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Design of Robust Chattering free Integral Sliding Mode Controller for Dual Input Buck Boost Converter

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Abstract

This paper proposes the application of modified Integral sliding mode control (ISMC), replacing the discontinuous part of control with continuous control for the output voltage regulation for dual input buck boost converter (DIBB). The design method is clearly illustrated for dual input buck boost converter with above control strategy. The simulation results reveal the reduction of settling time and chattering in the output of DIBB. The simulation results of DIBB for its responses to load and line regulations with modified ISMC are compared with the simulation results of discontinuous control in ISMC. The results show the effectiveness of modified integral sliding mode control with super-twisting algorithm as continuous part in ISMC.

Keywords: Dual input buck boost converter, Integral sliding mode control, Super-twisting algorithm, Discontinuous control.

INTRODUCTION

DC-DC converters are used in DC motor drives, Uninterrupted Power Supplies (UPS) etc. These converters with regulated output voltage are essential to ensure stable output voltage [1]. The conventional sources of energy such as solar, wind, tidal power etc. are used in many tropical regions. Integration of the above energy sources is inevitable to tap the maximum energy from these sources. Various topologies are available for dual input buck boost converters (DIBB) [2], [3], [4]. The topology available in [2] where a power source and energy storing device as two inputs of dual input buck boost converter are taken in this work.

The sliding mode is a robust control having properties like robustness, easy to tune and implementation, model order reduction, disturbance rejection etc. [5-8]. The performance of DIBB with conventional sliding mode control in cascaded structure [9] and the performance of DIBB with super twisting control [10] are available.

There are two phases in sliding mode control. First one is reaching phase and second one is sliding phase. The reaching phase is one in which the system states are driven from any initial state to reach the sliding manifold and sliding phase is one in which system is induced in to sliding manifold. The robustness cannot be guaranteed during reaching phase. The robustness comes in to action only after the occurance of sliding mode. Integral sliding mode controller (ISMC) is the best solution to eliminate the reaching phase [11]. The Bhatt and Berstein method of finite time stabilization without disturbance using chain of integrators [12] is not able to match non-vanishing matched disturbance. In order to reject non-vanishing matched disturbance, a discontinuous control is added with the nominal control [13] by some of the authors.

The discontinuous control may result in chattering. The chattering problem can lead to high heat loss in switches. There are many methods to reduce chattering problem [14]. Higher order sliding mode control is able to reduce the chattering problem while retaining the robustness. The most popular higher order sliding mode control techniques are twisting algorithm and super-twisting algorithm. In twisting algorithm the real time measurement of switching variable derivative is needed. But in some real time applications the measurement of derivative of switching variable is not possible. Such issues do not occur in super-twisting algorithm. Hence the integral sliding mode control with super-twisting algorithm is the best solution to eliminate reaching phase and to reduce chattering effect, while retaining the tracking performance and robustness. The control action becomes continuous in nature by the introduction of super-twisting algorithm [13].

The main objective of this paper is to apply the ISMC with super-twisting algorithm as an observer replacing the discontinuous control part of ISMC for DIBB and make the system more chattering free. In Section 2, brief introduction of Dual input buck boost converter is described. the design of integral sliding mode control with discontinuous control in ISMC and super-twisting algorithm in ISMC are explained in Section 3. The Performance of DIBB using integral sliding mode with discontinuous control, super-twisting algorithm and the comparisons are made in Section 4. The concluding remarks are given in Section 5.

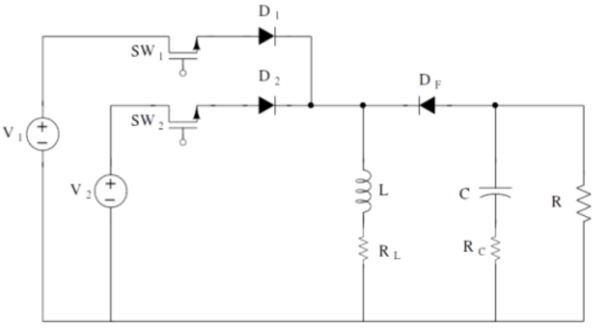

Figure 1: Dual Input Buck Boost Converter

Figure1 shows the Dual input buck boost converter as in [2]. The two input signals are V_1 and V_2 . The diodes D_1 and D_2 are connected to prevent the current flow from V_1 to V_2 and vice verse. Here the input V_1 is considered to be a stiff source and V_2 renewable energy source. The diode D_F is the free wheeling diode. There are three modes of operation [2]. In mode 1, SW_1 and D_1 are in conduction. In mode 2, SW_2 and D_2 are in conduction. Mode 3 is the free wheeling period.

