

SIMULATION ANALYSIS OF PWM BASED SLIDING MODE CONTROLLER FOR DC-DC BUCK CONVERTER

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ABSTRACT

A voltage control loop with nonlinear control action is proposed for the buck type dc-dc converter which operates with continuous source current. The non-linear sliding-mode control technique is mainly acclimated to achieve less complex uniform control for buck converter operates in steady state as well as transient conditions. Instead of the suggested design methods, the output voltage should be provided to the control loop without the need for a synchronous capacitor for the proposed control scheme. As a result, the analog implementation value decreases and the difficulty of connecting the sensor in order to measure the capacitor current of the converter is eradicated. The equation of control action is accomplished using some op-amps and resistors in a simple analog circuit best suited for automated operations. Design and modeling of the proposed system are provided to facilitate the existence of system manipulation and the derivation of equilibrium conditions. The efficiency of buck converter with PI controller is around 96%, with SMC control is around 96%. The proposed work will be simulated in Matlab / Simulink software.

KEYWORDS: *Simulink, DC-DC converter, Synchronous capacitor, Control loop, Controller comparative study.*

I. INTRODUCTION

Linear management techniques with classical voltage- and contemporaneous-mode manipulation are used in many packages, including DC drives, motors and household apparatus. The Linear functioning controllers are adequate for minor changes on the surrounding conditions for operation of the converter as they depend on short-signal version. Therefore targets for the controllers may not function as precise even at heavy-signal interruptions. Consequently, many studies have been devoted to implementing the Sliding-Mode Manipulate (SMC) method as substitute, due to the rigidity, balancing of large-scale signal and also compatibility with Varying Size Structures (VSS). Despite the great functions of SMC, still the linear controllers dominate most of the industrial programs. As the conventional controllers need very little effort for designing and are easy to implement in analog form, as the SM controller design requires more calculations and complex structure for controllers. In addition, the approach of SMC can lead to optimal problems such as chatter and varying cycle of frequency for switching operations. More number of study efforts was made combined to determine the effectiveness of the SMC for efficient operation of DC-DC converters with the help of embedded machine systems, with various researchers proposing analog SMC schemes.

Most of the proposed sliding mode controllers for switching converters are Hysteresis-Modulation (HM) based which require a bang-bang type of controller to perform the switching control 3–6. They inherit the typical disadvantage of having variable switching frequency operation and being highly control-sensitive to noise. The use of constant timer circuits into the hysteric SM controller ensures constant switching frequency operation, or the use of an adaptive hysteresis band that varies with the parameter changes to control and fixate the switching frequency. They require additional components and are less suited for low cost conversion applications. The best way is to change the modulation methods of the sliding mode controllers from HM to pulse width modulation, otherwise known as the duty cycle control. Thus the migration of a SM controller from being HM-based to PWM-based is made possible. The technique of PWM modulation is to compare a desired analogue control signal V_c with a ramp signal V_{ramp} , of which a pulse-like output switching signal having the

same frequency as the ramp signal is generated. The advantage is that by fixing the frequency of the ramp, the frequency of the output switching signal is made constant thereby a fixed frequency PWM based SM controller can be obtained. SM controllers are based on SM control law and classical PWM controllers are based on linear control law. PWM based SM controller refer to a pulse width modulator that employs an equivalent control (derived by applying SM control technique) to generate a control signal to be compared with the fixed-frequency ramp in the modulator. To achieve such a controller, a relationship between SM control and duty cycle control is required. The control signal of equivalent control approach in SM control is equivalent to the duty cycle control signal d of a PWM controller and also state space averaging technique is incorporated for the controller's modeling as PWM duty cycle control can be directly applied to the implementation of the SM controller¹⁰. Hence, PWM duty cycle control can be directly applied to the implementation of SM controller. The design and selection of the sliding coefficients of the controller is presented which is based on Ackermann's formula, which introduce a practical approach to the design, permits the control design to be carried out systematically. Additionally, an adaptive feed-forward control strategy is proposed to the controller in order to reduce the line variations.

II. DC-DC BUCK CONVERTER MODEL

A buck converter or step-down converter is a DC-to-DC converter which decreases voltage, while increasing current, from its input (*supply*) to its output (*load*). It is a class of switched-mode power supply. Switching converters (such as buck converters) provide much greater power efficiency as DC-to-DC converters than linear regulators, which are simpler circuits that dissipate power as heat, but do not step up output current. The block diagram of the proposed system is as shown in the Fig. 1 and it has the three controllers to change the voltage as per the requirement at the load.

