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(Research Article)

Design and Simulation of a Non-Isolated CUK Converter with PI Controller

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Abstract

Cuk converters are structures that convert a DC voltage to a DC voltage of varying amplitudes. Cuk converters can operate as both step-down and step-up converters. This study addresses the modeling of a non-isolated Cuk converter, its design using MATLAB Simulink software, and its simulations. A discrete-time PI controller was used to control the designed Cuk converter. The output DC voltage graph of the designed Cuk converter was obtained, and a comprehensive time response analysis was also performed. The rise time, settling time, peak time, peak voltage, and overshoot values were analyzed. A comprehensive time response analysis was conducted. The time response data indicate that the designed Cuk converter has a fast rise time, minimal overshoot, and a short settling time. The designed non-isolated Cuk converter can quickly reach the desired 60 V value. The analyses revealed that the designed Cuk converter operated successfully.

Keywords: Cuk converter; DC-DC power converters; Mathematical models; PI controller; Simulation; Voltage control

1. Introduction

Cuk converters are widely used in photovoltaic systems, wind energy systems, battery charging circuits for energy storage systems, and LED lighting [1]-[4]. Today, renewable energy systems are becoming increasingly widespread [5]. Renewable energy systems reduce environmental pollution, carbon emissions, and environmental pollution [6]. They require less maintenance and, unlike fossil fuel-powered systems, are sustainable [7]. They also enable energy independence [8]. All these advantages bring renewable energy systems to the forefront worldwide and lead to their growing demand. Battery charging circuits are needed to store the electricity generated by renewable energy systems [9]. Cuk converters are very important today because they are used in battery charging circuits [10]. Cuk converters are used as a voltage source for DC motor drives [11]-[13]. DC motors are used in air conditioners, computer drives, electric toothbrushes, portable vacuum cleaners, drilling machines, trimmers, food mixers, electric vehicles, elevators, and hoists [14]-[17]. DC motors are also used to turn the propellers of quadrotor unmanned aerial vehicles [18]-[22].

Meena et al. developed a method of reduced-order modelling for a Cuk converter. They used Kharitonov polynomials to reduce the obtained interval model [23]. Pandey et al. developed an e-bike charger using a Cuk converter followed by an LLC resonant converter [24]. Krishnamurthy et al. realized a Fuel Cell Fed Electrical Vehicle Performance Analysis with Enriched Switched Parameter Cuk (ESPC) Converter [25]. Shukla et al. developed a bridgeless buck-boost-Cuk converter-fed battery charging system for electric vehicle applications, and they improved the power factor profile [26]. Haider et al. developed a high-gain Cuk converter using a modified Cuk converter and voltage multiplier units. They performed simulations using MATLAB/Simulink and proved the advantages of their design [27]. Priyadarshi et al. proposed a switched-inductor capacitor and non-isolated high-step-up Cuk converter for a solar photovoltaic system. They designed and simulated the Cuk converter with MATLAB/Simulink [28]. Dutta et al. designed a single-phase bridgeless Cuk-derived power factor corrected (PFC) converter with reduced component count for an on-board electric

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vehicle (EV) charging application [29]. Gholizadeh et al. developed a modified Cuk-based high step-up DC-DC converter for renewable energy applications [30]. Cheng et al. designed a high step-up combined boost-Cuk converter with a switched inductor. In their work, they improved the voltage gain. They also realized a prototype to validate their simulations [31].

In this study, a non-isolated Cuk converter was modeled and controlled by a PI controller. Modeling and simulation studies were performed using MATLAB/Simulink. This study's advantage over traditional Cuk converters is its PI controller. Conventional non-isolated Cuk converters do not use a controller. In this case, the system exhibits higher overshoot, oscillates more, and it becomes more difficult to achieve the desired DC voltage value. In this work, the PI controller reduced the error and produced the desired DC output quickly. Thanks to the PI controller design, the system exhibited minimal overshoot and oscillations compared to conventional Cuk converters, reaching the desired DC voltage value with a faster settling time. Secondly, a detailed time response analysis was performed by examining the rise time, settling time, peak time, peak voltage, and overshoot data of the resulting simulated voltage output. Simulation results demonstrated that the PI-controlled non-isolated Cuk converter operated successfully and produced the desired DC voltage value.