The mode1 operation of DIBB is given in Figure 2. During this mode of operation, the inductor L is connected to the input voltage 1 (V_1) through SW_1 and D_1. The voltage across the capacitor discharges through the load and the current through inductor L builds up due to the positive voltage across inductor. Considering the state variable x_1 as inductor current I_L and state variable x_2 as the voltage across the capacitor v_c, the modeling can be done as:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix}=\begin{bmatrix}\frac{R_L}{L} & 0\\ 0 & \frac{-1}{C(R+R_C)}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}+\begin{bmatrix}\frac{1}{L}\\ 0\end{bmatrix}V_1 \qquad (1)$$

The state model can also be written as:

$$\dot{X}=\mathrm{F}(X)+G(X)u \qquad (2)$$

Where

$$\mathrm{F}(X)=\begin{bmatrix}\frac{R_L}{L} & 0\\ 0 & \frac{-1}{C(R+R_C)}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} \qquad (3)$$

$$G(X)=\begin{bmatrix}\frac{1}{L}\\ 0\end{bmatrix}V_1 \qquad (4)$$

Where

u =V_1 for mode1 operation and u=V_2 for mode 2 operation.

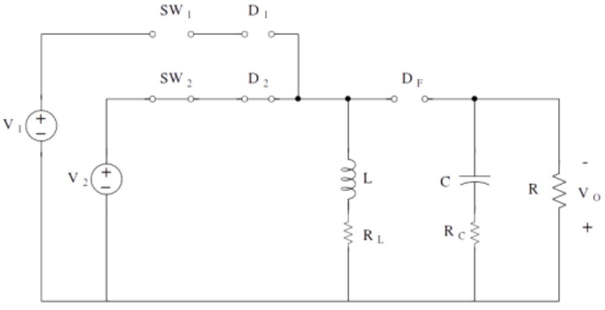

Figure 2: Mode 1 operation, sw_1 on sw_2 off

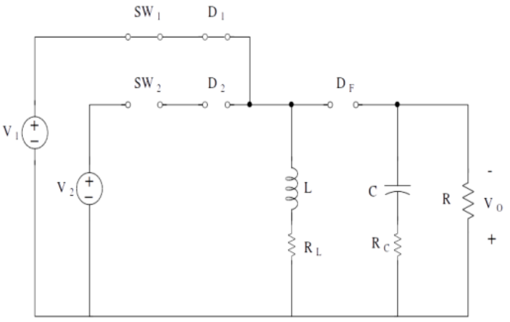

Figure 3: Mode 2 operation, sw_1 off sw_2 on

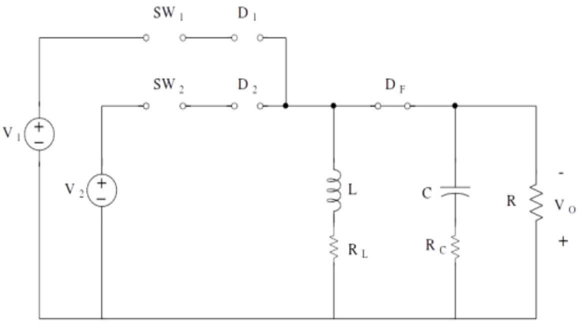

Figure 4: Mode 3 operation, sw_1 off sw_2 off

The mode 2 operation of DIBB is given in figure 3. During this mode of operation, inductor L is connected to the input voltage, (V_2) through SW_2 and D_2. The current through inductor L builds up and capacitor discharges through the load. The mode 3 operation of DIBB is given in figure 4. During this mode of operation, the capacitor gets charged through inductor L by the energy stored in the inductor.

Integral sliding mode control

The Dual input buck boost converter (DIBB) can be considered as two single input single output systems (SISO) connected in parallel. In this, the diodes D_1 and D_2 are introduced to reduce the coupling effect between the inputs. If we use sliding mode control, it consists of two phases, the first one is reaching phase and second one is sliding phase. The aim of this paper is to eliminate the reaching phase. The integral sliding mode is the best solution to eliminate the reaching phase, The integral sliding mode control is designed for each SISO system.The above system in figures 2 and 3 can be written in the following form by applying disturbance signal d as:

$$\dot{X}=\mathrm{F}(X)+G(X)u+d \qquad (5)$$

Where $\mathrm{F}(\mathrm{X})$ and $G(\mathrm{X})$ are the system matrix and input matrix respectively. The sudden changes in load, input voltages and reference voltages are considered as the disturbance d applied to the system. The integral sliding mode is added with either discontinuous control or continuous control (super-twisting algorithm) as per [13] to make the system robust.

