

Improved Delta Operator based Discrete Sliding Mode Fuzzy Controller for Buck Converter

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Abstract

A delta operator based Discrete Sliding Mode Fuzzy Controller (DSMFC) for dc-dc buck Converter is described. The discrete systems by means of shift operator turns into mathematically disordered at an unexpected sampling rates. In order to face this difficulty, the delta operator is introduced. The delta operator can convert continuous-time system into discrete-time system and vice-versa. The main aim is to increase the rate of response, develop efficiency, get excellent Robustness and chattering phenomenon inhibition. This method is easy to implement and the overall system is efficient and cost-effective. During discretization, to circumvent any data damage, quick sampling has to be done which can be achieved with the help of delta operator because of its well defined mathematical properties even at rapid sampling.

Keywords: DC-DC Converter, Delta Operator, Discrete Fuzzy Sliding Mode Controller, Discrete Sliding Mode Controller, Fuzzy logic controllers, Sliding Mode Controller

1. Introduction

The performance of Dc-Dc converters are exaggerated by the non-linear individuality of switching devices, saturation of inductance and voltage clamping. In dc-dc converters the buck converters are most universally used because of its trouble-free mathematical model and superior regulation of voltage even with constraint deviation. The universally worn closed loop control methods are closed loop voltage current control with PWM method. Even hysteresis control techniques are worn because of its effortlessness.

SMC requires only fairly accurate mathematical model and provide superior response in constraint fluctuations. The design of SMC is for first-order irrespective of system order and the control law can competent to grip worst case of dynamics. These characteristics of SMC fallout in chattering problem and performance can be enhanced by the introduction of boundary layer. The difficulty with the SMC is that while designing, the local non linearity is not taken into description. The main reward of using SMC is it ensures stability, flexibility in design, ease of implementation and robust against uncertainties.

Now-a-days Fuzzy Logic Controllers (FLC) are most commonly used because it is more robust than other non-linear controllers, it requires only fairly accurate mathematical model, can able to work with inexact inputs, consider restricted non-linearity. So the chattering problem introduced by SMC can be overcome by introducing FLC along with SMC.

Power Electronic converters are extremely nonlinear for the reason that of its dissimilarity in a single switching cycle, use of inductance saturation, voltage clamp. With the opening of resonant converter, power converters are being paid complicated because of the constraint of composite mathematical model. Introduction of Fuzzy Sliding Mode Controller (FSMC) overcomes these troubles and it is trouble-free to put into practice also.

The performance of the system is very slow in ordinary Discrete Time Sliding Mode (DTSM) controlled systems, so there may a chance of loss of information at rapid sampling. To overcome this problem delta operator is used which has well defined mathematical property because of which the performance of the system is very good even at high sampling rates. An additional advantage of delta operator is that there can be a charming transferring between continuous and discrete time systems⁹.

2. Block Diagram Description

In this paper the output voltage of dc-dc buck converter is measured and regulated by the implementation of DSMFC, the control variables are sampled by Σ - Δ -modulator, and the sampled continuous systems are called discrete time systems. Based on sliding mode algorithm fuzzy rule tables are shaped and the gains are tuned. Now the parameter to be tuned is output gain. With the use of discrete controller along with sliding mode algorithm the tuning time has reduced, and the simulation is very fast because of the use delta operator.

Figure 1 displays the block diagram of the delta operator based DSMFC for power converters. The power converter can be buck, boost, buck-boost or resonant converters. For ease of implementation buck converter is considered in this paper and its performance is analyzed. The power converter is controlled by adjusting gate signal of the switch by comparing the actual output voltage with the reference value. The sampling should be done at very high speed to avoid loss of information, so delta operator is for this purpose. The algorithm used for tuning the gate pulse is delta operator based discrete sliding mode fuzzy control algorithm.

