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RESEARCH ARTICLE – ENGINEERING (MISCELLANEOUS)

Enhancing Buck-Boost Converter Efficiency and Dynamic Responses with Sliding Mode Control Technique

Salah Hilo Mohammed Al-Attwani[1], Mustafa Teke[1*], Ethar Sulaiman Yaseen Yaseen[1], Enes Bektaş[1], Nurettin Gökşenli[2]

[1]Electrical and Electronics Engineering Department, Çankırı Karatekin University, Çankırı, Türkiye

[2]Vocational School, Çankırı Karatekin University, Çankırı, Türkiye

[*] Corresponding author E-mail: mustafateke@karatekin.edu.tr

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Abstract

DC-DC converters are an important class of power electronics due to their wide use in various applications as sources of efficient power supplies. They step down or step up the applied voltage so that it is always either lower or higher than the supplied voltage. This is crucial in power delivery and portable systems, especially in battery-operated systems. The purpose of the paper is to investigate how the efficiency of Buck-Boost converters improves by using sliding mode control when operating under different conditions. The work aims to develop a control strategy that increases the efficiency and reliability of Buck-Boost converters, employed in a myriad of power electronics applications. The research focuses on a sliding mode control approach to overcome the challenges of nonlinear dynamics and susceptibility to external disturbances. The methodology involves studying the behavior of the converter under different conditions such as changes in loads, input voltage variations, and reference voltage changes. The study uses theoretical modeling and simulation to evaluate the concept of sliding mode in addressing the challenges for improved efficiency. Such investigations show how sliding mode control improves efficiency. SMC approach reduces the response time by 5%, improves efficiency by 3%, and enhances overall stability under fluctuating conditions. The use of sliding mode control enhances the converters against disturbances and provides an efficient voltage regulator. The research is useful to the field as it offers more insights into the control strategy that significantly improves the performance of converters concerning efficiency and stabilization.

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Keywords: Buck-Boost Converter; Power Electronics; Sliding Mode Control; Optimizing.

1. Introduction

The remarkable progress in power electronics and several technological advancements have considerably increased the demand for efficient voltage regulation. Buck-boost converters are commonly used in different applications to accurately align the load voltage with the reference voltage. However, these converters generally operate in various modes that significantly affect their performance. In other words, two main modes are used in a buck-boost converter, including the continuous control mode and the discontinuous control mode. More so, the operations might alter during transient changes in the input and output; hence, it is challenging to regulate the efficiency of the converter.

At the same time, external disturbances and parameter uncertainties could threaten the electromagnetic nature of the buck-boost inductor. This could curtail the regulation of the load voltage and might, due to a high input current or a high-duty cycle, also damage the converter if the controller is unable to tackle these requirements. The high necessity of power electronics voltage regulation has enabled several new control methods. Notably, sliding mode control has emerged as a competitive solution due to its capacity to handle nonlinear dynamics and unknown distorting stimuli.

As illustrated by [1, 2], the sliding mode control can improve the dynamic response and anti-interference performance of the bidirectional and boost converters. [3] outlines the inherent sliding mode control approach to the implementation of a boost converter used to maintain the output voltage levels under unidentified sources and load variation. However, the sliding mode control approach is still relevant. This is demonstrated by [4], where an off-grid-used buck converter is shown to accommodate large-scale power or voltage fluctuation requirements.

Various recent investigations have pointed out the potential of sliding mode control to overcome efficiency and robustness problems in power electronics. Both [5] and [6] propose adaptive sliding mode control, capable of dealing with parametric uncertainties and disturbances, where the first is applied to nonlinear systems and the second to boost converters. Moreover, in [7], the authors applied sliding mode controls to wave energy converters and proved that it helps to increase energy absorption in the face of nonlinearities. The performance of sliding mode control is improved in [8] in work, where a dynamic sliding mode control is offered for a one-stage boost inverter that is robust for parametric uncertainties and input delays.

Nomenclature & Symbols			
CCM	Continuous Conduction Mode	S	Sliding Surface
V_S	Input Voltage	V_L	Inductive Voltage
V_C	Capacitor Voltage	V_{out}	Output Voltage
DCM	Discontinuous Conduction Mode	T_S	Temperature Switch
SMC	Sliding Mode Control	PWM	Pulse-Width Modulation
V_{In}	Input Voltage	D	Duty Cycle

Altogether, these works demonstrate the promising prospects of sliding mode control as an advanced and applicable power electronics controller. Undeniably, established classical control methods like PI regulation fail to resolve the constraints imposed by nonlinear dynamics and stochastic disturbances. To enhance efficiency amid such influences, sliding mode control has been proposed as a solution. Examination and use of sliding mode control in power electronics is far from novel, yet it has emerged as a promising sophisticated controller offering both variable mode regulation and resilience against external perturbations. It possesses various benefits over existing techniques.

The literature consistently supports the growth of sliding mode control as an advanced controller, particularly in the face of parametric uncertainties and nonlinearities. In [9, 10], both highlight its robustness and efficiency in complex, high-order nonlinear dynamic systems. [11] acknowledges the potential of sliding mode control in vehicle dynamics, despite the chattering phenomenon, and suggests that higher order sliding mode control algorithms could mitigate this issue. [12] further enhances the method by proposing a new adaptive sliding mode control for uncertain nonlinear systems, which combines the advantages of immersion and invariance adaptive scheme with sliding mode control. These studies collectively underscore the potential of sliding mode control in addressing the challenges posed by parametric uncertainties and nonlinearities.