Integral sliding mode control with discontinuous control as an observer

The integral sliding mode control is given by adding the nominal control with the discontinuous control. Here in this paper, the nominal control is designed using finite time stabilizing control and is given by [12]:

$$u_N = -\beta |e|^{1/2} sign(e) \tag{6}$$

where β is the nominal control gain and e, is the error between the actual value of the output voltage and reference value. It is found that if we use this control alone, the matched disturbance entering through control channel can not be rejected. So in order to reject such matched disturbance some authors designed additional discontinuous control u_D. The discontinuous control is used to make the system robust which is given by [13]:

$$u_D = -\lambda sign(e) \tag{7}$$

Where λ is the discontinuous controller gain.

The nominal control is added with the discontinuous control to reject the matched disturbance and the control signal u_1 given by [13].

$$u_1 = u_N + u_D \tag{8}$$

Now if we choose the control which is applied to the system as:

$$u = \frac{1}{G(X)}\left[-\mathrm{F}(X) + u_1\right] \tag{9}$$

By applying equation (8) in equation(9) and applying the control signal thus obtained u, in the system equation (5) , the system becomes:

$$\dot{X} = u_N + u_D + d \tag{10}$$

sliding surface is defined as:

$$s = X - X_0 - \int u_N \tag{11}$$

Where X_0 is the initial condition. The derivative of sliding surface becomes:

$$\dot{s} = \dot{X} - u_N \tag{12}$$

substituting for $\dot{X}$ in equation (12)

$$\dot{s} = u_N + u_D + d - u_N \tag{13}$$

When the system is on sliding mode, the equivalent value of the control is calculated by substituting the derivative of sliding surface is equal to zero [13]. Hence we can write

$$u_N + u_D + d - u_N = 0 \tag{14}$$

or

$$u_D = -d \tag{15}$$

This means that the disturbance can be rejected when the system is on sliding mode. The chattering in the control signal can be avoided by continuous control.

Integral sliding mode control with super-twisting algorithm as an observer

The super-twisting algorithm is one of the continuous control method. Hence if we replace the discontinuous control in equation (8) with super-twisting algorithm, the control signal given to the system is given by [13]:

$$u_1 = u_N + u_{STC} \tag{16}$$

where

u_N is the nominal control and u_{STC} is the super-twisting control. The nominal control is given by [12];

$$u_N = -\beta |e|^{1/2} sign(e) \tag{17}$$

Here β is the nominal control gain, and e is the error between the actual value of the output voltage and reference value. The super-twisting controller u_{STC} is given by [6]:

$$u_{STC} = -\gamma_1 |e|^{1/2} sign(e) - \gamma_2 \int sign(e) \tag{18}$$

Where γ_1 and γ_2 are positive gains. The parameters γ_1 and γ_2 are calculated using the equation:

$$\gamma_1 = 1.5L^{1/2}$$

$$\gamma_2 = 1.1L \tag{19}$$

With sufficient convergence conditions,

$$\gamma_2 > L,$$

$$\frac{2(\gamma_2 + L)^2}{\gamma_1^2(\gamma_2 - L)} < 1 \tag{20}$$

The value of L is chosen such that $|f(x)| \le L$. The appropriate choice of this γ_1 and γ_2 ensures the finite time convergence of the sliding variable. Defining the sliding surface ‘s’ for the system given in equation (2) as:

$$s = X - X_0 - \int u_N \qquad (21)$$

Where X_0 is the initial condition. Taking the derivatives of the surface as

$$\dot{s} = \dot{X} - u_N \qquad (22)$$

The control signal is given by:

$$u_1 = u_N + u_{STC} \qquad (23)$$

Applying equation (23) in equation (9) and substituting the resulting control signal in the system given in equation (5), the value of $\dot{X}$ can be calculated. Substituting this value in equation (22). The resulting equation is obtained as:

$$\dot{s} = u_N + u_{STC} + d - u_N \qquad (24)$$

When system is on sliding surface, the equivalent value of control is calculated by substituting derivative of sliding surface equal to zero [13].

$$u_N + u_{STC} + d - u_N = 0 \qquad (25)$$

or

$$u_{STC} = -d \qquad (26)$$

This means that the disturbance can be rejected when the system is on sliding sliding mode. Since the control applied to the system consists of continuous control, the chattering is reduced.