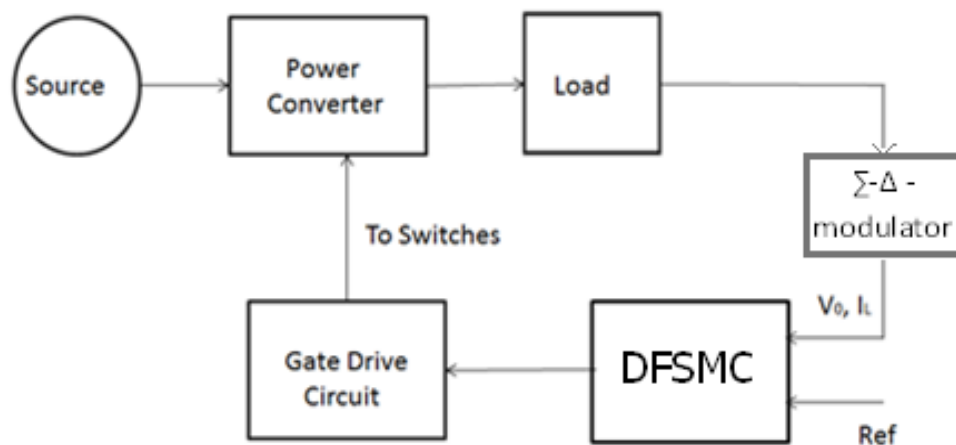


Figure 1. Block Diagram of Delta operator based DSMFC for Power Converter.

3. Delta Operator Methodology

In this segment, a Σ - Δ -modulator is prepared of a definite number of integrator circuits and a switching task in charge of producing the digital equivalent of analog signal. This type of modulator proceeds benefit of the high sampling frequency rate by allocating the quantization error without troubling the signal to modulate, creating it an perfect candidate for analog digital conversion practices.

The basic block diagram of Σ - Δ -modulator is shown in figure 2. Let the signal $x(t)$ is the smooth, constrained input signal and let the output of the modulator be $y(t)$, the difference between input signal $x(t)$ and output signal

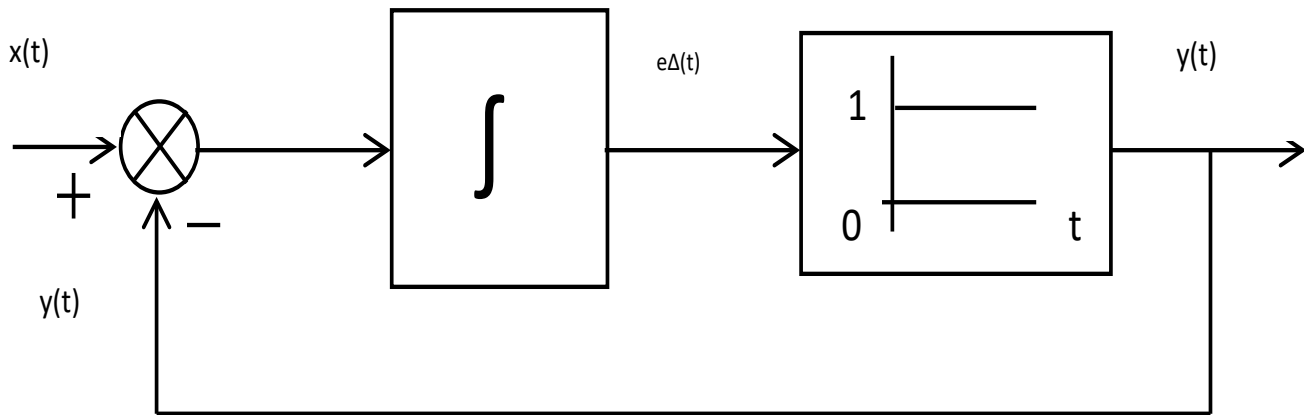


Figure 2. Block diagram of Σ - Δ -modulator.

$y(t)$ is the error signal $e_{\Delta}(t)$ which touches to zero in a limited time t_h . For that input signal $x(t)$ should be between 0 and 1. The following equations satisfy the function of modulator^{5,9}.

$$e_{\Delta} = x(t) - y(t) \tag{1}$$

where $0 < x(t) < 1$

$$y = \frac{1}{2}[1 + \text{sign}(e_{\Delta})] \tag{2}$$

$$e_{\Delta} e'_{\Delta} = -|e_{\Delta}| \left\{ \frac{1}{2}[1 + \text{sign}(e_{\Delta})] - x \text{sign}(e_{\Delta}) \right\}$$

$$e_{\Delta} e'_{\Delta} = e_{\Delta} \left\{ x - \frac{1}{2}[1 + \text{sign}(e_{\Delta})] \right\} \tag{3}$$

If $e_{\Delta} > 0$ then from equation (3) = $-e_{\Delta} (1-x)$ which means $e_{\Delta} e'_{\Delta} < 0$. Else $e_{\Delta} < 0$ then $e_{\Delta} e'_{\Delta} = -|e_{\Delta}| x < 0$. Under ideal discretization, the conditions like $e_{\Delta} = 0$, $e'_{\Delta} = 0$ exists which means $x(t) = y(t)$, then sliding region exists all the time. The finite striking time t_h is obtained by evaluating the modulator under worst conditions like giving different input signals $x(t)$ under both $e_{\Delta} > 0$ and $e_{\Delta} < 0$ conditions. The part of this modulator in sliding mode control system is to sidestep complete scale

measurement and the controller is the average based controller.

