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Control of SEPIC Converter Using Advanced Non-Linear Control Technique for Electric Vehicle Applications

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A B S T R A C T

This paper presents a sliding-mode input–output linearization controller for a DC/DC zero-voltage switching (ZVS) CLL-T resonant converter. The proposed control strategy enhances transient response and disturbance rejection while maintaining closed-loop stability. A large-signal dynamic model of the converter, derived without small-signal approximations, serves as the foundation for the controller design, ensuring accurate prediction of system behaviour. A novel discrete self-sustained oscillating modulation (DSSOM) technique is integrated with the controller to achieve ZVS operation across a wide load range while limiting the regulating frequency range. The combination of the controller and modulation technique provides robustness, fast transient response, and improved efficiency. Theoretical predictions are validated through experimental and simulation results, demonstrating the superior performance of the nonlinear controller compared to conventional linear controllers.

Keywords: Non-linear controller, resonant converter, zero-voltage switching, sliding-mode control.

INTRODUCTION

As the demand for electric vehicles (EVs) continues to rise, the need for efficient and reliable power conversion systems has become increasingly critical. Among the various power electronics solutions, the Single-Ended Primary Inductor Converter (SEPIC) offers significant advantages due to its ability to provide both step-up and step-down voltage regulation with a non-inverted output. This makes it highly suitable for EV applications, where the input voltage from the battery can vary widely under different load and operating conditions. However, conventional control methods often struggle to maintain optimal performance in the presence of system nonlinearities, parameter variations, and external disturbances typical of EV environments.

To overcome these challenges, advanced non-linear control techniques are being employed to regulate the SEPIC converter more effectively. Techniques such as sliding mode control, back stepping, and adaptive control provide enhanced dynamic response, robustness, and improved system stability compared to traditional linear controllers. By integrating these advanced control strategies, the SEPIC converter can maintain consistent performance, improve energy efficiency, and extend the overall lifespan of the electric vehicle's power system. This research explores the application of non-linear control techniques in managing SEPIC converters, aiming to contribute toward the development of more reliable and efficient EV powertrains.

1. Methodology

The methodology involves modelling EV powertrains using differential algebraic equations, designing a Sliding Mode Control (SMC)-based controller, and implementing the Discrete Sliding Surface Observer Modulation (DSSOM) technique for improved transient response. Performance is evaluated through MATLAB simulations and hardware testing, comparing SMC with conventional control methods to ensure robustness, efficiency, and enhanced nonlinear control in EV applications.

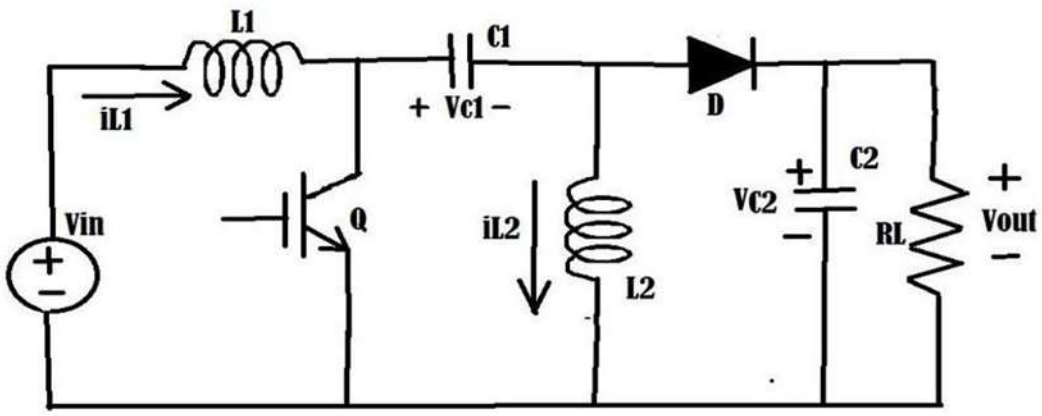

Fig-1: Circuit Diagram of SEPIC Converter

The Sliding Mode Control (SMC) methodology for Electric Vehicles (EVs) addresses nonlinear dynamics, robustness, and transient response challenges. It begins with system modelling of the EV powertrain using differential algebraic equations (DAEs) and derives an averaged model for non-isolated SIMO converters via the quasi-Weier strass transformation.