RESULT AND DISCUSSION

The simulation is carried out to validate the the integral sliding mode control for the Dual input buck boost converter. The values for capacitance and inductance are calculated using the switching frequency 25KHz and it is given in Table 1. Figure 5. shows the error with respect to time. It is observed that the error attains zero value within 0.05 seconds during boost operation of dual input buck boost converter when ISMC with discontinuous control as an observer is used. This is due to the elimination of reaching phase when integral sliding mode is used. Figure 6 shows the error with respect to time when ISMC with super-twisting control is used. Here also we can observe that the reaching phase is eliminated. Figure 7 shows the two input voltages and regulated output voltage during boost operation of dual input buck boost converter when ISMC with discontinuous control as an observer is used. Figure 8 clearly shows the overshoot and settling time of the output voltage. It is obvious from the figure that there is an initial overshoot of 60 percent and the settling time of 0.05 seconds. Figure 9 shows chattering in output voltage. There exists a ripple voltage of 0.4V which is not within the tolerance limit. Chattering will be high when discontinuous control is used. Figure 10 shows the two input voltages and regulated output voltage during boost operation of dual input buck boost converter when ISMC with super-twisting control as an observer is used. Figure 11. clearly shows the overshoot and settling time of the output voltage. It is obvious from the figure that there is no overshoot and becomes steady within 0.005 second on-wards. Figure 12 shows chattering in output voltage. It is obvious that there exists a ripple voltage of 0.1V in the output voltage which is within the tolerance limit. The chattering is reduced with the continuous action of super-twisting control.

Figure 13 shows the variation of output voltage with the change in input voltage (V1) (line regulation), when ISMC with discontinuous control as an observer is applied . The step change in input voltage from 12V to 24V occurs at 1.5 sec. It is noted that there is no overshoot or undershoot at the time of step change in input voltage. But the chattering is much high after the occurance of change in input voltage and this is due to the application of discontinuous control in ISMC. Figure 14. shows the zoomed version of output voltage after the occurance of line regulation at 1.5 seconds. It is observed that the chattering is 0.4V. Figure 15 shows the variation of output voltage with the change in input voltage (V1), (line regulation) when ISMC with super-twisting control is used. The step change in input voltage from 12V to 24V occurs at 1.5 sec. It is noted that there is small overshoot of 30 percent at the time of step change in input voltage and attains the steady state value within 0.15second and this explains the robustness of the ISMC with super-twisting control. Figure 16 clearly shows the chattering after the occurance of line regulation of DIBB. It is observed that there is a chattering of 0.1V which is within tolerance limit. The chattering is reduced with the use of super-twisting in ISMC.

Figure 17 shows the load regulation of DIBB with ISMC when discontinuous control as an observer is applied. It is observed that there is no change in output voltage at the time of step change in load. The chattering is about 0.4Vdue to discontinuous action of the control signal. Figure 18 shows the load regulation of DIBB with ISMC when super-twisting control as an observer is applied. It is observed that there is no change in output voltage at the time of step change in load. The chattering is reduced due to continuous action of the super-twisting control.

Figure 19 shows the regulated output voltage of DIBB when the reference is changed from 30V to 40V at 1.5 seconds when discontinuous controller as an observer is used. It is observed that there is no overshoot during the step change in the reference voltage and the output attains the desired value in 0.02 second. Figure 20 clearly shows the chattering in the control signal which is about 0.2V after the step change in reference voltage. Figure 21 shows the regulated output voltage of DIBB when the reference is changed from 30 V to 40 V at 1.5 seconds when super-twisting controller as an observer in ISMC is applied. It is observed that there is no overshoot during the step change in the reference voltage and the output attains the desired value in 0.1 second. Figure 22 clearly shows the chattering in regulated output voltage of DIBB when the reference is changed from 30V to 40V at 1.5 seconds. It is noticed that the chattering is about 0.2V when super-twisting control is used in ISMC.

