Super-twisting Control for Improved Performance of Dual Input Buck Boost Converter

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Abstract: ***This paper proposes the application of super-twisting control for the output voltage regulation of dual input buck boost converter (DIBB). The design method is clearly illustrated for dual input buck boost converter with the above control strategy. The simulation results of DIBB for its responses to load and line regulations are compared with the conventional sliding mode controller. The results reveal the effectiveness of the super- twisting based sliding mode control over conventional sliding mode control. The simulation results also reveal the reduction of settling time and chattering.***

Keywords: Dual input buck boost converter (DIBB), super-twisting control

1. Introduction

DC-DC converters have a wide range of applications in day to day life. They are used in DC motor drives, Uninterrupted Power Supplies (UPS) etc. The converters are used to regulate output voltage. It is thus essential to make use of DC-DC converters to ensure stable output voltage [1].

In many tropical regions the conventional source of energy such as wind, solar, tidal power etc. are available. In order to tap the maximum energy from these sources, integration of the above energy sources is inevitable. Various types of topologies are available for dual input buck boost converters (DIBB) in [2], [3] &[4]. In this work the topology available in [2] where a power source and energy storing device are taken as two inputs of Dual input buck boost converter.

The performance of sliding mode control applied to DIBB in cascaded structure is available in [5]. The sliding mode is a nonlinear robust control having properties like system order reduction, insensitivity to the parameter variation, easy tuning and implementation, disturbance rejection etc. [6-7]. There are two parts in the design of conventional sliding mode control. The first part is the design of sliding surface and second part is the design of control law. But the main disadvantage of conventional sliding mode control is the high frequency in switching which causes chattering. Although the system becomes robust by the application of sliding mode control, the system suffers from the high frequency switching in the control signal. The chattering problem leads to high heat loss in the circuits. There are many methods by which the chattering problem can be mitigated and these are available in [6].

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 control and super-twisting control. The twisting control needs the real time measurement of switching variable derivative. The measurement of derivative of switching variable is not possible in some real time applications. In super-twisting control algorithm such issues do not occur. Hence the super-twisting control technique [8-9] is the best solution to reduce chattering effect while retaining the robustness and tracking performance. The super-twisting control technique reduces the chattering because of the continuous time nature of controller action [10]. The control law is a linear combination of continuous and discontinuous functions of switching variable.

The main objective of this paper is to apply the super-twisting control algorithm for DIBB and make the system more chattering free. Brief introduction of Dual input buck boost converter is described in Section II. Super-twisting controller design is provided in Section III. The Performance of the DIBB with Super-twisting control and conventional sliding mode control are given in Section IV. The concluding remarks are made in Section V.

2. Working principle of Dual input Buck Boost Controller

Fig.1 shows the Dual input buck boost converter as in [2]. The two input signals are V_1 and V_2 respectively. To prevent the current flow from V_1 to V_2, the diodes D_1 and D_2 are connected. Here the input V_1 is considered to be renewable energy source and V_2 a stiff 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.

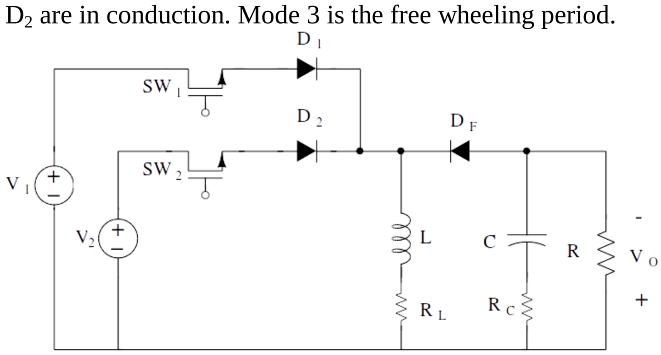

Figure 1: Dual input Buck Boost Converter

The different modes of operation of DIBB explained in [2] is once again repeated here for quick reference. The mode1 operation of DIBB is given in fig.2. During this mode of operation, the input voltage 1 (V_1) is connected to inductor

L through SW_1 and D_1. The current through inductor L builds up and capacitor discharges through the load. By considering the state variable x_1 as inductor current I_L and state variable x_2 as the voltage across the capacitor, the state space representation of mode 1 is written as per [2].

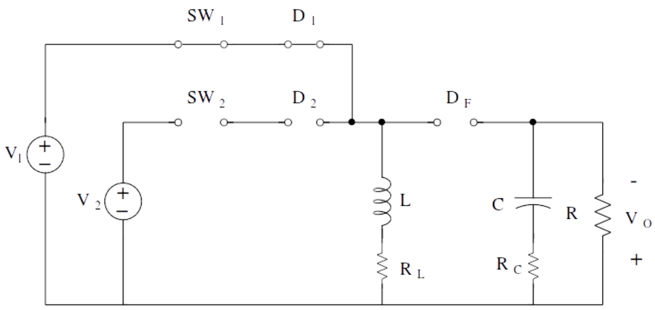

Figure 2: Mode 1, SW_1 and D_1conduct, SW_2 Off

The state model is given by

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

The output voltage is given by

$$v_0=\begin{bmatrix}0 & \frac{R}{R+R_c}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} \tag{2}$$

The mode 2 operation of DIBB is given in fig.3. During this mode of operation, the input voltage 2 (V_2) is connected to inductor L through Sw_2 and D_2. The current through inductor L builds up and capacitor discharges through the load.