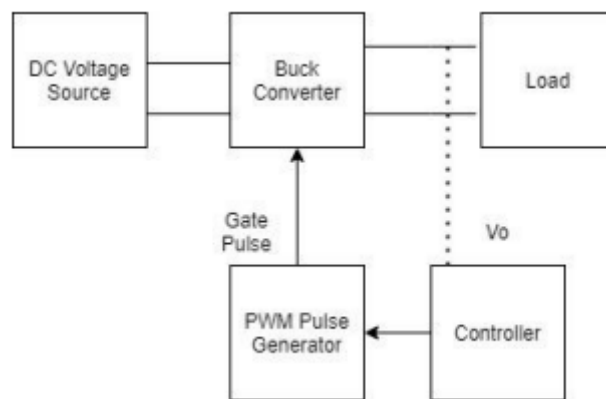


Figure.1 Proposed system

The efficiency of buck converters can be very high, often over 90%, making them useful for tasks such as converting a computer's main supply voltage, which is usually 12 V, down to lower voltages needed by USB, DRAM and the CPU, which are usually 5, 3.3 or 1.8 V.

III. SLIDING MODE CONTROL (SMC)

In control systems, sliding mode control (SMC) is a nonlinear control method that alters the dynamics of a nonlinear system by applying a discontinuous control signal (or more rigorously, a set-valued control signal) that forces the system to "slide" along a cross-section of the system's normal behavior. The state-feedback control law is not a continuous function of time. Instead, it can switch from one continuous structure to another based on the current position in the state space. Hence, sliding mode control is a variable structure control method. The multiple control structures are designed so that trajectories always move toward an adjacent region with a different control structure, and so the ultimate trajectory will not exist entirely within one control structure. Instead, it will *slide* along the boundaries of the control structures.

The motion of the system as it slides along these boundaries is called a *sliding mode* and the geometrical locus consisting of the boundaries is called the *sliding (hyper) surface*. In the context of modern control theory, any variable structure system, like a system under SMC, may be viewed as a special case of a hybrid dynamical system as the system both flows through a continuous state space but also moves through different discrete control modes.

The three distinguished features of the proposed adaptive sliding mode controller are as follows:

- (i) The structured (or parametric) uncertainties and unstructured uncertainties (un-modeled dynamics, unknown external disturbances) are synthesized into a single type uncertainty term called lumped uncertainty. Therefore, a linearly parameterized dynamic model of the system is not required, and the simple structure and computationally efficient properties of this approach make it suitable for the real-time control applications.
- (ii) The adaptive sliding mode control scheme design relies on the online estimated uncertainty vector rather than relying on the worst-case scenario (i.e., bounds of uncertainties). Therefore, a-priori knowledge of the bounds of uncertainties is not required, and at each time instant, the control input compensates for the uncertainty that exists.
- (iii) The developed continuous control law using fundamentals of the sliding mode control theory eliminates the chattering phenomena without trade-off between performance and robustness, which is prevalent in boundary-layer approach.

Intuitively, sliding mode control uses practically infinite gain to force the trajectories of a dynamic system to slide along the restricted sliding mode subspace. Trajectories from this reduced-order sliding mode have desirable properties (e.g., the system naturally slides along it until it comes to rest at a desired equilibrium). The main strength of sliding mode control is its robustness. Because the control can be as simple as a switching between two states (e.g., "on"/"off" or "forward"/"reverse"), it need not be precise and will not be sensitive to parameter variations that enter into the control channel. Additionally, because the control law is not a continuous function, the sliding mode can be reached in *finite* time (i.e., better than asymptotic behavior). Under certain common conditions, optimality requires the use of bang–bang control; hence, sliding mode control describes the optimal controller for a broad set of dynamic systems.