An SMC-based controller is then designed with a sliding surface for stability and rapid disturbance response. The DSSOM technique enhances transient performance by optimizing the control angle γ. The controller is tested through MATLAB/Simulink simulations, comparing PID, Fuzzy Logic, MPC, and FOC based on response time, accuracy, and disturbance rejection. Hardware validation follows, using a DC-DC SIMO converter, power electronics, and a digital controller, assessing voltage regulation, transient response, and efficiency. This approach ensures a robust and efficient nonlinear control system, improving EV performance over conventional techniques.

2. Equations used in modelling

The differential equation for inductor current can be written as follows:

$$\frac{di_{L1}}{dt} = \frac{1}{L_1}\left(V_{in} - R_i i_{L1} - (V_{c1} + V_{out})(1 - V)\right)$$

where V denotes the switching state, which is 1 for ON state and 0 for OFF state. The continuous-tir derivative of i_{L1} can be approximated in discrete-time using Euler's forward method as follows:

$$\frac{di_{L1}}{dt} = i_{L1}(k+1) - i_{L1}(k)\frac{t_s}{T_s}$$

where T_s is the sampling period. By using equations (1) and (2), the future value of i_{L1} at $k+1$ sampling interval can be obtained as:

$$i_{L1}(k+1) = i_{L1}(k) + \frac{T_s}{L_1}\left(V_{in}(k) - R_i i_{L1}(k) - (V_{c1}(k) + V_{out}(k))(1 - V(k))\right)$$

Equation (3) predicts the value of i_{L1} in the next sampling interval.

The objective of the **Model Predictive Control (MPC)** method is to minimize the error between the predicted and reference values. The current error in the next sampling interval can be obtained using the following cost function:

$$g_i(k+1) = |i_{L1}(k) - i_{L1}(k+1)|$$

As mentioned before, the main objective of MPC is to determine the **optimal control action** in each sampling time for all possible switching states, such that the cost function in (4) is minimized. The cost function requires a second term to penalize the difference between two consecutive switching states, given as:

$$g_v(k) = |V(k) - V(k-1)|$$

Thus, the total cost function is obtained by combining equations (4) and (5):

$$g(k+1) = g_i(k+1) + \lambda g_v(k)$$

where I_{in} is the average of i_{L1}. Assuming that V_{out} is equal to its reference V_{out} in the steady-state, the duty ratio can be written as:

$$a = \frac{V_{out}}{V_{out} + V_{in}}$$

Assuming the duty ratio is known from (8), i_{in} can be expressed as:

$$i_{in} = \frac{di_{out}}{1-a}$$

By substituting $i_{out} = \frac{V_{out}}{R_L}$ into (9), the expression of i_{in} in terms of V_{out} and R_L is derived as:

$$i_{in} = \frac{dV_{out}}{(1-a)R_L}$$

3. SIMULATION RESULTS

Fig- 2 represents the simulation output for the DC-DC SEPIC Converter using Discrete time sliding mode control when input voltage is 30,referance voltage is 48V and the output voltage attained is 48 V with some error. It is concluded that the output voltage is greater than input voltage, so this converter is used as boost converter.