4. Mathematical Modeling of Discrete Sliding Mode Controller for Dc-Dc Buck Converter

The circuit illustration of buck converter is displayed in figure 3. Let the input excitation of V_{in} is given to the circuit and it has diode D, switch S1, filter capacitor C is in shunt with inductor L, and resistor R. For buck converter

the output voltage is less than or equal to input voltage (i.e.) $V_0 \leq V_{in}$.

Let $i_L = x_1$ and $V_c = x_2$ where i_L is current of the inductor and V_c is the voltage of the capacitor are the regulator variables of the system. Then the estimated discrete time comparable system prototypical for the buck converter is specified by the following equations^{1,2}.

$$x_1[k + 1] = x_1[k] + \frac{T}{L}\{V_{in} u[k] - x_2[k]\} \tag{4}$$

$$x_2[k + 1] = x_2[k] + \frac{T}{C}\{x_1[k] - \frac{1}{R}x_2[k]\} \tag{5}$$

The sliding surface is specified by

$$S[k] = ke_1[k] + e_2[k] \tag{6}$$

Where k is the sliding co-efficient. Let e_1 be the change between the expected value and the real value of the output voltage, $e_1 = V_{ref} - V_0$

$$e_2[k] = \dot{e}_1[k] \tag{7}$$

According to discrete sliding mode regulator law for the buck converter¹ from Lyapunov continuous state is given by, (i.e.) $|S[k+1]| < |S[k]|$

$$S[k + 1] - S[k] = \left(\frac{kTRC + TRC - T^2}{RC^2}\right)x_1[k] + \left(\frac{T^2L - kTRCL - TRCL - T^2R^2C}{R^2C^2L}\right)x_2[k] + \frac{T^2}{LC}V_{in}u[k] - kr[k + 1] + kr[k] \tag{8}$$

5. Mathematical Modeling of Delta Operator Based Discrete Sliding mode Controller for Dc-Dc buck Converter

If delta operator is introduced along with discrete sliding mode control algorithm for the buck converter,⁸ then the estimated comparable system prototypical for

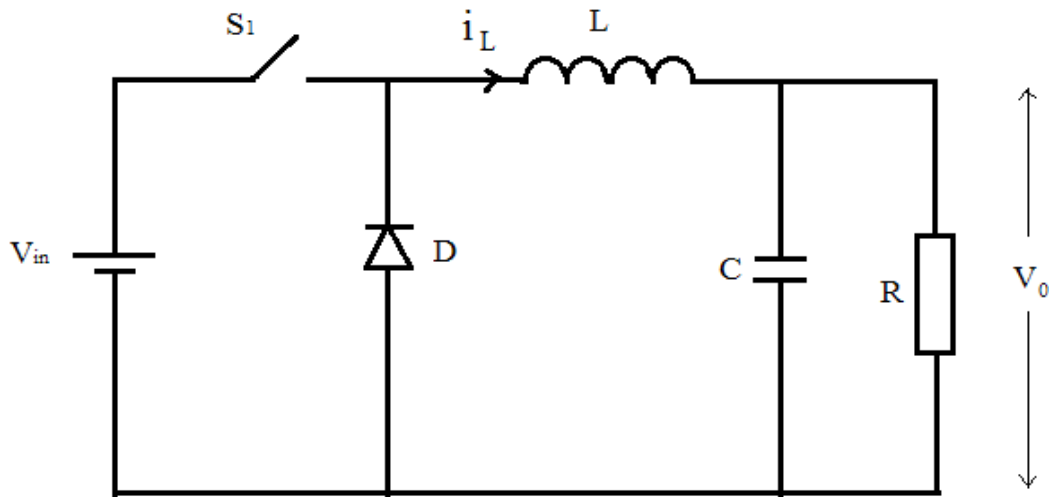


Figure 3. Circuit diagram of buck converter.

the buck converter is specified by the subsequent equations,

$$\delta x_1[k] = x_1[k] + \frac{T}{L} \{V_{in} u[k] - x_2[k]\} \quad (9)$$

$$\delta x_2[k] = x_2[k] + \frac{T}{C} \{x_1[k] - \frac{1}{R} x_2[k]\} \quad (10)$$