One application of sliding mode controller is the control of electric drives operated by switching power converters. Because of the discontinuous operating mode of those converters, a discontinuous sliding mode controller is a natural implementation choice over continuous controllers that may need to be applied by means of pulse-width modulation or a similar technique of applying a continuous signal to an output that can only take discrete states. Sliding mode control has many applications in robotics. In particular, this control algorithm has been used for tracking control of unmanned surface vessels in simulated rough seas with high degree of success. Sliding mode control must be applied with more care than other forms of nonlinear control that have more moderate control action. In particular, because actuators have delays and other imperfections, the hard sliding-mode-control action can lead to chatter, energy loss, plant damage, and excitation of modeled dynamics. Continuous control design methods are not as susceptible to these problems and can be made to mimic sliding-mode controllers

Fig.2 indicates the sliding mode control. The proposed system consists of DC voltage source providing supply to the buck converter which provides the required DC/DC conversion and the output of buck converter is to be provided to load. The SMC controller provides the duty ratio depending on the error voltage and it is provided to PWM pulse generator. The PWM pulses are provided to the buck converter which provides the voltage regulation as per the reference voltage.

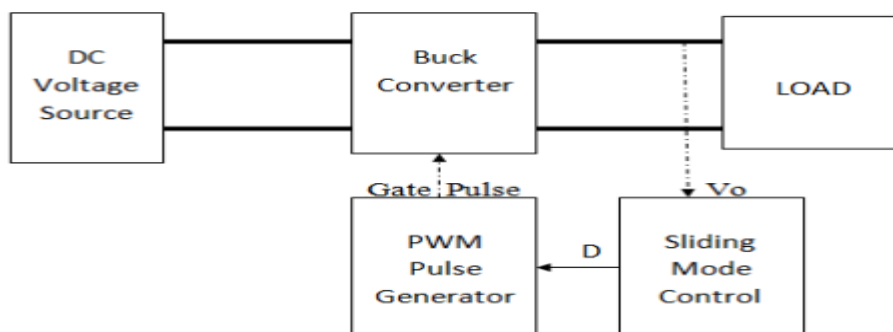


Figure.2 sliding mode control

Buck converter gives venture down activity to DC voltage. In a buck converter, when the switch is in the on position, the inductor is charged and furthermore gives the stockpile to the heap. The heap voltage is given by Eq. (1)

$$V_o = V_{in} - V_{ind} \quad (1)$$

The DC voltage when the switch is in off state is given by the Eq. (2)

$$V_o = V_{ind} \quad (2)$$

The buck converter with SM control circle is given in the Fig.3.

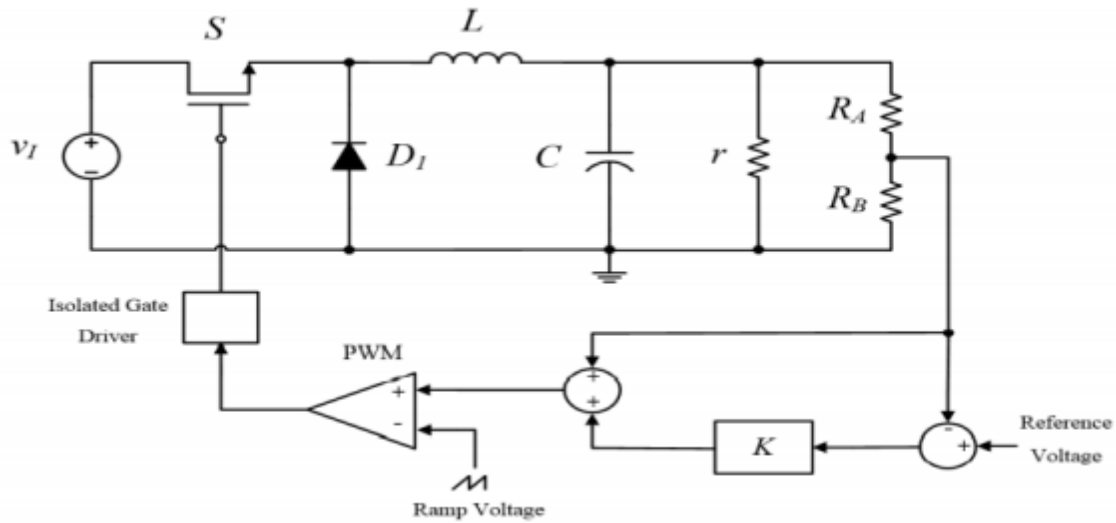


Figure 3: Buck Converter with SM Control Circuit

The sliding surface of the sliding mode controller is provided as

$$\varphi = \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 \quad (3)$$

The boundaries α_1 , α_2 , and α_3 are positive constants that signify the coefficients of sliding surface. A law for controlling the switching action that satisfies the given constraint is,

$$u = \begin{cases} 1 & \text{if } \varphi > 0 \\ 0 & \text{if } \varphi < 0 \end{cases} \quad (4)$$

The Eqs. (3) And (4) provide the controller and the duty ratio

A. PI Controller

The P-I controller is used specifically to deal with frequent state errors caused by the P controller. But, in terms of reaction rate and general stability of the system, it has terrible implications. This controller is basically used in areas where system speed is not always a problem.