Table 1: DIBB Parameters

Parameters	Values
1. Load Resistance	100Ω
2. Inductance. L	375µ H
3.Internal resistance of inductor , RL	0.01Ω
4.Capacitance, C	150 µF
5.Internal resistance of capacitor, RC	0.01Ω
6.Switching Frequency, F	25KHz
7.Input Voltage1, V1	12V
8.Input Voltage2, V2	10V

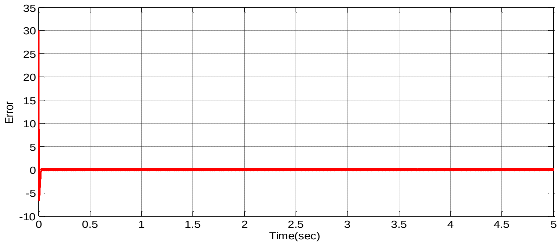

Figure 5: Error of DIBB with discontinuous control in ISMC

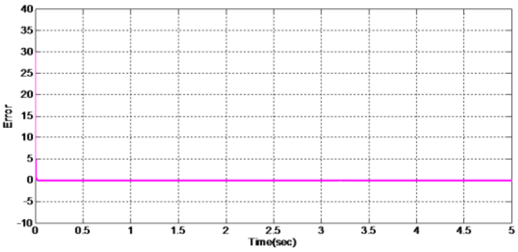

Figure 6: Error of DIBB with super-twisting algorithm in ISMC

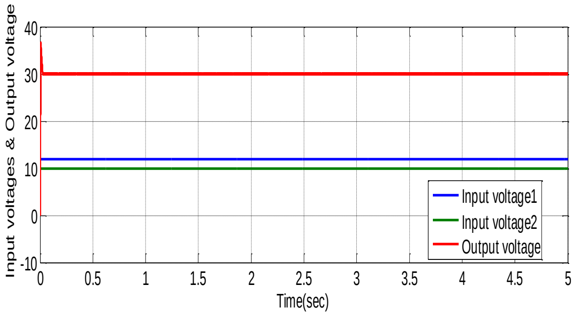

Figure 7: Output voltage of DIBB with discontinuous control in ISMC during boost operation

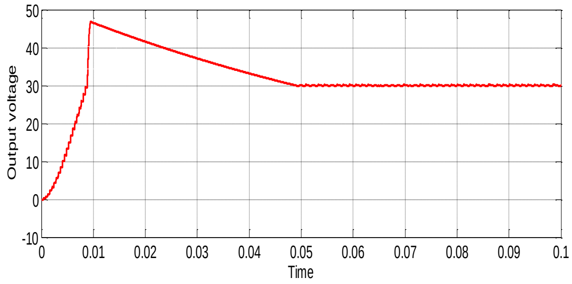

Figure 10: Zoomed version of initial Output voltage of DIBB with discontinuous control in ISMC during boost operation

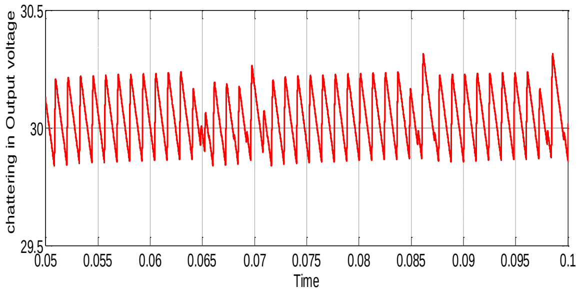

Figure 9: Zoomed version of chattering in Output voltage of DIBB with discontinuous control in ISMC during boost operation.

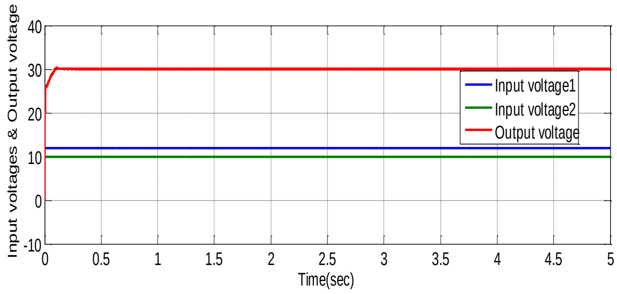

Figure 10: Output voltage of DIBB with super-twisting algorithm in ISMC during boost operation.