Buck-boost converters facilitate continuous, steady-state energy flow and ideally ought to be engineered to regulate higher output voltages from the input voltage source as well as to initiate under light load circumstances. Widely applied in low-power, battery-powered systems, buck-boost converters ensure the output voltage stays regulated throughout the complete battery discharge cycle. They are also employed in EV charging systems, where they accommodate varying voltage levels and contribute to efficient and reliable charging infrastructure. Furthermore, the design and implementation of a boost-buck converter for battery charging applications has been shown to reduce ripple and improve efficiency [13]. These converters are invaluable in portable electronics where preserving a constant output voltage over the full range of battery voltage is crucial. Additionally, they are utilized in automotive, communication, and other industrial uses where the output voltage must be kept constant, even as the input voltage may vary above or below this level. Buck-boost converters can be viewed as switching power supplies that yield a voltage greater than or less than the input voltage magnitude.

The study focuses on improving the efficiency and stability of buck-boost converters by implementing sliding mode control. This approach is particularly beneficial for managing these systems under varying operational conditions. The study demonstrates how sliding mode control can handle nonlinear dynamics and disturbances, providing insights into how advanced control strategies can be applied in practical power electronics tasks. The study also highlights the importance of improving the converters' dynamic response, which is crucial for adjusting to varying input voltage and load effectively and rapidly. This improvement is essential for applications that require systems to respond to power demand fluxes in rapid and unpredictable ways. The study provides valuable insights into how advanced control strategies can be used in practical power electronics tasks.

2. Methodology

2.1. Buck-boost converter

Buck-boost converters, as shown in Fig.1, employ switching components, inductors, and capacitors to regulate output voltage beyond what traditional converters can achieve. This versatile topology allows the output to be tuned precisely to meet various applications' electrical needs. Its regulated power flow benefits a vast array of systems and gadgets needing dynamic voltage control. Some sentences showcase its deft equalization of levels higher or lower than input power. Elsewhere, switching at rapid rates, it efficiently steers voltage across thresholds. Overall, buck-boost conversion's flexibility in levelling voltage suit it for countless uses demanding finely-managed electrical diets [14-16].

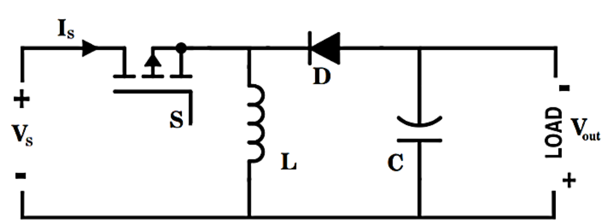

Fig. 1. Buck-Boost Converter circuit

Modeling of a buck-boost converter is conducted by establishing the dependencies between circuit components and the operating principle of the circuit. The key assumption considered in the case of flawless components and ideal conditions, that model focuses on the operation in A-CCM. The outcomes of the model are given through equations establishing the relationships between circuit variables, including inductor current and capacitor voltage, and the power switch's operation. It is possible to refine the developed model, accounting for such non-ideality factors as switching losses, component parasitic, and voltage dips. The refined model produces an output of a buck-boost converter with a negative value, as shown in Eq. 1 to Eq. 4 and visualized in Fig. 2 during the buck-boost converter operation, switch S is turned on [17].

$$-V_S + V_L = 0 \tag{1}$$

$$V_S = V_L = L\frac{di}{dt} \tag{2}$$

$$-V_C + V_{out} = 0 \tag{3}$$

$$V_{out} = V_C \tag{4}$$

$Where\ V_S$ represents the input voltage, V_L represents the inductive voltage, $L\ \frac{di}{dt}$ is the change in the current of the inductance, V_C is the capacitor voltage and V_{out} is the output voltage.

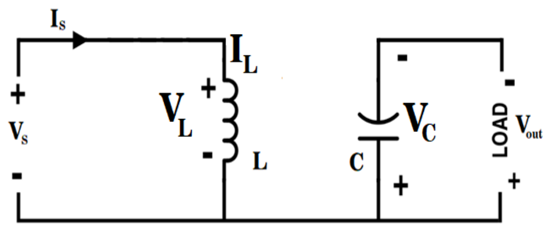

Fig. 2. Switching on operation, $S = 0$

When the switch S is opened, the voltage and current across the inductor and capacitor are described by Eq. (5) to (7), as illustrated in Fig. 3.

$$+V_L + V_C = 0 \tag{5}$$

$$L\frac{di}{dt} + V_C = 0 \tag{6}$$

$$\frac{di}{dt} = -\frac{V_C}{L} \tag{7}$$

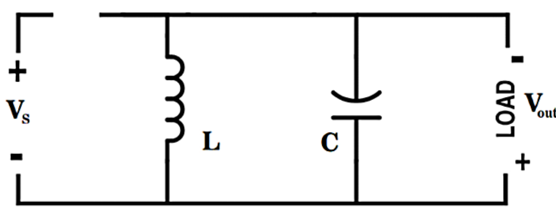

Fig. 3. Switching off operation, $S = 1$

Fig. 4 displays the voltage and electrical current waveforms of the buck-boost converter, as referenced in [17].