2. Working Principles of the Non-Isolated Cuk Converter

The Cuk converter was invented in 1976 by Slobodan Ćuk, a professor at the California Institute of Technology. There are several variations of the Cuk converter. In this study, a non-isolated Cuk converter was used [32]-[34].

In a non-isolated Cuk converter, the input and output circuits share the same common ground. The non-isolated Cuk converter consists of a DC input source, input inductor *L1*, controllable switch *S*, energy transfer capacitor *C*, diode *D*, filter inductor *L2*, filter capacitor *C2*, and load resistor *R* [35], [36].

This converter transfers energy between inductor *L1*, capacitor *C1*, and inductor *L2* to convert the input DC voltage to the required output voltage. A power transistor switch, such as a MOSFET, is used to control the amount of energy transferred [37]. Off-state and on-state diagrams of the non-isolated Cuk converter are given in Figure 1.

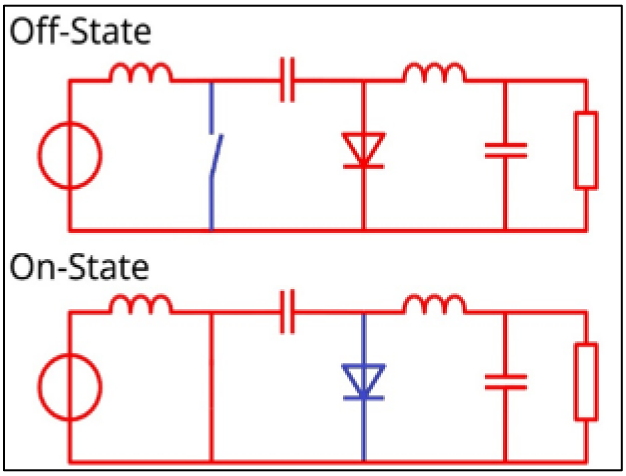

Figure 1 Off-state and on-state diagrams of the non-isolated Cuk converter

The energy in the inductor is calculated using the formula given in equation (1).

$$E = \frac{1}{2} L I^2 \quad (1)$$

The evolution of the current flowing through an inductor is related to the voltage across it. The voltage V_L is found as in equation (2).

$$V_L = L \frac{dI}{dt} \quad (2)$$

In the off-state, inductor L_1 is connected in series with V_s voltage and C_1 capacitor. Therefore, the V_{L1} voltage is obtained as in equation (3).

$$V_{L1} = V_s - V_{C1} \ (3)$$

L_2 is directly connected to the output capacitor. Therefore, the voltage V_{L2} is written as in equation (4).

$$V_{L2} = V_0 + V_C \ (4)$$

On the on-state, inductor L_1 is directly connected to the input voltage source. Therefore, the V_{L1} voltage is obtained as in equation (5).

$$V_{L1} = V_s \ (5)$$

The inductor L_2 is connected in series with the C capacitor and the output capacitor, C_0. Therefore, the V_{L2} voltage is obtained as in equation (6).

$$V_{L2} = V_0 + V_c \ (6)$$

The Cuk converter operates in the on state from $t = 0$ to $t = DT$, and D is the duty cycle. The Cuk converter operates in off-state from *D-T* to *T*, and this period equals *(1-D)T*. The average values of V_{L1} and V_{L2} are presented in equations (7) and (8), respectively.

$$\bar{V}_{L1} = (V_s - (1 - D)V_c) \ (7)$$

$$\bar{V}_{L2} = (V_0 + DV_c) \ (8)$$

Since both average voltages must be zero to ensure steady-state conditions, we can write equation (9) using the last equation:

$$V_c = -\frac{V_0}{D} \ (9)$$

Therefore, the average voltage across *L1* is written as in equation (10).