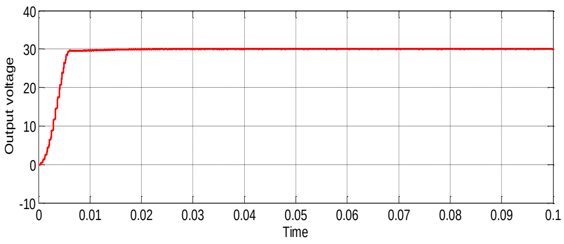

Figure 11: Zoomed version of initial Output voltage of DIBB with super-twisting algorithm in ISMC during boost operation.

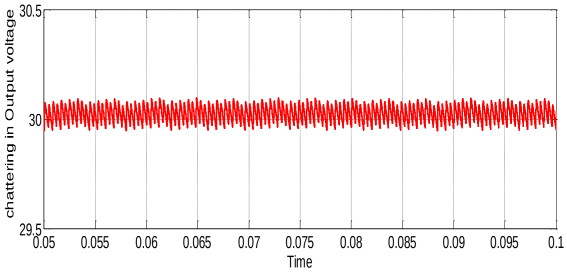

Figure 12: Zoomed version of chattering in Output voltage of DIBB with super-twisting algorithm in ISMC during boost operation

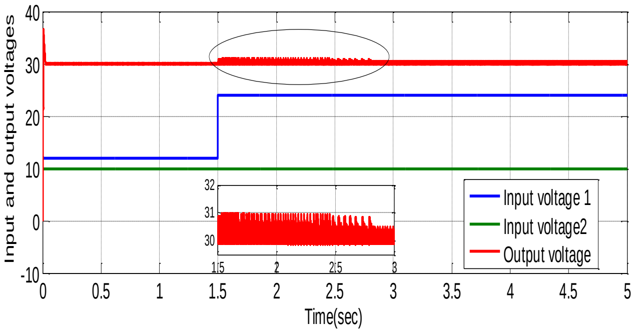

Figure 13: Line regulation of DIBB with with discontinuous control in ISMC

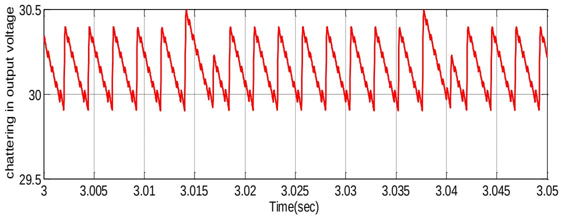

Figure 14: Zoomed version of chattering in Line regulation of DIBB with discontinuous control in ISMC

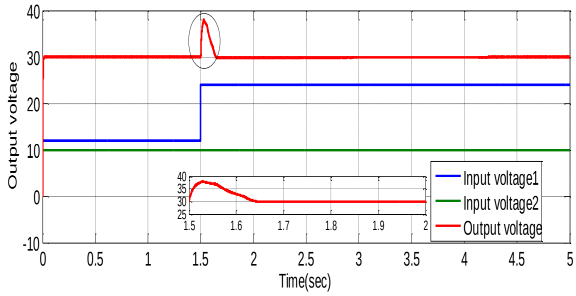

Figure 15: Line regulation of DIBB with super-twisting algorithm in ISMC

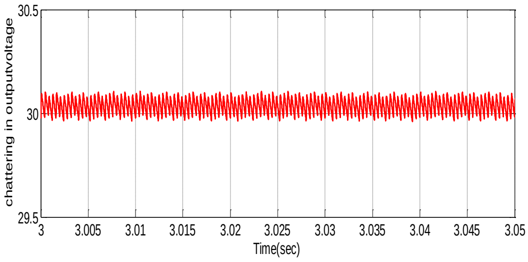

Figure 16: Zoomed version of chattering after Line regulation of DIBB with super-twisting algorithm in ISMC.