Where $\delta x[k] = \frac{x[k+1]-x[k]}{T}$

The sliding surface is given by the equation

$$S[k] = ke_1[k] + \delta e_1[k] \quad (11)$$

$$e_2[k] = \dot{e}_1[k] = \delta e_1[k] \quad (12)$$

According to discrete sliding mode control law after introducing delta for the buck converter from Lyapunov continuous condition, (i.e.) $\delta |S[k]| < |S[k]|$, where

$$\delta s[k] = \frac{s[k+1]-s[k]}{T}$$

$$\delta S[k] - S[k] = \left(\frac{kTRC + TRC - T^2}{RC^2} \right) x_1[k]$$

$$+ \left(\frac{T^2L - kTRCL - TRCL - T^2R^2C}{R^2C^2L} \right) x_2[k]$$

$$+ \frac{T^2}{LC} V_{in} u[k] - k\delta r[k] + kr[k] \quad (13)$$

The delta operator system is theoretical to be unchanging if all the roots of the structure matrix are within the circle of radius $1/T^2$.

6. Delta Operator based Discrete Sliding Mode Fuzzy Controller Design

The DSMFC practices the surface $S[k]$ and its derived $\delta S[k]$ to describe deviations on the regulator signal, the main goal is to ensure Lyapunov stability condition $|\delta S[k]| < |S[k]|$. The regulation centered table is established to outfit this condition. The conditions are (1) if $S[k] > 0$ and $\delta S[k] > 0$ then duty cycle has to increase (2) if $S[k] < 0$ and $\delta S[k] < 0$ then duty cycle has to decrease. Thus $S[k]$ & $\delta S[k]$ are the input variables to the DSMFC, the yield is the regulator raise Δt to t such that the control law is reorganized.

The proposed DSMFC uses Mamdani fuzzy inference system. Table-1 represents the rule base table, which is the developed table to implement the delta DSMFC in the converter circuit. Control signal is given in equation (14).

Table 1. Rule base table for delta DSMFC

$\delta S[k] \setminus S[k]$	NN	ZO	PP
PP	ZO	PM	PB
ZO	NM	ZO	PM
NN	NB	NM	ZO

$$u(k) = \Delta u(k) + \Delta u(k - 1) \quad (14)$$

7. Flow Chart of Delta Discrete Sliding Mode Fuzzy Controller Design

Figure 4 indicates the flowchart of the delta operator based DSMFC for the buck converter. Initially gate

pulse is produced for the buck converter. The inductor current and output voltage are given as input to the Σ - Δ -modulator.

The sampled output voltage is then related with the desired for the error control. Then sliding surface S and change in sliding surface are calculated. There are two conditions, If $S[k] > 0$ and $\delta S[k] > 0$ then u is positive so that the pulse to the converter is set high else u