$$\bar{V}_{L1} = \left(V_s + (1 - D)\frac{V_0}{D}\right) = 0 \ (10)$$

In this case, the ratio of the output voltage to the source voltage can be written as in equation (11).

$$\frac{V_0}{V_s} = -\frac{D}{1 - D}$$

3. Modeling and Simulation of the Non-Isolated Cuk Converter

In this section, the non-isolated Cuk converter was modeled and simulated using MATLAB/Simulink. Figure 2 shows the Simulink model of the non-isolated Cuk converter operating in continuous mode and controlled by a PI controller.

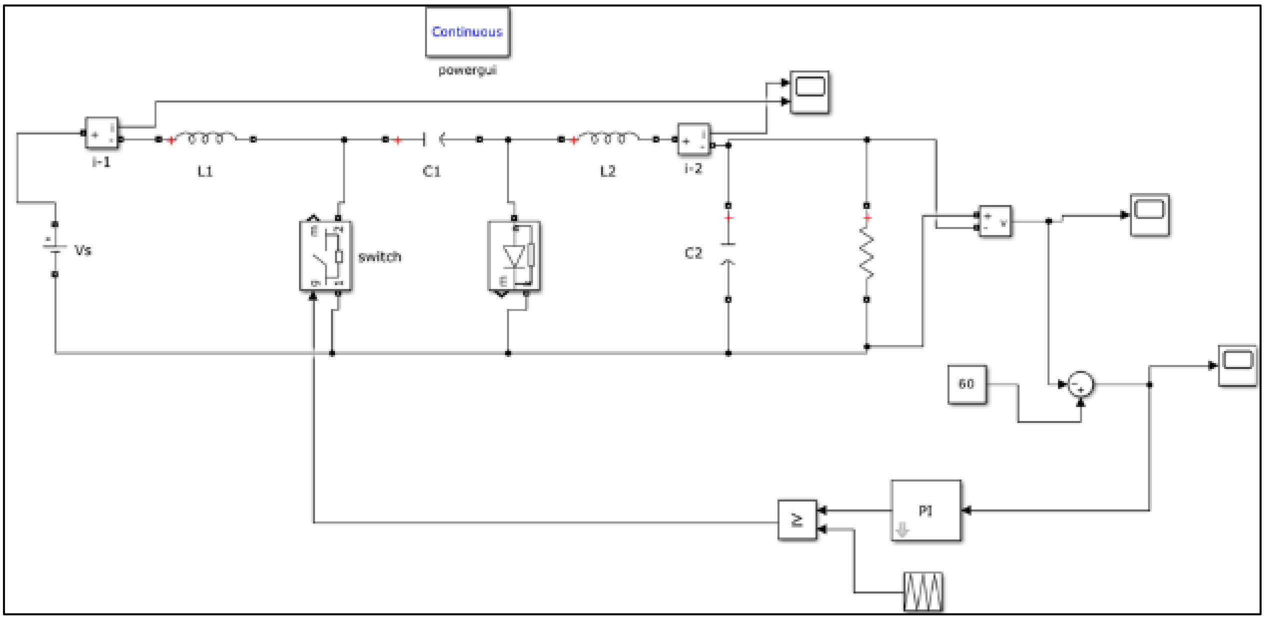

Figure 2 Simulink model of the non-isolated Cuk converter

Table 1 shows the values of the parameters used in the non-isolated Cuk converter design.

