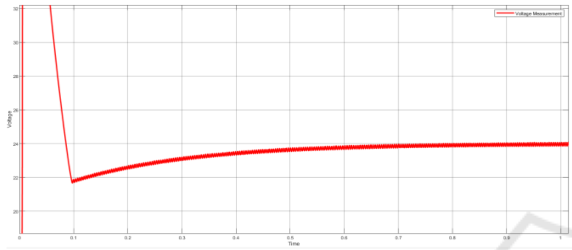

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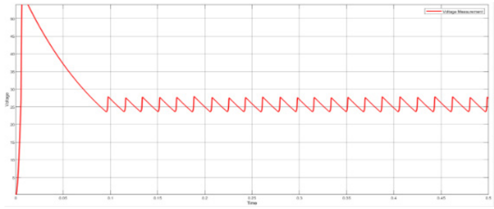
Figure 4.2.3: Output Waveform for Type-II controller for Boost Converter; (a) K-factor, (b) PSO

From the values obtained from the GUI, it is observed that the maximum overshoot is less in the K-Factor method than the PSO method, but the rise time is the same in the K- Factor method and the PSO method and settling time is less in the K-Factor method than the PSO method, so it sic concluded that K-Factor method is more suitable for getting the required output for Type-II controller for boost converter. The output voltage obtained for the buck converter with the K-factor method and PSO method is presented in Fig. 6. The time domain specifications of the boost converter with Type-II and Type-III controllers are recorded in Table II.



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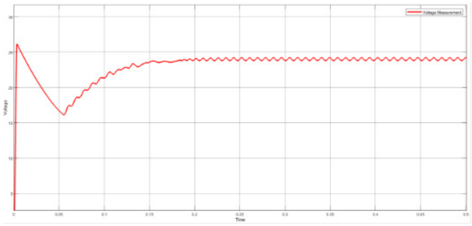
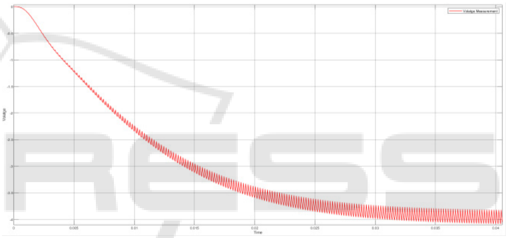


(b)

Figure 4.2.4: Output Waveform for Type-III controller for Boost Converter; (a) K-factor, (b) PSO



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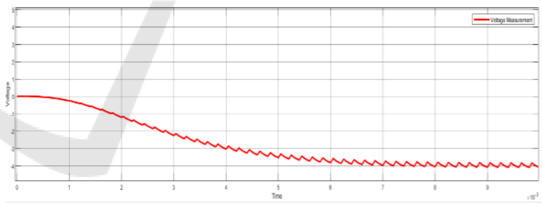
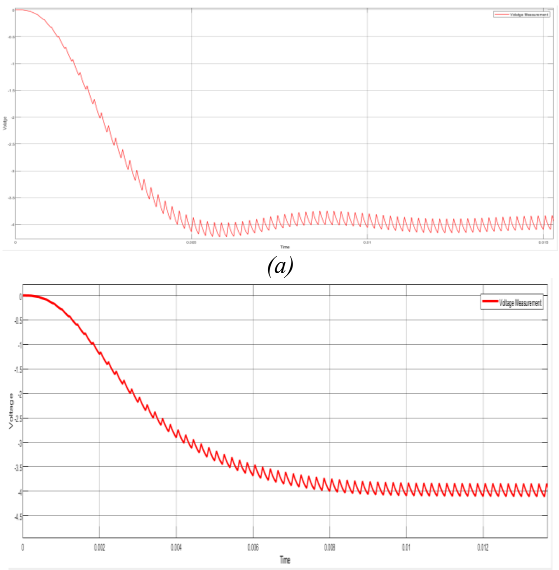


(b)

Figure 4.2.5: Output Waveform for Type-II controller for Buck- Boost Converter; (a) K-factor, (b) PSO

From the values obtained from the GUI, it is observed that the maximum overshoot, rise time and settling time are less in the K-Factor method than in the PSO method, so it is concluded that K-Factor is more suitable for getting the required output for Type-III controller for the buck-boost converter. The output voltage obtained for the buck converter with the K-factor method and PSO method is presented in Fig. 8. The time domain specifications of the buck-boost converter with Type-II and Type-III controllers are recorded in Table III



(a)

(b)

Figure 4.2.6: Output Waveform for Type-III controller for Buck-Boost Converter; (a) K-factor, (b) PSO

Table 3: Time Domain Specifications for Buck-Boost converter with controllers

	Buck-Boost (Type-II)		**Buck-Boost (Type-III)**	
Specifications	**K-Factor**	**PSO**	**K-Factor**	**PSO**
Maximum Overshoot	7.5%	5.0%	5.0%	12.5%
Rise Time (s)	0.03000	0.01640	0.00460	0.01760
Settling Time (s)	0.04020	0.02482	0.01842	0.02220

5 CONCLUSIONS

By presenting MATLAB-based GUI, the design of Type II and Type III controllers for DC-DC converters can easily be performed, in the sense that engineers can obtain optimized converter performance in terms of improved stability, faster transient response and lower steady-state error. The interface integrates computational algorithms with traditional design techniques to increase precision and efficiency in parameter selection for a wide range of converter types such as buck, boost, and buck-boost. The dual controller characteristic of GUI enables greater performance over a broad range of operating conditions between theoretical models and practical realization.

The GUI can be extended for a future scope with other converter types, such as Cuk or SEPIC converters and other control strategies such as predictive or adaptive control. Its utility could further be expanded with integration to real- time hardware in the loop testing and machine learning algorithms for automated optimization. In addition, the web-based interface would increase accessibility and usability to the broader engineering audience.

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