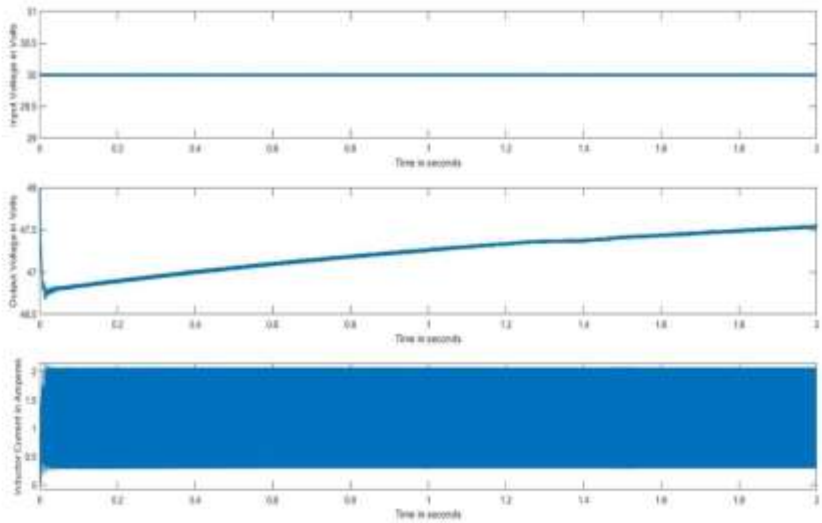

Fig-2:Simulation results for input voltage, output voltage and inductor current

Fig-3 represents the simulation output for the DC-DC SEPIC Converter using Discrete time sliding mode control when input voltage is 60V,referance voltage is 48V,load resistances,R1=80 ohm and R2=80 ohm and the output voltage attained is 48 V even there is a sudden change in load resistance from 80 ohm to 40 ohm. From this it is concluded that output voltage is not sensitive to load variation.