Table 1 Parameters of the non-isolated Cuk converter

Parameter	Value
L1 inductance	$0.1x10^{-3}$ H
L2 inductance	$2x10^{-3}$ H
C1 capacitor	$100x10^{-6}$ F
C2 capacitor	10^{-3} F
R resistance	100 Ω
Diode Ron resistance	0.001 Ω
Diode Lon inductance	0 H
Diode Vf forward voltage	0.8 V
Diode Rs snubber resistance	500 Ω
Diode Cs snubber capacitance	$2500x10^{-9}$ F
Switch Ron internal resistance	0.001 Ω
Switch initial state	0 (open)
Switch Rs snubber resistance	10^{-5} Ω
Switch Cs snubber capacitance	Inf F
Vs source voltage	25 V
Powergui	Continuous

A discrete-time PI controller was used to control the designed non-isolated Cuk converter. This aimed to reduce the error signal and achieve the desired DC voltage value more quickly. The PI controller was chosen because its parameters are easily adjustable and it is widely used in the industry. [38]-[40].

The coefficients of the designed discrete-time PI controller were set manually. The PI controller parameters are listed in Table 2.

Table 2 Parameters of the discrete-time PI converter

Parameter	Value
Kp proportional gain	0.01
Ki integral gain	1
Output limits [Upper Lower]	[1-1]
Output initial value	0
Sample time	$50x10^{-6}$

Figure 3 shows the DC voltage output simulation. The simulation was run for 0.5 seconds. The vertical axis represents the voltage, and the horizontal axis represents the time (s).

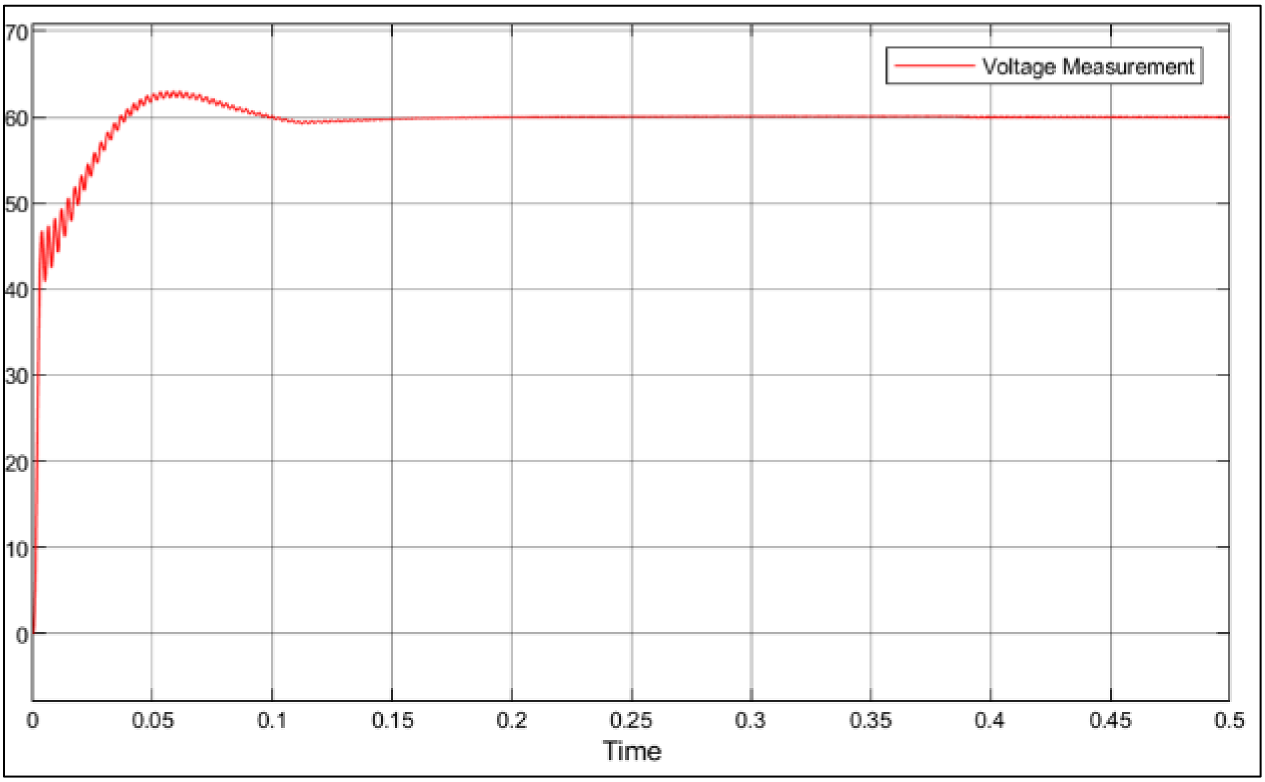

Figure 3 DC voltage output simulation

Analysis of the simulation reveals that after some oscillation, the desired 60 V value was reached. In this case, the designed Cuk converter is observed to operate successfully.