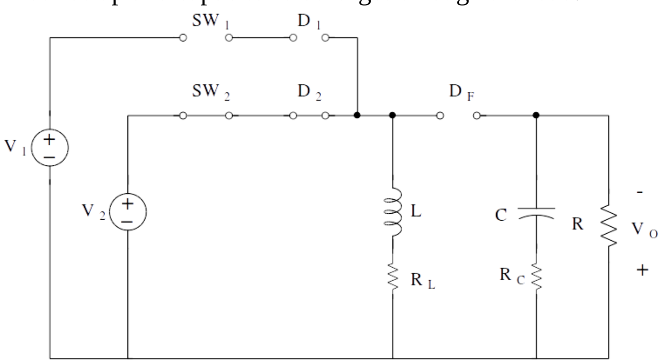

Figure 3: Mode 2, SW_2 and D_2 conduct, SW_1 off

The state model is given by:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix}=\begin{bmatrix}\frac{R_L}{L} & 0\\ 0 & \frac{-1}{C(R+R_C)}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}+\begin{bmatrix}\frac{1}{L}\\ 0\end{bmatrix}V_2 \tag{3}$$

The output is given by:

$$v_0=\begin{bmatrix}0 & \frac{R}{R+R_c}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} \tag{4}$$

The mode 3 operation of DIBB is given in fig.4. During this mode of operation, both switch SW_1 and SW_2 and diodes D_1 and D_2 are off. The capacitor gets charged during this period.

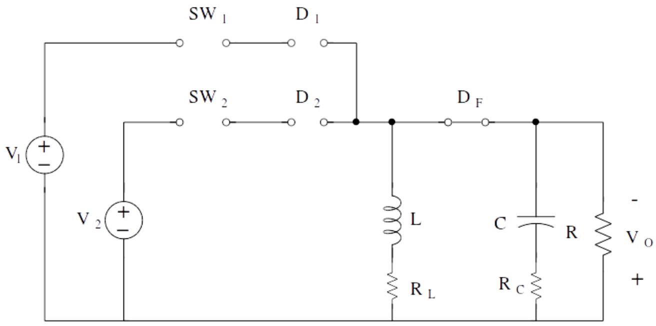

Figure 4: Mode 3, Freewheeling period

The state model is given by:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix}=\begin{bmatrix}-R_L+R\parallel R_C & \frac{-R}{L(R+R_C)}\\ \frac{R}{C(R+R_C)} & \frac{-1}{C(R+R_C)}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} \tag{5}$$

The output voltage is given by:

$$v_0=\begin{bmatrix}R_C\parallel R & \frac{R}{R+R_c}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} \tag{6}$$

3. Design of super-twisting controller for DIBB

The Dual input buck boost converter (DIBB) can be considered as two single input single output systems (SISO) connected in parallel. The super-twisting control is designed for each system. The coupling effect between the inputs is made to be zero with the introduction of the diodes D_1 and D_2.

The conventional sliding mode control for DIBB using cascaded structure [5] needs two control loops. Inner current loop and outer voltage loop. Generally for most converters, motion rate of current is much faster than the motion rate of voltage. Because of this reason, sliding mode control is applied in inner current loop and proportional integral (PI) controller is given in outer voltage loop. The conventional sliding mode control is given by

$$u=0.5(1-sign(S)) \tag{7}$$

This conventional sliding mode control generates high frequency switching in control signal which is also known as chattering problem. In order to avoid chattering problem in control signal, super-twisting control algorithm is used. There are two parts in the super-twisting control algorithm. One is continuous control part and other one is discontinuous control part. The continuous control part reduces the chattering effect and discontinuous control part stabilizes the system. The super twisting control as given in [6] can be written as :

$$\begin{aligned}u&=-\beta_1|e|^{1/2}\,sign(e)+u_1\\ \dot{u}_1&=-\beta_2 sign(e)\end{aligned} \tag{8}$$

Hence super-twisting control can be written as:

$$u=-\beta_1|e|^{1/2}sign(e)-\beta_2\int sign(e) \tag{9}$$

Where u is the super twisting control signal, β_1 and β_2 are positive parameters, *e* is the error between the actual value of the output voltage and desired output voltage. The large value of β_2 of the super-twisting control will attract the desired trajectory in finite time. Once the control u enters the required segment in finite time, it never leaves from there. The parameters β_1 and β_2 are calculated using the equation:

$$\beta_1 = 1.5L^{1/2}, \quad \beta_2 = 1.1L \qquad (10)$$

With sufficient convergence conditions,

$$\beta_2 > L, \quad \frac{2(\beta_2 + L)^2}{\beta_1^2(\beta_2 - L)} < 1 \qquad (11)$$

The appropriate choice of this β_1 and β_2 ensures the finite time convergence of the sliding variable.