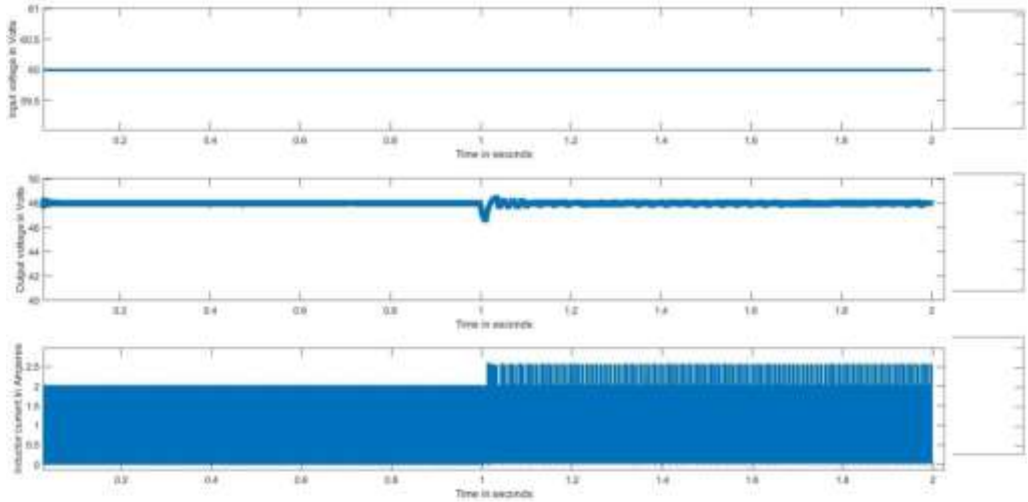

Fig-3: Simulation results for input voltage, output voltage and inductor current

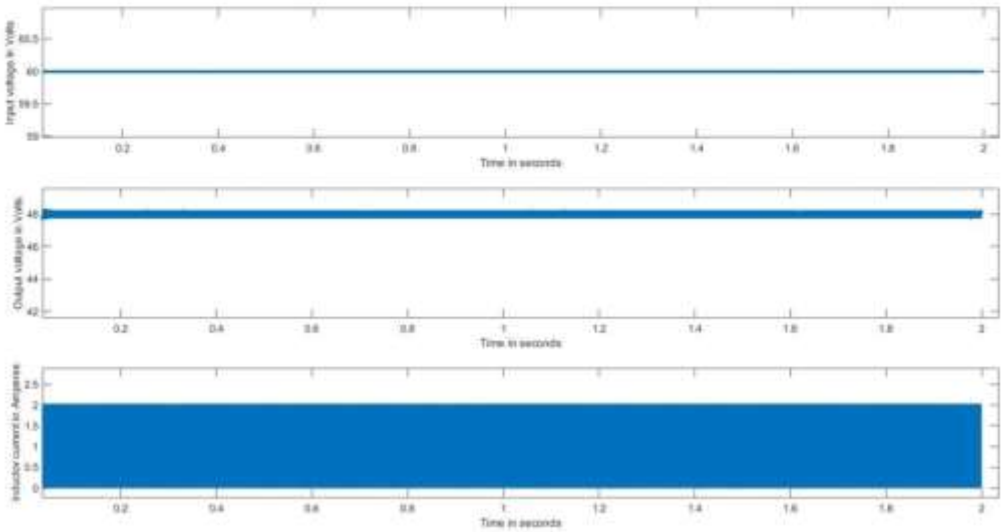

Fig-4: Simulation results for input voltage, output voltage and inductor current

Fig-4 represents the simulation output for the DC-DC SEPIC Converter using Discrete time sliding mode control when input voltage is 60,referance voltage is 48V and the output voltage attained is 48 V. From this, it can be concluded that the output voltage is less than the input voltage, so this circuit can be used as buck converter.

4. FUTURE SCOPE

The use of advanced non-linear control techniques for SEPIC converters in electric vehicle (EV) applications presents several promising directions for future research and development. As EV technology continues to evolve, there is significant potential to further enhance the performance, efficiency, and reliability of power converters. Future work could focus on the integration of intelligent control methods such as artificial intelligence (AI) and machine learning (ML) algorithms to enable real-time adaptive control, self-tuning, and predictive maintenance capabilities. Additionally, implementing these control strategies with digital signal processors (DSPs) and field-programmable gate arrays (FPGAs) could improve processing speed and system responsiveness.

Research can also explore the design of highly compact, lightweight, and thermally efficient SEPIC converters, which are crucial for reducing the overall weight and improving the range of electric vehicles. Furthermore, expanding the application of non-linear control techniques to multi-input and multi-output (MIMO) converter systems could enable the management of complex EV architectures involving renewable energy integration, energy storage systems, and regenerative braking. Finally, extensive real-time validation and testing under various dynamic driving conditions will be essential to ensure robustness and reliability, paving the way for large-scale deployment of advanced converter systems in next-generation electric vehicles.

5. CONCLUSION

The control of SEPIC converters using advanced non-linear techniques offers a powerful solution to the challenges faced in electric vehicle (EV) power management systems. Through the application of methods such as sliding mode control, backstepping, and adaptive control, the converter's performance is greatly improved in terms of stability, robustness, and efficiency under varying operating conditions. These techniques effectively address issues like input voltage fluctuations, load disturbances, and the inherent non-linear nature of power electronic systems commonly found in EVs.

The enhanced control not only ensures precise voltage regulation but also contributes to better battery utilization, increased driving range, and improved safety and reliability of electric vehicles. By maintaining stable operation even during dynamic changes, these controllers help extend the lifespan of the electrical components and optimize overall energy consumption.

Furthermore, the findings of this study emphasize the crucial role that intelligent and adaptive control strategies will play in the next generation of electric vehicles. As the automotive industry pushes toward higher performance, reduced emissions, and greater energy efficiency, the development and integration of sophisticated power converter control systems will become increasingly essential.

Overall, this work demonstrates that advanced non-linear control of SEPIC converters is a promising approach to meeting the growing demands of electric mobility, setting the foundation for further research into smarter, more resilient, and highly efficient EV power systems.

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