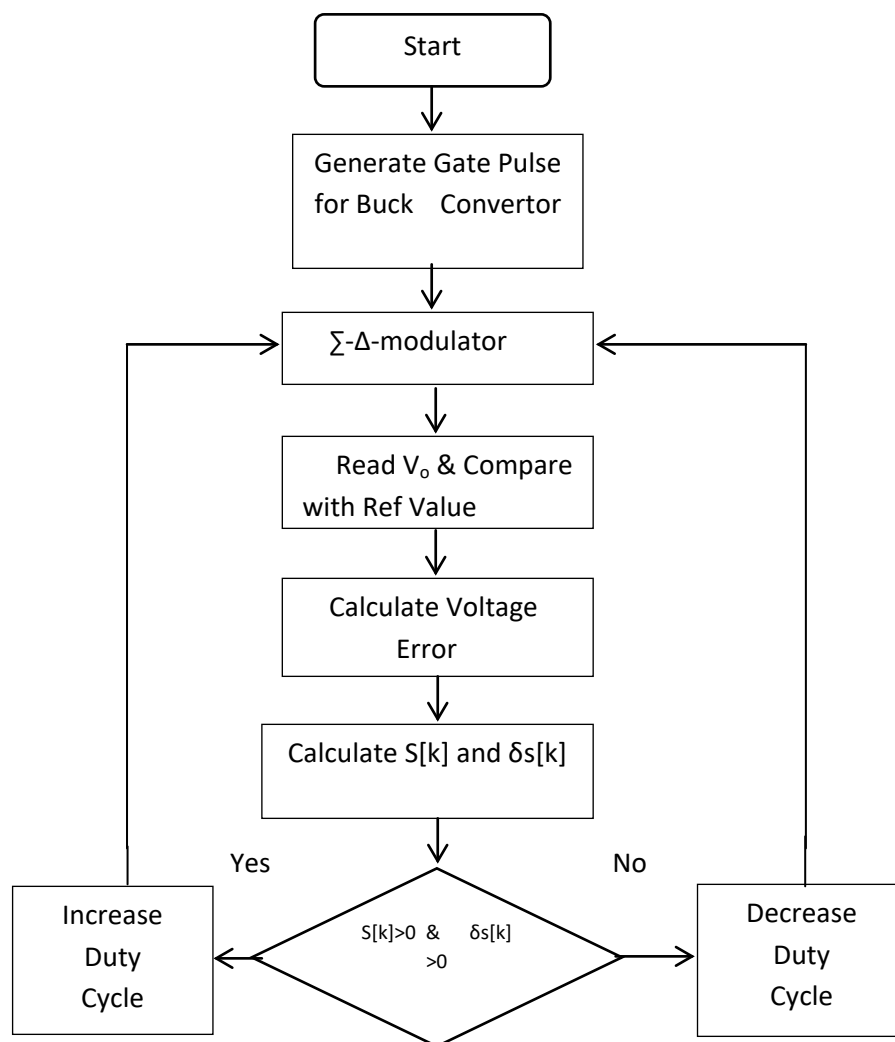


Figure 4. Flow chart for DFSMC for buck converter.

is negative and the pulse to the converter is set low. The loop is getting closed by reading the control variables.

3. Simulation Results and Discussion

The Delta operator based DSMFC of Buck converter is simulated in MATLAB SIMULINK and the established model is given in Figure 5. MOSFET is used in this converter which has great speed of reaction and the switching is through controlling the gate signal by Delta operator based DSMFC.

Figure 6. shows the Mamdani type fuzzy inference system for dc-dc buck converter. This is done with the help of rule editor where input and output variables are defined with the help of membership functions. Then the rules are formed by selecting proper membership function from each input variables and selecting membership function from output variable. One of the input variables is $S[k]$ and its membership functions are shown in figure 7 and the other input variable is $\delta S[k]$ and its defined membership functions are shown in figure 8. The output variable is the control signal given by $U[k]$ and its defined membership function is given in figure 9. With the help