Table 3 shows the time response data of the DC voltage output simulation. Rise time, settling time, and peak time are in seconds. Peak voltage is in Volts, and overshoot is in percent. Rise time is taken as the time to reach 90% of the given reference value. Settling time is the time to settle within ± 2% of the given reference value. Peak time is taken as the time to reach the highest voltage value. Peak voltage is the highest voltage value.

Table 3 Time response data of the designed Cuk converter

Time response data	Value
Rise time (s)	0.022 s
Settling time (s)	0.079 s
Peak time (s)	0.059 s
Peak voltage (V)	63 V
Overshoot (%)	5 %

Examining the time response data, it is observed that the system's rise time is 0.022 seconds. In this case, the system quickly reaches 90% of the given reference value. The system's settling time is 0.079 seconds. Thus, the system quickly settles within 2% of the given reference value. The system's peak time is 0.059 seconds. The peak voltage is 63 volts. The overshoot is 5%. It exhibits a small overshoot and quickly reaches the reference value. The time response data show that the Cuk converter quickly reaches the desired 60V voltage.

4. Conclusion

In this study, the design and simulation of a non-isolated Cuk converter controlled by a PI controller were performed. First, the operating principles of the Cuk converter are explained. Next, the Cuk converter was modeled using MATLAB/Simulink software. The Cuk converter parameters are presented in a table. A simulation of the Cuk converter was performed. The time response data obtained from the simulation were analyzed. An examination of the output voltage of the designed Cuk converter revealed a fast rise time, minimal overshoot, and a rapid settling time. The designed Cuk converter successfully reaches the desired 60 V value in a short time.

Compliance with ethical standards

Disclosure of conflict of interest

The authors state no conflict of interest.

References

[1] Devi, V. V., & Manthati, U. B. (2024, February). Comparitive Study of Solar PV with Bidirectional CUK Converter for BESS. In 2024 IEEE International Conference on Computing, Power and Communication Technologies (IC2PCT) (Vol. 5, pp. 372-377). IEEE.

[2] Kumar PK, V., & JJ, J. (2025). Analysis and Design of CUK-SEPIC-based Converter for Hybrid Power Generation Systems. Recent Patents on Engineering, 19(2), E110124225542.

[3] Krishnamurthy, K., & Devi, V. L. (2024). Fuel cell fed electrical vehicle performance analysis with enriched switched parameter Cuk converter. Recent Advances in Electrical & Electronic Engineering, 17(10), 954-965.

[4] Kumar, K., Lakshmi Devi, V., Dhanamjayulu, C., Kotb, H., & ELrashidi, A. (2024). Evaluation and deployment of a unified MPPT controller for hybrid Luo converter in combined PV and wind energy systems. Scientific Reports, 14(1), 3248.

[5] Mızrak, F., & Akkartal, G. R. (2024). An analysis of alternative energy sources and applications in maritime transportation with a strategic management approach. Decision Making in Interdisciplinary Renewable Energy Projects: Navigating Energy Investments, 97-109.

[6] Wiredu, J., Yang, Q., Lu, T., Sampene, A. K., & Wiredu, L. O. (2025). Delving into environmental pollution mitigation: does green finance, economic development, renewable energy resource, life expectancy, and urbanization matter?. Environment, Development and Sustainability, 1-30.