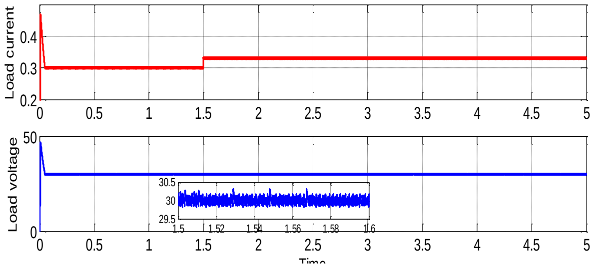

Figure 17: Load regulation of DIBB with discontinuous control in ISMC

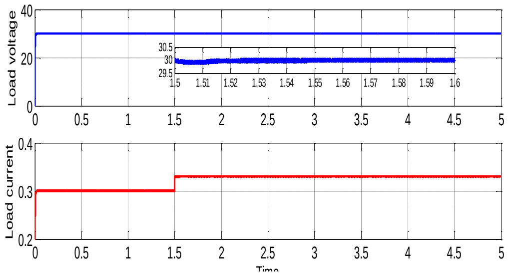

Figure 18: Load regulation of DIBB with super-twisting algorithm in ISMC

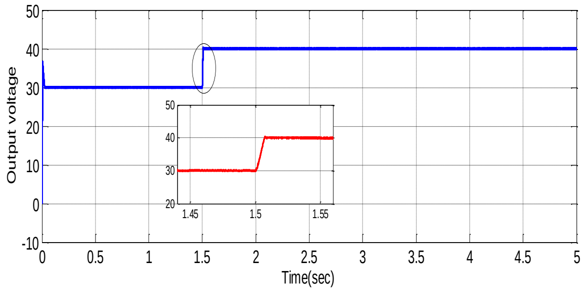

Figure 19: Output voltage of DIBB with discontinuous control in ISMC when reference is changed.

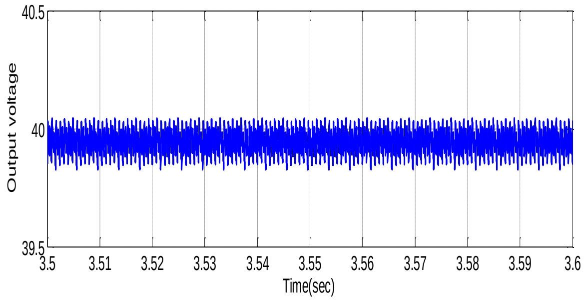

Figure 20: Zoomed version of chattering in Output voltage of DIBB with discontinuous control in ISMC

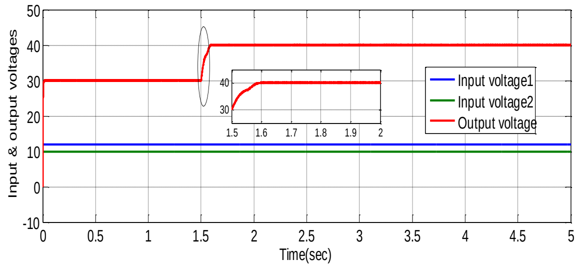

Figure 21: Output voltage of DIBB when reference is changed from 30V to 40V with super-twisting algorithm in ISMC

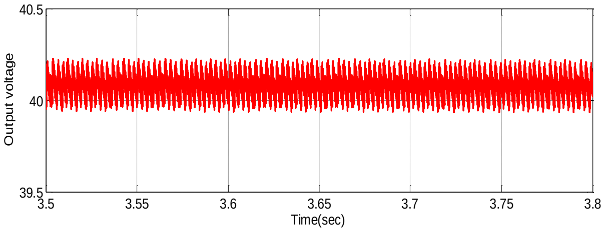

Figure 22: Zoomed version of chattering in output voltage of DIBB with super-twisting control in ISMC

Table 1: Performance comparison of DIBB using

	Super-twisting control in ISMC	Discontinuous control in ISMC
Chattering in output	0.1V	Settling time: 0.05sec Overshoot: 60percent
Initial transients	Settling time: 0.005sec Overshoot: nil	0.5V
Chattering in output voltage after the occurance of line regulation	0.1V	Settling time: 1.5 sec Chattering of 1V
Transients after line regulation	Settling time:0.15sec Overshoot: 30 percent	0.5V
Chattering in output voltage after the occurance of load regulation	0.1V	0.1 V
Chattering in output voltage after the occurance of Reference voltage change	0.2V	Settling time:0.02sec Overshoot: nil
Transients after reference change	Settling time:0.1sec Overshoot:30 percent	Settling time: 0.05sec Overshoot: 60percent

CONCLUSION

Application of integral sliding mode control with super-twisting algorithm in the dual input buck boost converter is the main contribution of this work. The output voltage of the Dual input buck boost converter is regulated using integral sliding mode control with discontinuous control as well as continuous control (super-twisting algorithm) as an observer. The output voltage is insensitive to the changes in the input voltages and also to the variation in the load current. The chattering in control as well as in output voltage is much reduced with the use of super-twisting algorithm in ISMC. The control signal obtained using super-twisting algorithm in ISMC can be used in real time application.

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