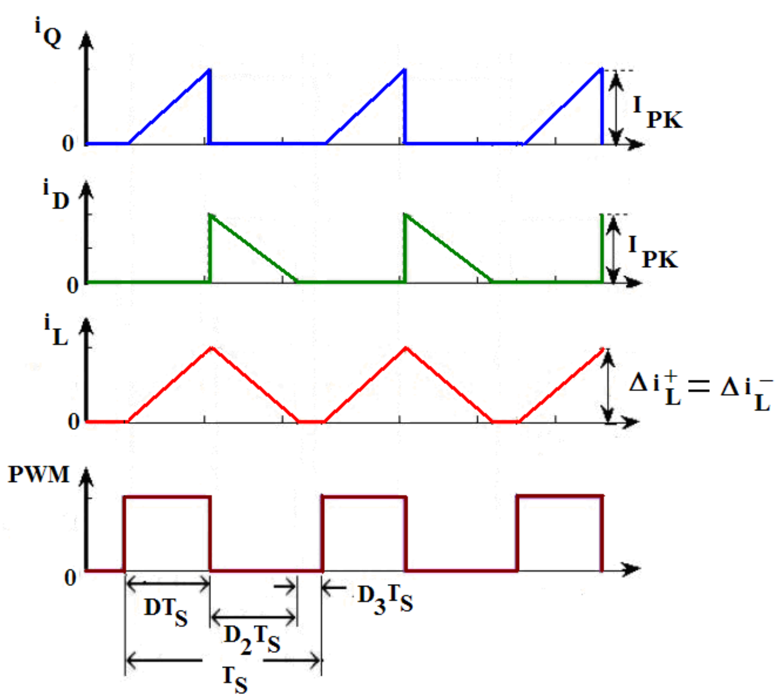

Fig. 4. Buck-boost converter supplies current, diode current, inductor current [17]

Waveforms of current and voltage in a buck converter during DCM. Three waveforms are demonstrated – MOSFET current, diode current, and inductor current. Q – MOSFET flows only during the switch's ON state since the MOSFET is inactive during this stage, allowing its current to be positive. The inductor is charged using a current flow when the MOSFET is on. The MOSFET remains ventilated for a time of $D{\cdot}T_S$, where D is the inversion cycle, and T_S is the inversion phase. D – Diode current: The polarity of diode D is turned around and reactivated when the MOSFET is turned off; the indicator begins discharging. In reality, diode current flows in the way indicator current flows while the converter is OFF. L – Inductor current: The most critical aspect in DCM is the inductor current. The inductor current increases linearly while the MOSFET is activated since the inductor stores energy. It also decreases linearly while the MOSFET is ventilated since the inductor releases power. Because the inductor current has just fallen to zero at the end of the timing cycle, an idle cycle takes place. The MOSFET is activated, and the inductor is attached to the source voltage when the switch is stumbled upon L. The source of the inductor is the source voltage without a volt, resulting in a current increase within the inductor. Both the MOSFET and the diode are turned off throughout the idle state, and the inductor current remains zero.

The rise in the inductor current is shown in Eq. (8) when switch S is on.

$$Rise\ in\ the\ Inductor\ Current = I_{max} - I_{min} = \frac{V_S}{L}DT \tag{8}$$

A fall in the inductor current is shown in Equation (9) when switch S is off.

$$Fall\ in\ the\ Inductor\ Current = I_{min} - I_{max} = -\frac{V_S}{L}(1-D)T \tag{9}$$

When combining Eq. (7) and (8), we get the average inductance current, which is presented in Eq. (10) to Eq. (12).

$$\frac{V_S}{L}DT = \frac{V_C}{L}(1-D)T \tag{10}$$

$$V_{out} = V_C = \frac{D}{1-D}V_S \tag{11}$$

$$(I_L) = \frac{I_{min}+I_{max}}{2} \tag{12}$$

The power is shown in Eqs. (13) and (14) present the output power.

$$(P_{IN}) = \frac{I_{min}+I_{max}}{2}DV_S \tag{13}$$

$$(P_{OUT}) = \frac{{V_{out}}^2}{R} \tag{14}$$

If there is no switching loss, the output power is equal to the input power, as in Eqs. (15) and (16).

$$P_{OUT} = P_{IN} \tag{15}$$

$$I_{max} + I_{min} = 2D\frac{V_S}{R(1-D)^2} \tag{16}$$

From Equations (15) and (16), we can get the minimum and maximum current as in Eq. (17) and (18), respectively.

$$I_{min} = D\frac{V_S}{D(1-D)^2} - \frac{V_S}{2L}D \tag{17}$$

$$I_{max} = D\frac{V_S}{D(1-D)^2} + \frac{V_S}{2L}D \tag{18}$$

In the CCM of operation for a buck-boost converter, $I_{min} = 0$ it means that the minimum current flowing through the inductor during each switching cycle is zero. Equation (19) represents the minimum inductor current, Eq. (20) represents the ripple voltage across the capacitor, and finally, Eq. (21) represents the output voltage.

$$L_{min} = \frac{(1-D)^2}{2}TR \tag{19}$$

$$\Delta V_C = \frac{\Delta Q}{C} = \frac{DTI_{out}}{C} = \frac{DTV_{out}}{RC} = \frac{D^2TV_S}{(1-D)RC} \tag{20}$$

$$V_{out} = \frac{D}{(1-D)}V_S \tag{21}$$

D<0.5: Step-down (buck) converter; D>0.5: Step-up (boost) converter. When D=0.5, the converter is a step-up (boost) converter. V_{out}=V_S; the buck-boost converter deals with its analysis, control scheme, and simulation through a mathematical model. From this model, engineers can design control methods to regulate the output voltage, and they can also evaluate the converter's performance, efficacy, and stability.