[7] Reddy, V. J., Hariram, N. P., Maity, R., Ghazali, M. F., & Kumarasamy, S. (2024). Sustainable vehicles for decarbonizing the transport sector: a comparison of biofuel, electric, fuel cell and solar-powered vehicles. World Electric Vehicle Journal, 15(3), 93.

[8] Beslik, S. Financing the Transition for Energy Independence. In European Energy Independence through Investing in Renewables (pp. 79-92). Routledge.

[9] Palanisamy, S., & Lala, H. (2024). Optimal sizing of renewable energy powered hydrogen and electric vehicle charging station (HEVCS). IEEE Access, 12, 48239-48254.

[10] Sivaperumal, N., & Jothimani, G. (2024). A single-stage bridgeless isolated positive output Cuk configuration-based unidirectional onboard battery charger. International Journal of Circuit Theory and Applications, 52(1), 396-419.

[11] Jacob, M., & Aishwarya, V. (2016, March). Sensorless brushless DC motor drive fed by Cuk converter. In 2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT) (pp. 1-7). IEEE.

[12] Dhanasekar, R., Aishwari, S., Vijayaraja, L., Kumar, S. G., & Rivera, M. (2024, November). Control of Cuk Converter Fed Brushless DC Motor Drive System. In 2024 IEEE Silchar Subsection Conference (SILCON 2024) (pp. 1-6). IEEE.

[13] Arshad, M. H., & Abido, M. A. (2021). Hierarchical control of DC motor coupled with Cuk converter combining differential flatness and sliding mode control. Arabian Journal for Science and Engineering, 46(10), 9413-9422.

[14] Karahan, M. (2024, April). Modeling of a DC Motor and Position Angle Control Using Optimized PID Controller. In 2024 11th International Conference on Electrical and Electronics Engineering (ICEEE) (pp. 107-110). IEEE.

[15] Villanueva, D., Cordeiro-Costas, M., Feijoo-Lorenzo, A. E., Fernandez-Otero, A., & Miguez-Garcia, E. (2021). Towards DC energy efficient homes. Applied Sciences, 11(13), 6005.

[16] Vlachou, V. I., Karakatsanis, T. S., & Kladas, A. G. (2023). Energy savings in elevators by using a particular permanent-magnet motor drive. Energies, 16(12), 4716.

[17] Baranidharan, M., & Singh, R. R. (2023). Solar-Powered Gearless Elevator Drive Control Using Four Quadrant DC to DC Converter System. In Advanced Power Electronics Converters for Future Renewable Energy Systems (pp. 83-104). CRC Press.

[18] Karahan, M. (2025). Robust Backstepping Control of a Quadrotor Unmanned Aerial Vehicle under Colored Noises. Computers, Materials and Continua, 82(1), 777-798.

[19] Karahan, M. (2024). Nonlinear Modelling and Robust Backstepping Control of a Quadcopter in Aggressive Maneuvering. Studies In Informatics and Control, 33(3), 29-38.

[20] Karahan, M., Kasnakoglu, C., & Akay, A. N. (2023). Robust Backstepping Control of a Quadrotor UAV under Pink Noise and Sinusoidal Disturbance. Studies in Informatics and Control, 32(2), 15-24.

[21] Karahan, M., & Kasnakoglu, C. (2021). Modeling a Quadrotor Unmanned Aerial Vehicle and robustness analysis of different controller designs under parameter uncertainty and noise disturbance. Journal of Control Engineering and Applied Informatics, 23(4), 13-24.

[22] Karahan, M. (2024). Reinforcement Learning and PD Control Based Trajectory Tracking for a Quadcopter UAV. Journal of Computer Science and Technology Studies, 6(4), 131-141.

[23] Meena, V. P., & Singh, V. P. (2022). Kharitonov polynomial-based interval reduced order modelling of cuk converter. International Journal of Modelling, Identification and Control, 41(3), 231-242.

[24] Pandey, R., & Singh, B. (2021). A Cuk converter and resonant LLC converter based E-bike charger for wide output voltage variations. IEEE Transactions on Industry Applications, 57(3), 2682-2691.