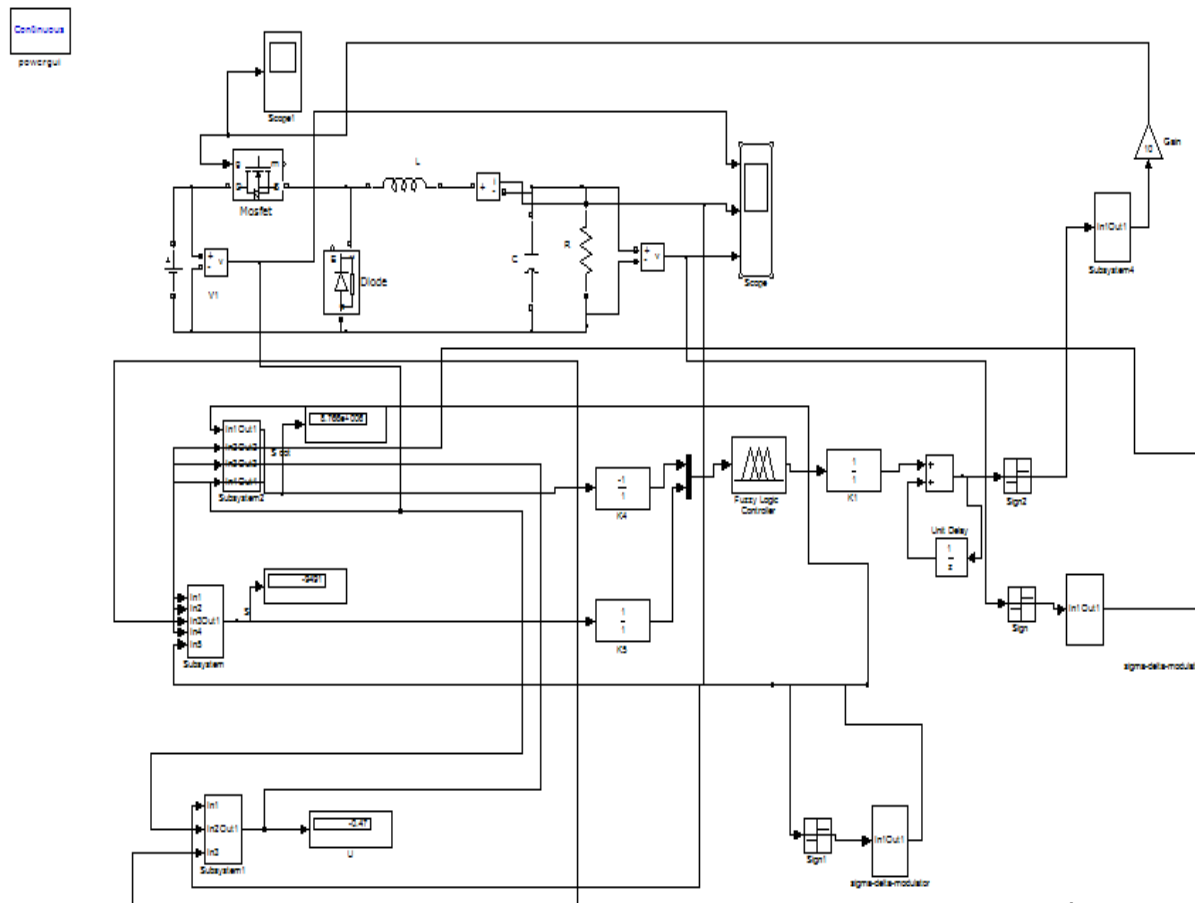


Figure 5. MATLAB SIMULINK model of delta operator based DSMFC Buck Converter.

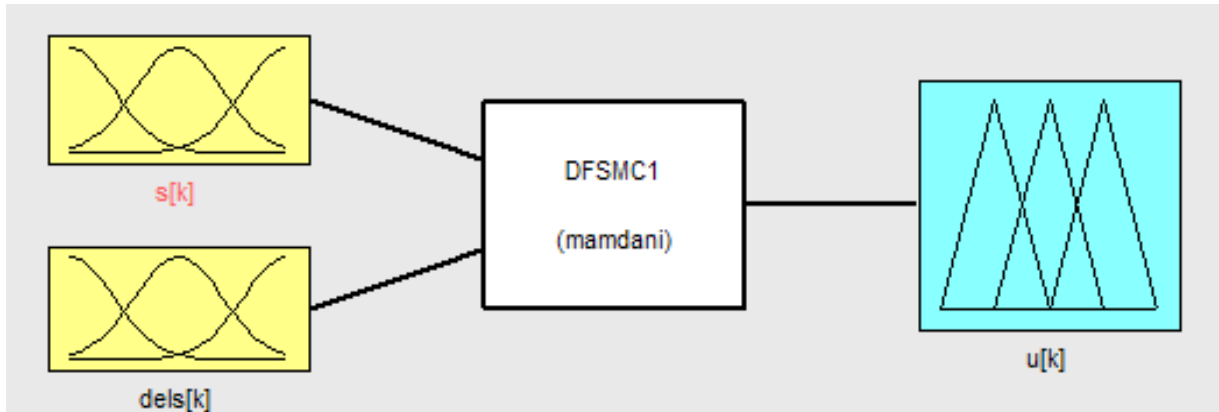


Figure 6. Mamdani fuzzy inference system model for delta operator DSMFC Buck Converter.

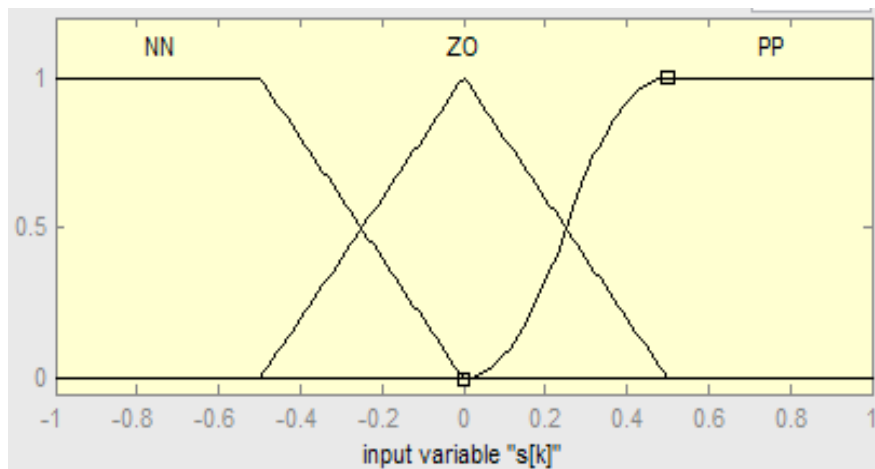


Figure 7. Membership functions of sliding surface $S[k]$.