A relative basic subsidiary regulator (PID regulator) is a control circle input instrument (regulator) generally utilized in modern control frameworks. A PID regulator computes a blunder an incentive as the contrast between a deliberate cycle variable and an ideal set point. The regulator endeavors to limit the mistake by changing the interaction through utilization of a controlled variable. The PID regulator calculation includes three separate consistent boundaries, and is likewise in some cases called three-term control: the relative, the necessary and subsidiary qualities, meant P, I, and D. Basically, these qualities can be deciphered regarding time: P relies upon the current mistake, I on the aggregation of past blunders, and D is a forecast of future blunders, in view of current pace of progress. The weighted amount of these three activities is utilized to change the cycle by means of a control component like the situation of a control valve, a damper, or the force provided to a warming component. Without information on the fundamental interaction, a PID regulator has verifiably been viewed as the most valuable regulator. By tuning the three boundaries in the PID regulator calculation, the regulator can give control activity intended to explicit interaction prerequisites.

The reaction of the regulator can be portrayed regarding the responsiveness of the regulator to a mistake, how much the regulator overshoots the set point, and the level of framework swaying. Note that the utilization of the PID calculation for control doesn't ensure ideal control of the framework or framework soundness. A few applications may require utilizing just a couple of activities to give the proper framework control. This is accomplished by setting different boundaries to nothing. A PID regulator will be known as a PI, PD, P or I regulator without the separate control activities. PI regulators are genuinely normal, since subordinate activity is touchy to estimation commotion, though the shortfall of a fundamental term may keep the framework from arriving at its objective incentive because of the control activity.

V. RESULTS AND DISCUSSION

The simulation circuit for the buck converter with PI controller is provided below figure, in this, the information voltage is differed from 24V to 16V at $t=0.5s$. The reference voltage of 12V is contrasted and estimated load voltage and the blunder voltage is given to PI regulator. The PI controller provides the duty ratio based on the error voltage and the duty ratio is compared with carrier signal of 5 KHz in order to generate pulses.

Table 1

Simulation Parameters

Input Voltage	24-16V
Switching Frequency	5 kHz
Inductor	2.86 mH
Capacitor	87.5 μ F
R Load	30hms
Load Voltage	12V
Load Power	48W

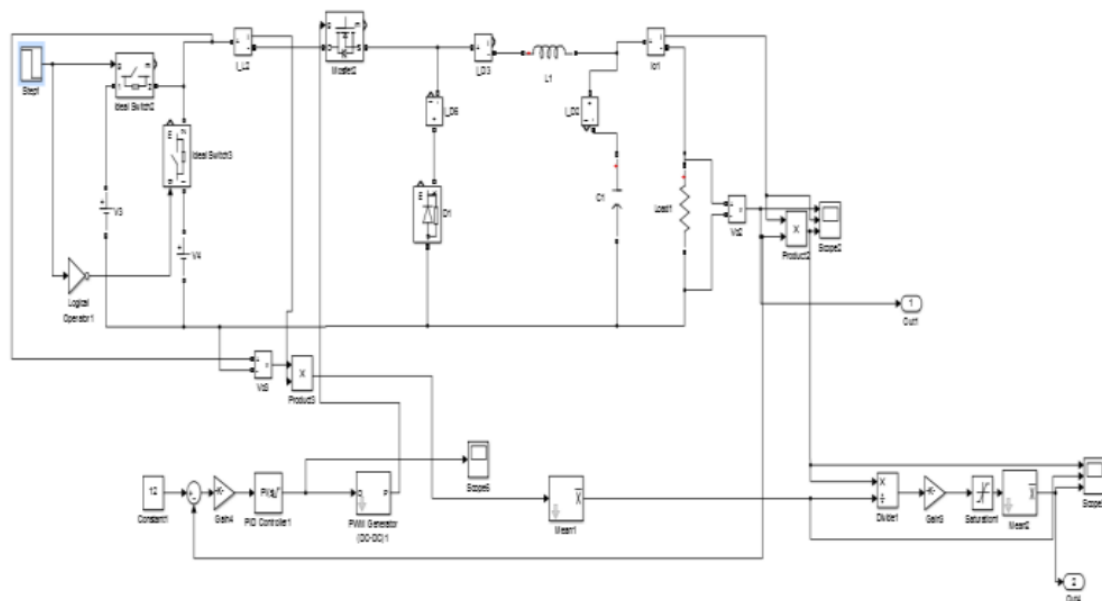


Figure 4: PI controller-based Buck converter.