[25] Krishnamurthy, K., & Devi, V. L. (2024). Fuel cell fed electrical vehicle performance analysis with enriched switched parameter Cuk converter. Recent Advances in Electrical & Electronic Engineering, 17(10), 954-965.

[26] Shukla, T., Prasad Patidar, N., & Adhikari, A. (2023). A power factor profile-improved EV charging system using bridgeless Buckboost-Cuk converter. International Transactions on Electrical Energy Systems, 2023(1), 9713102.

[27] Haider, Z., Ulasyar, A., Khattak, A., Zad, H. S., Mohammad, A., Alahmadi, A. A., & Ullah, N. (2022). Development and analysis of a novel high-gain CUK converter using voltage-multiplier units. Electronics, 11(17), 2766.

[28] Priyadarshi, N., Bhaskar, M. S., Azam, F., Singh, M., Dhaked, D. K., Taha, I. B., & Hussien, M. G. (2022). Performance evaluation of solar-PV-based non-isolated switched-inductor and switched-capacitor high-step-up cuk converter. Electronics, 11(9), 1381.

[29] Dutta, S., Gangavarapu, S., Rathore, A. K., Singh, R. K., Mishra, S. K., & Khadkikar, V. (2022). Novel single-phase Cuk-derived bridgeless PFC converter for on-board EV charger with reduced number of components. IEEE Transactions on Industry Applications, 58(3), 3999-4010.

[30] Gholizadeh, H., Gorji, S. A., Afjei, E., & Sera, D. (2021). Design and implementation of a new cuk-based step-up DC–DC converter. Energies, 14(21), 6975.

[31] Li, H., Cheng, L., Sun, X., & Li, C. (2022). High step-up combined boost-Cuk converter with switched-inductor. IET Power Electronics, 15(15), 1664-1674.

[32] Sovik, G. (2020). Volume-Constrained High-Coversion Ratio Dc-Dc Converters (Doctoral dissertation, Ben-Gurion University of the Negev).

[33] Driantama, N., Dahono, A., Rizqiawan, A., & Furqani, J. (2024). Analysis of the effect of mutual inductance on reducing output current ripple of the modified DC-DC Cuk converter. International Journal of Power Electronics and Drive Systems (IJPEDS), 15(2), 1017-1030.

[34] Kathi, L. (2020). Small-signal analysis of non-isolated Cuk DC-DC converter (Doctoral dissertation, Wright State University).

[35] Venugopal, R., Chandrasekar, B., Savio, A. D., Narayanamoorthi, R., Aboras, K. M., Kotb, H., ... & Elgamli, E. (2023). Review on unidirectional non-isolated high gain DC–DC converters for EV sustainable DC fast charging applications. IEEE Access, 11, 78299-78338.

[36] Almalaq, Yasser, "Design and Analysis of a Non-Isolated High Gain Step-Up Cuk Converter" (2019). Electronic Theses and Dissertations. 1558. https://digitalcommons.du.edu/etd/1558

[37] Almalaq, Y., & Matin, M. (2018). Three topologies of a non-isolated high gain switched-inductor switched-capacitor step-up cuk converter for renewable energy applications. Electronics, 7(6), 94.

[38] Karahan, M., & Kasnakoglu, C. (2022, April). Stability analysis and optimum controller design for an inverted pendulum on cart system. In 2022 International Conference on Smart Information Systems and Technologies (SIST) (pp. 1-4). IEEE.

[39] Karahan, M., & Kasnakoglu, C. (2019, June). Modeling and simulation of quadrotor UAV using PID controller. In 2019 11th International Conference on Electronics, Computers and Artificial Intelligence (ECAI) (pp. 1-4). IEEE.

[40] Karahan, M., Akay, A. N., & Kasnakoglu, C. (2021, October). Nonlinear modeling and robust control of a quadrotor uav under uncertain parameters and white gaussian noise. In 2021 5th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT) (pp. 252-256). IEEE.