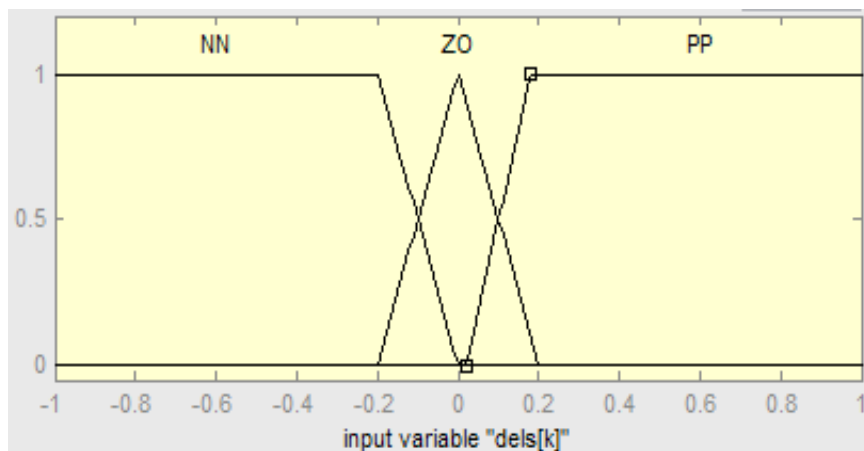


Figure 8. Membership functions of change in sliding surface $\delta S[k]$.

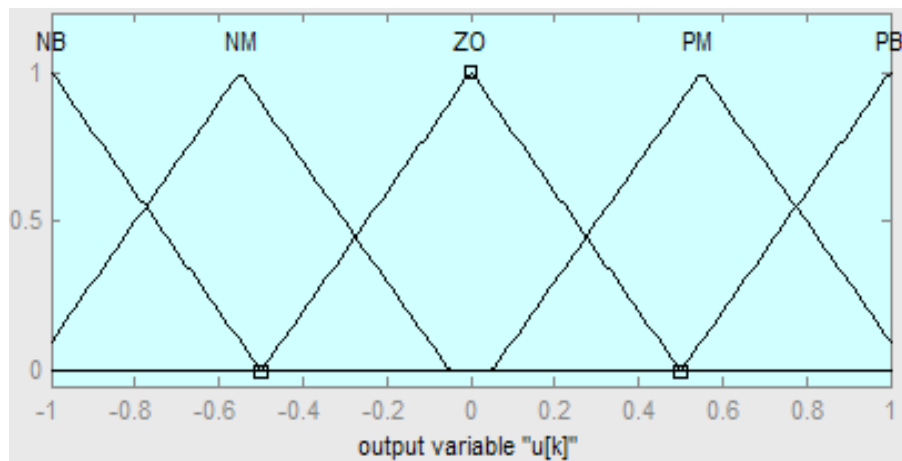


Figure 9. Membership functions of output variable $u[k]$.

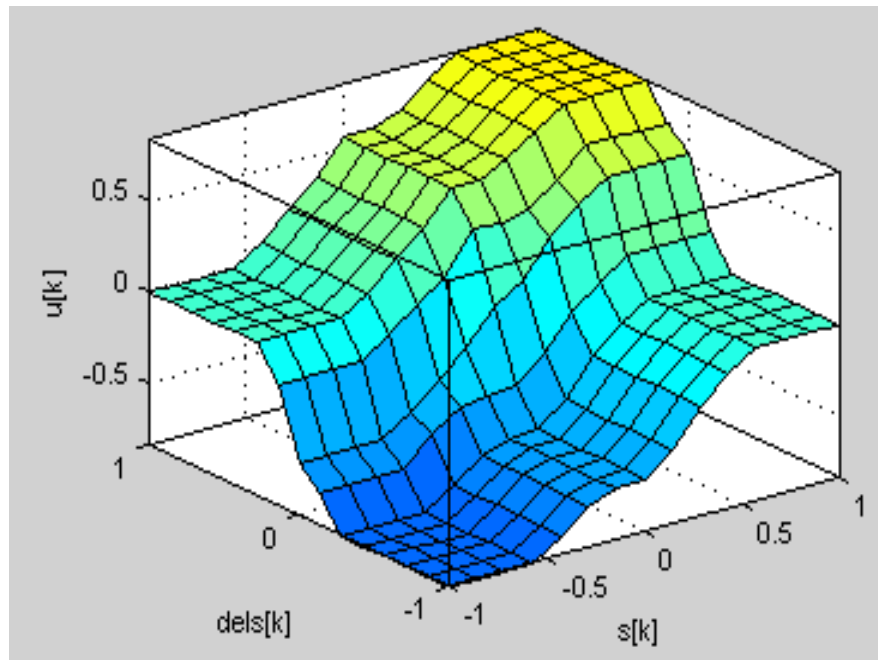


Figure 10. Delta operator based DSMFC control surface.

of rule edit viewer we can able to see the control surface shown in Figure 10.