The step-down converter operates differently depending on whether the switch is in the ON or OFF position. A typical state space model for the converters can be developed by utilizing two distinct modes, as delineated in Eq. (22) [18, 19].

$$\begin{aligned} \dot{I}_L &= \frac{1}{L}(sVs - V_0) \\ \dot{V}_0 &= \frac{1}{C}\left(I_L - \frac{V_0}{R}\right) \end{aligned} \tag{22}$$

Where $\dot{I}_L$ represents the inductor current and $\dot{V}_0$ is the output voltage. The input control, denoted by u, determines the state of the switch: 0 a value of V_0 indicates the switch is off, while a value of 1 means it's on. Additionally, there are new terms derived from discrepancies in the output voltage and its associated derivatives, as shown in Eqs. (23) to (25) [14].

$$x_1 = V_0 - V_{ref} \tag{23}$$

$$\dot{x}_1 = \dot{V}_0 - \dot{V}_{ref} = \dot{V}_0 = x_2 \tag{24}$$

$$\dot{x}_2 = -\frac{x_2}{RC} + \frac{1}{LC}\left(uV_{\text{in}} - V_{ref} - x_1\right) \tag{25}$$

The voltage error at the output terminal is represented as x_1. Its derivative is signified by $\dot{x}_1$. Meanwhile, V_{ref} is the reference voltage at the terminal used as a benchmark.

Published materials have examined sliding surfaces. The traditional depiction of a sliding surface is as in Eq. (26) [13].

$$s = \lambda x_1 + x_2, \qquad \lambda > 0 \tag{26}$$

Where λ is a positive constant.

As in Eq. (27) [15], the terminal SMC is a proposed nonlinear sliding surface designed to enhance the performance model.

$$s_{TSMC} = \dot{x}_1 + \lambda x_1^{\gamma}, \qquad 0 < \gamma < 1 \tag{27}$$

Where λ represents a fractional power.

Designing an SMC for a buck-boost converter involves defining the sliding surface and designing the control law. The sliding surface is chosen to ensure accurate tracking of output voltage, and the desired behavior depends on specific control objectives and system requirements. The control law design includes the reaching term, which introduces a high-gain control action for fast convergence, and the sliding term, which maintains the system's states on the sliding surface using a discontinuous control action for robustness and accurate tracking [20, 21]. The control signal generation involves combining the reaching and sliding terms to obtain the total control signal, which is calculated based on the control law and the system's states. The control signal is typically proportional to the sliding surface and its derivative, along with other control parameters. The control signal is then applied to adjust the duty cycle of the power switch in the buck-boost converter, regulating energy transfer and output voltage. The control loop implementation involves measuring the output voltage, computing the error between the measured output voltage and the reference voltage, using the control law and the error to calculate the control signal, applying the control signal to adjust the power switch's duty cycle, and continuously monitoring the system's states to adjust the control signal for accurate tracking and robustness. Fig. 5 shows the control diagram for the closed loop.

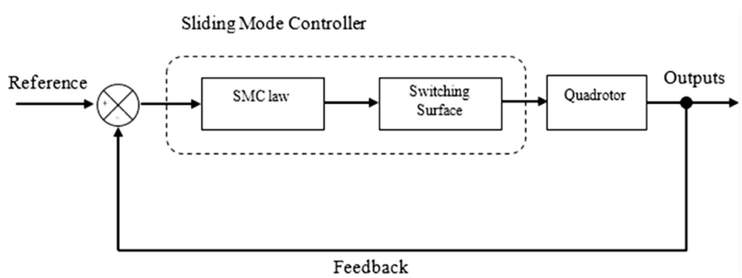

Fig. 5. SMC control block diagram for closed loop

The design of SMC for the buck-boost converter is most commonly done using simulation and iterative experimental analysis to obtain the desired system parameters and the controller's parameters. Other advanced control methodologies like gain scheduling or adaptive control can also be used in this controller design to improve SMC performance.

2.2. SMC theory

Sliding Mode Control (SMC) is a control strategy that ensures system stability and performance under uncertainty and variability. It is particularly effective in power electronics, including buck-boost converters. SMC operates based on two main phases: the reaching phase and the sliding phase. The core idea is to drive the system state to a predefined sliding surface and maintain it on this surface for the duration of the operation. The sliding surface must be designed to lead to desired system behavior, meeting performance specifications such as stability, accuracy, or response time. The choice of the sliding surface is crucial as it defines the desired system dynamics once the surface is reached. The reaching phase involves driving the system states to the sliding surface from their initial conditions, with control laws designed to ensure finite time convergence. The sliding phase exploits the system's dynamics restricted to the sliding surface, simplifying the overall dynamics and often resulting in linear behavior on a nominally nonlinear system. Applying SMC involves defining the system dynamics, designing the sliding surface, developing switching control laws, and addressing practical implementation considerations. These considerations include reducing chattering, ensuring system robustness, and handling uncertainties and external disturbances. Fig. 6 shows the SMC topology.

The diagrams illustrate the nature of the system's state trajectory with sliding mode control. The Reaching Phase refers to the behavior of the system states trying to station their trajectory on a sliding surface, which is a special manifold designed in the state space planeThe Reaching Phase shows the trajectory of the system states on their way to the sliding surface, designed to be reached in finite time. Meanwhile, in the Sliding Phase, the control law is designed to push the state onto the surface. The trajectories perform a zigzag to illustrate how the control strategy changes to fail, keeping the system states lying on the sliding surface, leading to the back and forth reflecting on the behavior of the state sliding on the line. This zigzag motion is typical of the so-called "chattering" phenomenon, which is unavoidable in sliding mode control due to high-frequency switching of the control input. This method is beneficial and suitable for systems that demand such a strategy due to the concern about robustness against model uncertainties or disturbances.