The simulation circuit of buck converter with sliding mode control is provided in below figure,

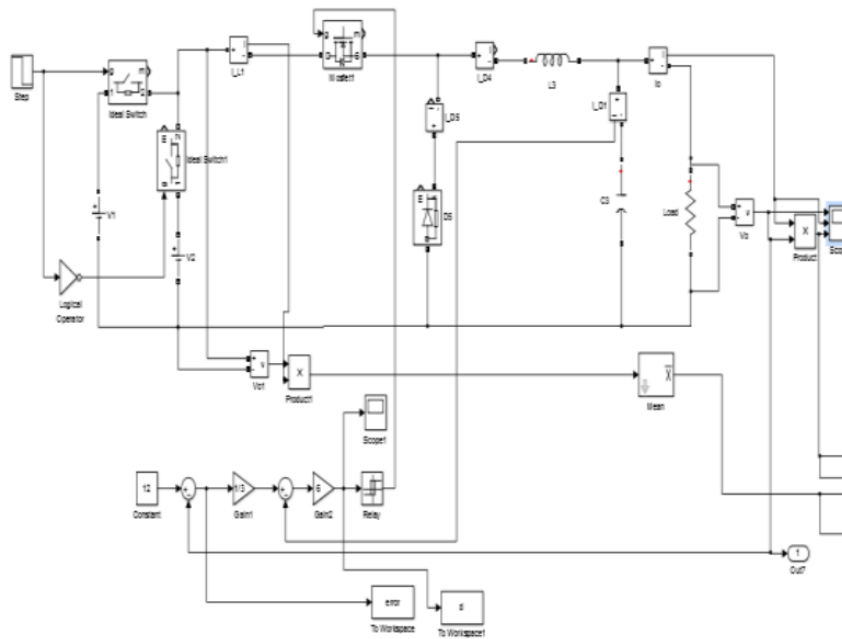


Figure 5: Sliding Mode Controller based Buck Converter.

A. PI controller based Bulk convertor

In this the voltage deviation from the reference voltage is around 0.6V which 5% of the required load voltage. The voltage, current and power waveforms are shown in Fig.6 at the load side

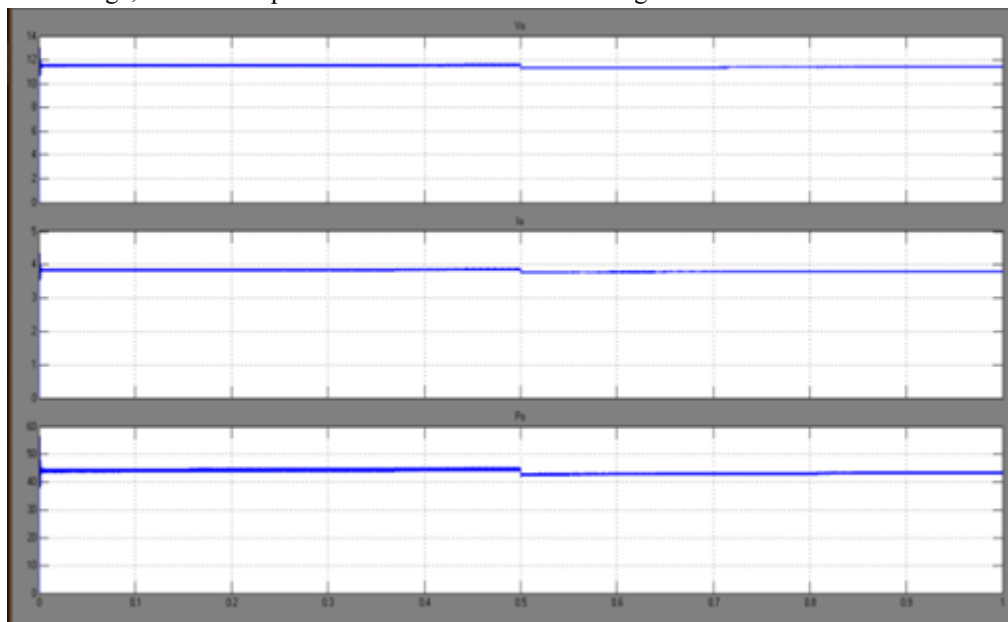


Figure 6 Voltage, Current & Power at the load.