The DSMFC MATLAB SIMULINK model was simulated with the specified parameters and the response

of input voltage, Inductor current and output voltage responses were taken which is shown in Figure 11. From the response we can make out that output voltage is less than the input voltage and it is working in continuous

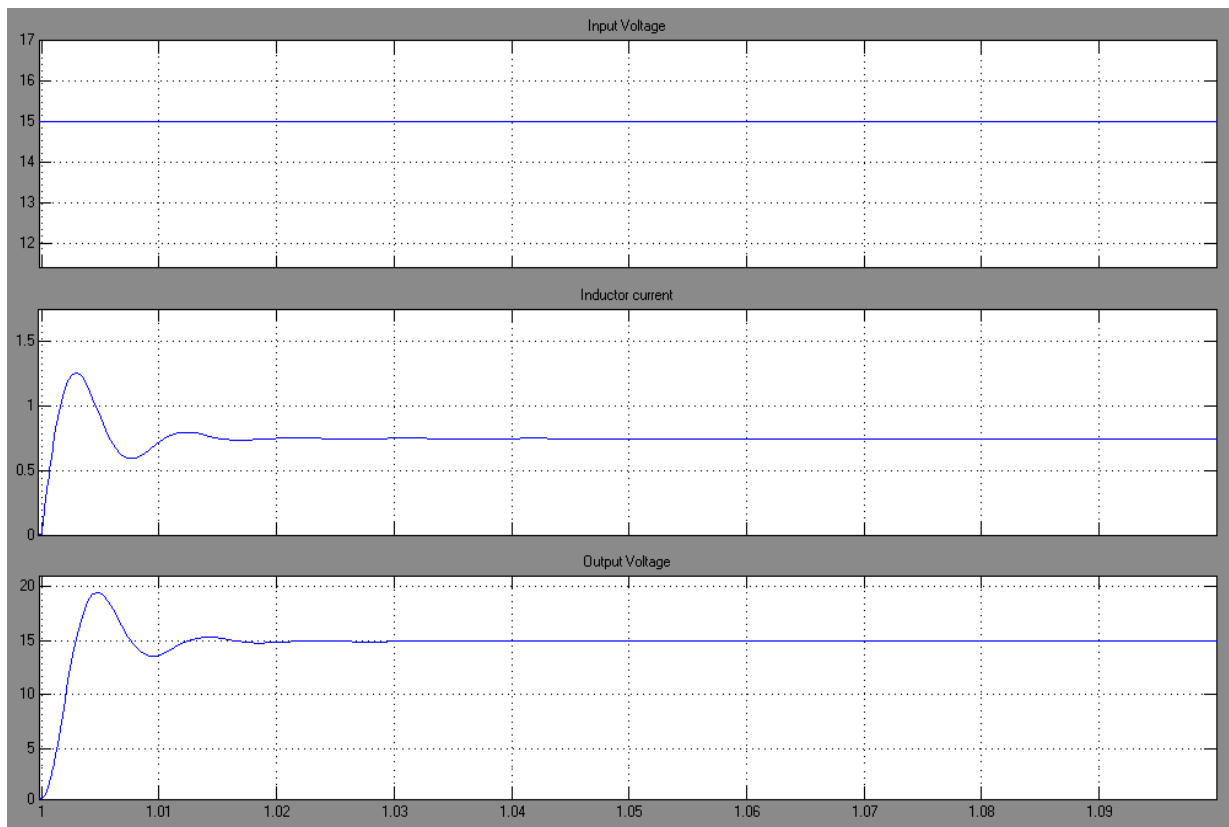


Figure 11. MATLAB SIMULINK Simulated response of Input voltage, Inductor current and output voltage.

current mode. References^{8,9} have done related work in non-linear systems that I have improved by implementing delta DSMFC concept.

9. Conclusion

In this paper Delta operator Based DSMFC for buck converter is proposed which will suit for power converters. If we are comparing the result of other controllers with this controller output we can able see rapid response in its performance and it is chattering free also. This shows it is reliable and efficient.

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