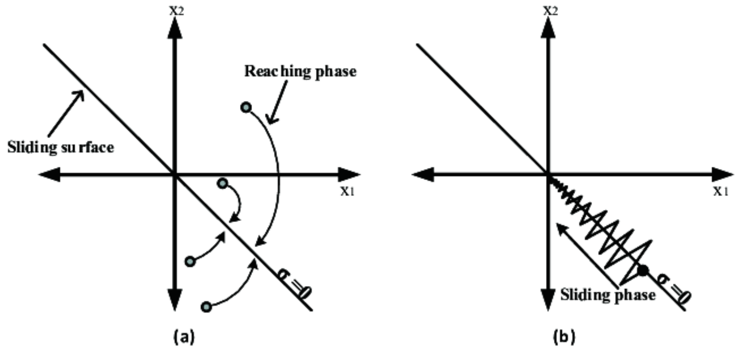

Fig. 6. SMC topology; (a) reaching, (b) sliding

In a buck-boost converter, Eq. (28) outlines a common choice for the sliding surface.

$$S = \left(V_{out} - V_{ref}\right) + \lambda \,.\, \mathrm{X}\, (V_{out\_dot}) \tag{28}$$

By denoting the output voltage as V_out, reference voltage as V_ref, a positive constant k, and time derivative as d/dt, the following control expression is obtained:in order to develop a control strategy for a buck-boost converter, it is necessary to define the dynamics of the system assuming that a control signal must drive its state towards the sliding surface and maintain it there until the sliding surface S is equal to 0. The control rule in sliding mode control defines the system's control input changing according to the condition that the state trajectories converge to the sliding surface ($s = 0$) in regulation time period and remain on the sliding surface S despite disturbances or changes in the plant's parameters. The control rule for a buck-boost converter can be developed by integrating the converter's state-space model with the selected sliding surface. $Consider\ a\ scenario\ where\ the\ output\ voltage\ error(e = V_{out} - V_{ref})$ and its derivative ($\dot{e} = \dot{V_{out}} - \dot{V_{ref}}$)are used to compute the sliding surface S in a linear manner. The equation can be expressed as: $\dot{s} = e + \lambda\dot{e}$, with being a positive parameter that influences the form of the sliding surface. To achieve the objective of reducing S to zero, the control law σ, which might represent the duty cycle of the converter's switch, must be formulated to align with the requirements of reaching the sliding surface ($s = 0$) and sustaining the system state on it ($\dot{s} = 0$). Three factors that significantly influence the dynamics of the buck-boost converter are the switch position, input voltage (V_{in}), and load resistance (R). The control rule will adjust the converter's operation between buck and boost modes depending on the system's status in relation to the sliding surface.

3. Results and Discussion

The designed SMC-based buck-boost converter in the MATLAB/Simulink environment is exemplified in Figs. 7 and 8. This model is established by combining various electrical components and control systems that combine the fundamental DC into a venture with an output level lower or higher than the input, thus applicable in multiple situations. Critical components visible from the schematic are the DC power source, the switch MOSFET, the inductor denoted as L, the capacitor denoted as C, and a load indicated by two resistors. The control system encompasses a Pulse Width Modulation block that runs with the control of the relay. The relay function in Sliding Mode Control as a part of the controller is necessary for supporting discontinuous control actions that will lead to the system state's forced moving into the sliding surface, followed by keeping it there. It shapes robustness against various disturbances and parameter drifts to make the performance stable and effective, as it is popular with DC-DC converters and similar applications. The pulse generator hence is configured to issue the gating signals to the MOSFET according to the sliding mode control strategy. Measurement blocks will incorporate sensors for current and voltage placed for current control. These measurement sensors shall have their signals fed to outputs such as the output scope and the voltage scope for real-time plotting and analysis. The parameters applied in this study are illustrated in Table 1.

Fig. 9 shows the PWM (duty cycle) of SMC. The PWM duty cycle is a vital component in the PWM, as it defines the average voltage sent to the load. The SMC alters the duty cycle to ensure that the system continues to operate properly or optimally in light of the current state of conditions. A high-duty cycle means longer periods of "on," and the power delivered is high, whereas a low duty cycle means low periods, and the power delivered is low.

Various scenarios were employed to assess the performance of sliding mode control in response to voltage transients and load fluctuations. Fig. 10 depicts a simulation designed to evaluate the performance of two converter modes, the boost converter, and the buck converter, by adjusting the reference voltage. At 2s, the reference voltage is increased from 98V to 148V for the boosting phase, resulting in an output signal that shows a prompt reaction time without any overshoot or damping. Furthermore, when the reference voltage is reduced from 150V to 50V at 4 seconds (Bucking phase), the signal stabilizes within 0.1s, again exhibiting neither overshoot nor damping.

Also, when we altered the scenario by holding the reference voltage constant and testing the output voltage by changing the input voltage (Vin), we found that the system was unaffected by this change. The reference point of the SMC controlled the output signal without any discernible difference, as shown in Fig. 11.

Table1. Parameters applied in this study

Parameter	Value
Inductor mH	0.001
Capacitor mF	0.002
Resistance ohm	100
Frequency	20000
Pulse width	50%