B. Sliding Mode Controller (SMC) based Bulk Converter

Fig.15 shows voltage, current and power waveforms using SMC controller on Bulk Converter. In this the voltage deviation from the reference voltage is around 0.1V which 0.83% of the required load voltage.

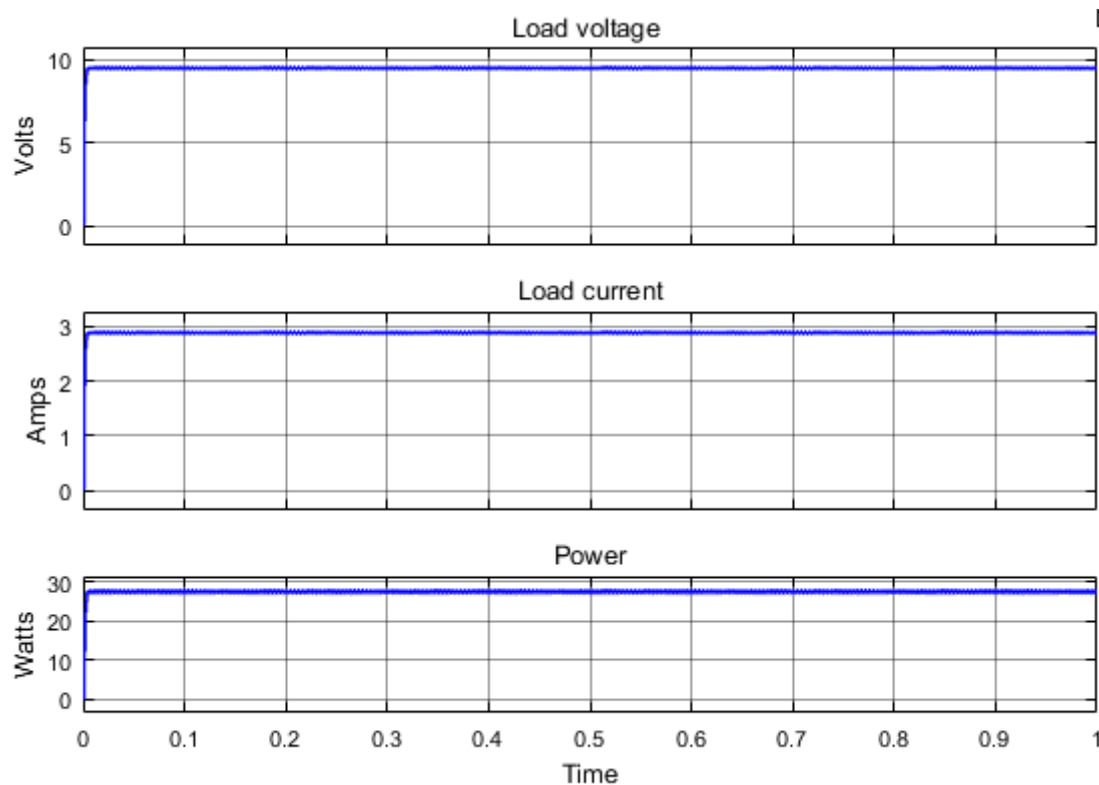


Figure 7: Voltage, Current and Power using SMC controller on Bulk Converter.

V. CONCLUSION

In this paper, a voltage control loop with nonlinear control action is proposed for the buck type dc-dc converter which operates with continuous source current. Design and modeling of the proposed system are provided to facilitate the existence of system manipulation and the derivation of equilibrium conditions. The proportional Integral, sliding mode and Artificial neural network controllers are designed and provided to the buck converter individually and the performance of the converter under such controllers are noted. The source voltage is varied and the regulated load voltage is measured and the efficiency of buck converter with PI controller is around 96%, with SMC control is around 96%.

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