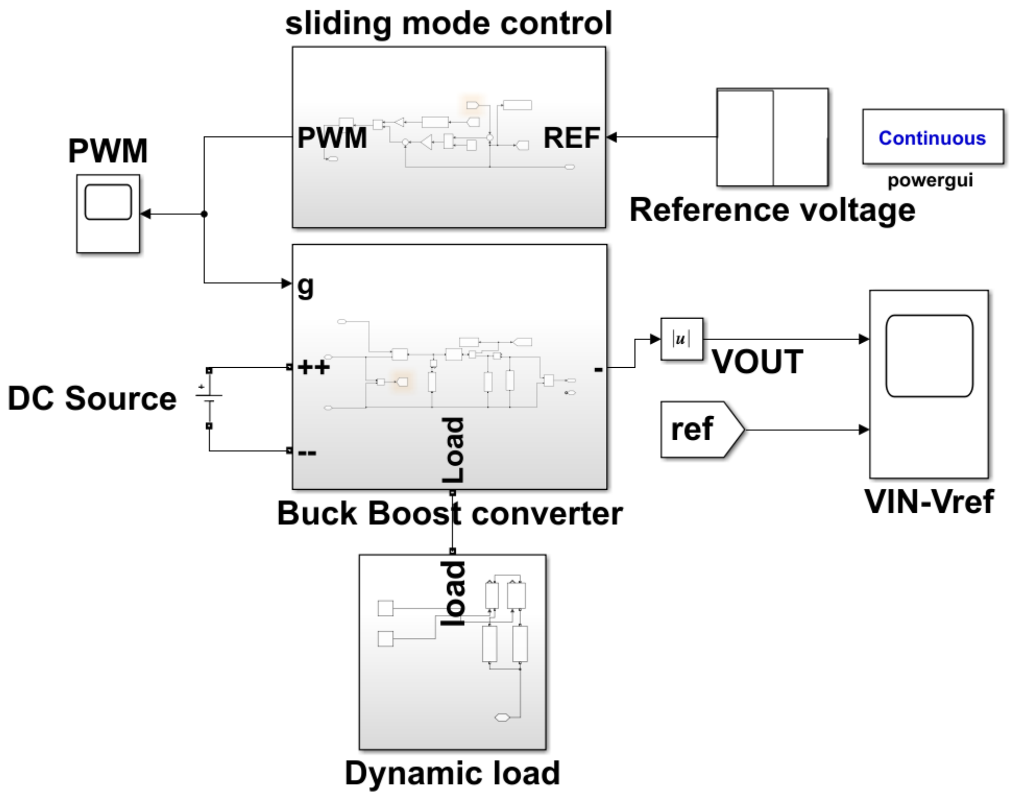

Fig. 7. General view of the proposed design

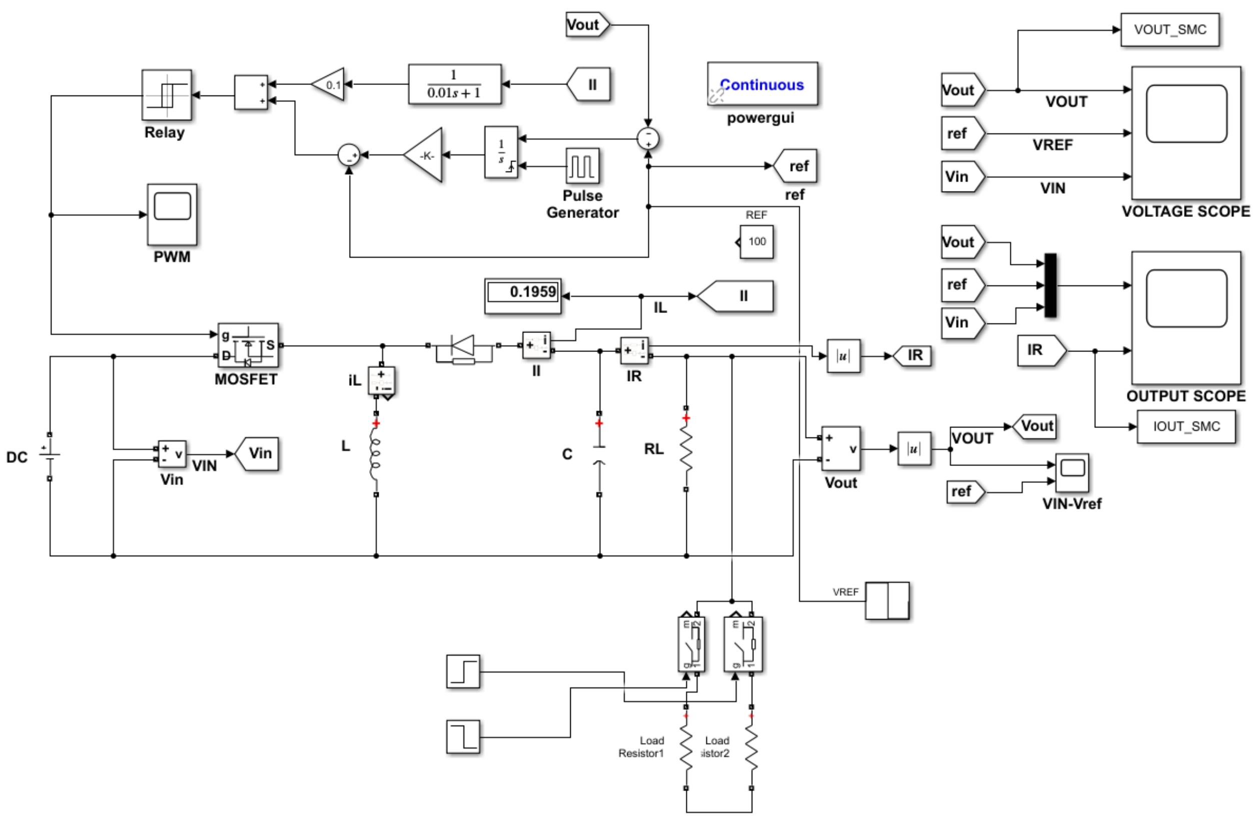

Fig. 8. SMC-based buck-boost converter in MATLAB environment

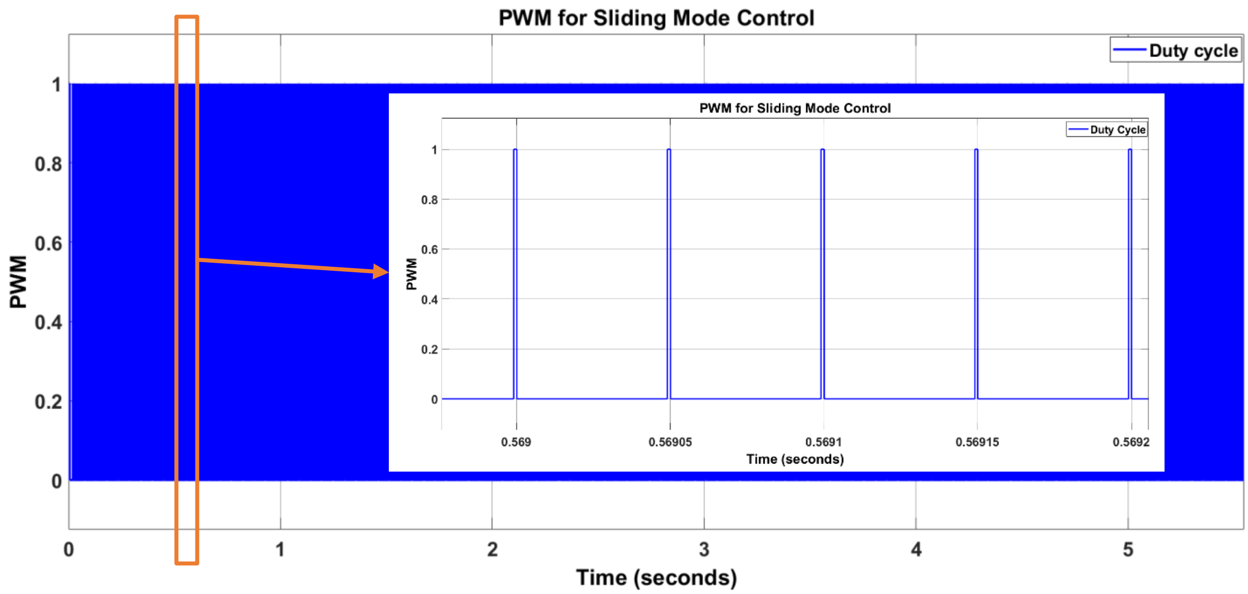

Fig. 9. Duty cycle

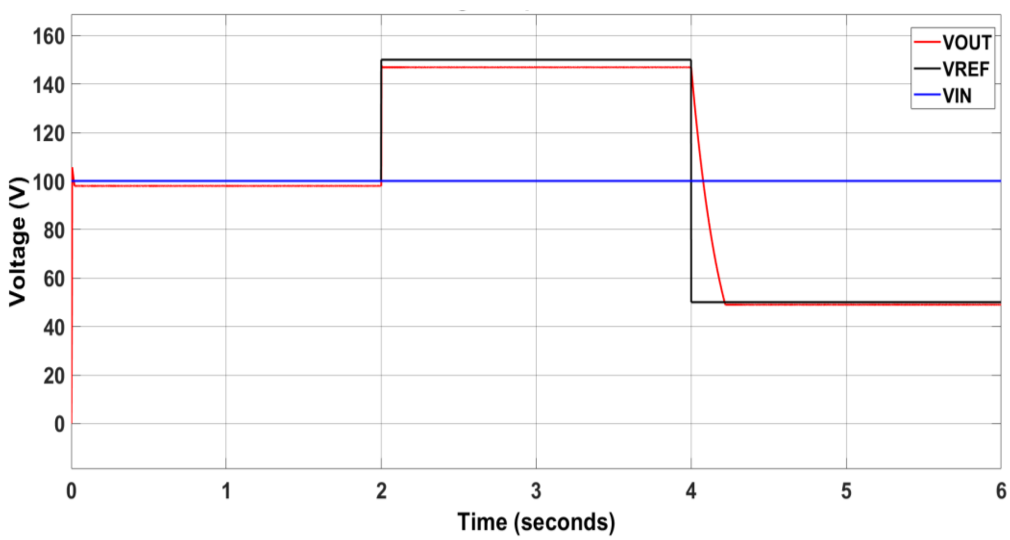

Fig. 10. Transient of SMC under reference voltage changes

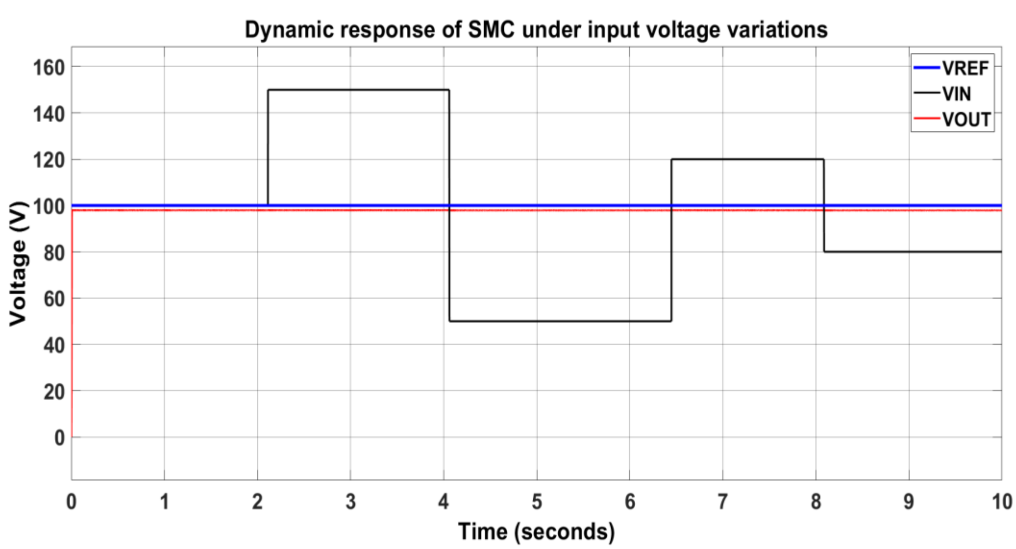

Fig. 11. SMC under input voltage changes

Fig. 12 illustrates the SMC performance in the context of dynamic load variations, and as shown, the control algorithm is robust and flexible. The major area of concern is that the SMC should be able to handle the variations effectively such that it achieves the desired output even when faced with changes. Concerning SMC performance, the output voltage response should always be within the desired range, and the output current response should achieve the desired range by modifying the duty cycle of the PWM to control the magnitude variation.. All of these should achieve stability and the SMC is capable of adjusting to changes in current demand within milliseconds. The figure also illustrates the areas where change occurs, and in all scenarios, the SMC is capable of responding to change. From the increase and decrease, the change points are perfect since they indicate that the controller can take either change. The subsequent analysis indicates that SMC performs a critical role in maintaining the desired power output levels even when the load changes.

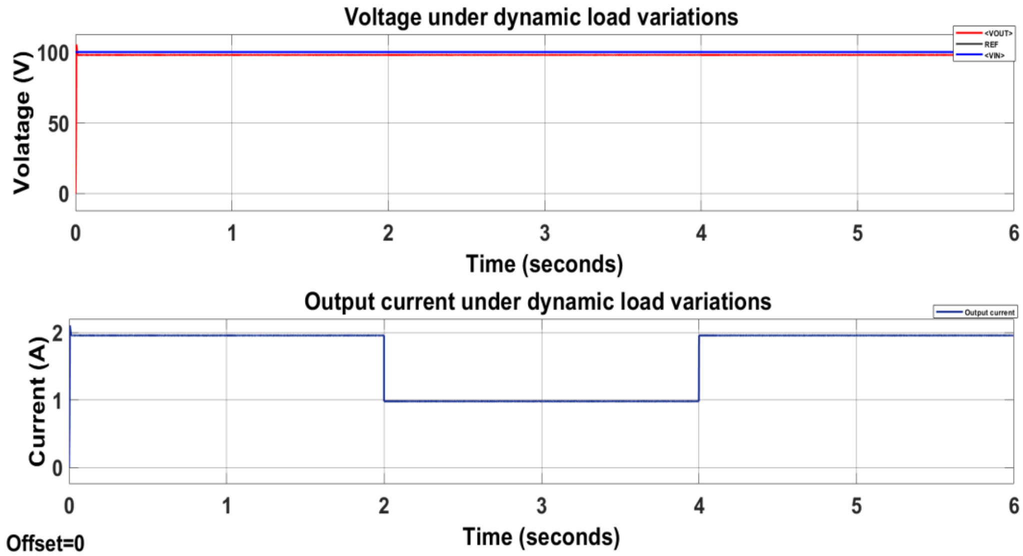

Fig. 12. Output voltage and current under load variations

With the first spark of the dynamic load, in the second instance, the load based on Ohm's law begins to decrease evenly. However, this occurs without a spark. At two seconds, the load increased to 200 ohms, and at the fourth second, it was switched off. The dynamic variation of load demonstrates a significant threat in controlling the power equipment, as the power system needs to adjust quickly enough to maintain the same stability. The operating SMC without a spark demonstrated stability and a small change in output. The performed analysis indicated that the system can rapidly change the load without causing a spark, which would otherwise lead to an unexpected increase in voltage and decrease in current, potentially causing electrical arcing.

The MATLAB/Simulink environment's SMC-based buck-boost converter is designed to convert a fundamental DC input into an output value that can be less or more than the input. A Pulse Width Modulation block in the feedback control system driven by the relay function in Sliding Mode Control is employed to achieve robustness against disturbances and parameter drifts and perform smoothly. To evaluate the SMC's performance in reacting to voltage transients and fluctuating loads, several scenarios are used: One of the simulations predicts the converter's performance in boosting and bucking modes at several reference voltages. As seen, the boosting signal exhibits a fast response time with neither over-damping nor under-damping, and the bucking signal remains stable within 0.1 seconds.. The SMC's performance is tested in another simulation under dynamic load changes, which demonstrates the voltage and current output change. At two seconds, a dynamic load introducing the load increases to 200 ohms and is turned off at four seconds. As evident in the above graph, the SMC performs differently; the output is intended to stabilize by rapidly responding to changes, demonstrating how the SMC block can successfully and rapidly address issues, thus avoiding voltage increases or decreases in current flow that may trigger arcing. This situation allows for maximum control of power equipment and ensures the system's equilibrium.

4. Conclusion

This paper investigates the potential for enhancing the performance and efficiency of Buck-Boost converters through the application of Sliding Mode Control (SMC). Our research involved extensive testing of this control methodology under a variety of operational conditions. We observed that SMC significantly improves the control system, potentially enhancing the performance of Buck-Boost converters in scenarios demanding highly efficient power supply. The paper demonstrates that SMC is highly effective in addressing the challenges posed by non-linear dynamics and external disturbances that typically impact the performance and efficiency of Buck-Boost converters. Through rigorous tests of voltage transients and analyses of load changes, the findings show marked improvements in system response and stability. The SMC approach reduces response time by 5%, improves efficiency by 3%, and enhances overall stability under fluctuating conditions. For future work, we suggest examining the scalability and applicability of Sliding Mode Control in Buck-Boost converters by testing its performance in large-scale energy systems and comparing it to other systems. Additionally, future work could integrate SMC with machine learning algorithms for predictive control and adaptive system response control.

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