4. Performance of DIBB with super-twisting and conventional slide mode controller

The simulation is carried out to validate the Super twisting 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 two input voltages and regulated output voltage during boost operation of dual input buck boost (DIBB) converter when super-twisting control is used. It is obvious from the figure that there is no initial overshoot or undershoot. It becomes steady from 0.1 second on-wards. There exists a ripple voltage of 0.045V which is within the tolerance limit. Figure 6 shows two input voltages and regulated output voltage during buck operation of dual input buck boost (DIBB) converter, when super-twisting control is used. It is obvious from the figure that there is an initial overshoot and settles in 0.25 second.

Fig. 7 shows the super-twisting control signal with respect to time. The output of the super-twisting controller is compared with the 25 KHz saw-tooth signal and is given as the control signal to DIBB. It is clear that the super-twisting control signal changes according to the duty ratio. Since there is no chattering in the control signal, the control value can be used in real time application. Fig. 8 shows the error surface with respect to time. It is noted that the error attains zero value in 0.1 second which explains the efficiency of the super-twisting control. Fig. 9 shows the regulated output voltage of DIBB when the reference is changed from 30 V to 40 V at 2.5 seconds. 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.

Fig. 10 shows the variation of output voltage with the change in input voltage1 (V_1) (line regulation), when super-twisting control is applied. The step change in input voltage from 12V to 24V occurs at 1.5 sec. It is noted that there is small overshoot at the time of step change in input voltage and attains the steady state value within 0.2 second and this explains the robustness of the super-twisting control. Fig. 11 shows the load regulation of DIBB using super-twisting control. It is observed that there is no change in output voltage at the time of step change in load.

Figure 12 shows the two input voltages and regulated output voltage during boost operation of dual input buck boost (DIBB) converter when conventional sliding mode control is used. It is obvious from the figure that there is an overshoot of 16.6 percent. It becomes steady from 0.25 second on-wards. There exists a ripple voltage of 0.002V in the output which is within the tolerance limit. Figure 13 shows two input voltages and regulated output voltage during buck operation of dual input buck boost (DIBB) converter, when conventional sliding mode control is used. It is obvious from the figure that there is an initial overshoot of 16.66 percent and settles in 0.1 second.

Fig. 14 shows the Error surface. It is noted that the thickness of this error surface obtained using conventional sliding mode control is greater than that using super twisting control. This is because as the order of sliding mode increases the thickness of the sliding surface reduces. Fig. 15 shows the control signal with respect to time. It is clear that the conventional sliding mode control generated cannot be applied in real time application.

Fig. 16 shows the load regulation of DIBB using conventional sliding mode control. It is observed that there is small change in output voltage at the time of step change in load and attains the steady value within 0.2 seconds. Fig. 17 shows the variation of output voltage with the change in input voltage1 (V_1) (line regulation), when conventional sliding mode control is applied. The step change in input voltage from 12V to 24V occurs at 1.5 sec. It is noted that there is small overshoot at the time of step change in input voltage and attains the steady state value within 0.1second and this explains the robustness of the conventional sliding mode control. Thus the advantages of the application of super-twisting control in dual input buck boost converter are as follows: 1) the system becomes invariant to the changes in the input voltages and load currents 2) There is an improvement in the transient performances like reduction in settling time and overshoot. 3) The high frequency switching of the control signal is reduced. The simulation results of DIBB using super-twisting control is compared with the simulation results of DIBB obtained using conventional sliding mode control in Table II. It is noted that chattering effect in the control signal is high when conventional sliding mode control is used. The chattering effect is reduced with the use of super-twisting control and can be applied in real time.

Table 1: DIBB converter parameter

Description	*Parameter*	*Values*
Load Resistance	R	100Ω
Inductance	L	375μ H
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Internal resistance of inductor	R_L	0.01Ω
Capacitance	C	150 μF
Internal resistance of capacitor	R_C	0.01Ω
Switching Frequency	F	25KHz
Input Voltage1	V_1	12V
Input Voltage2	V_2	10V

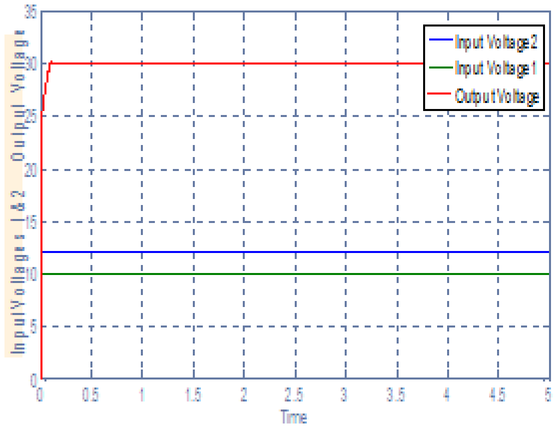

Figure 5: Output voltage of DIBB with Super-twisting control during boost operation

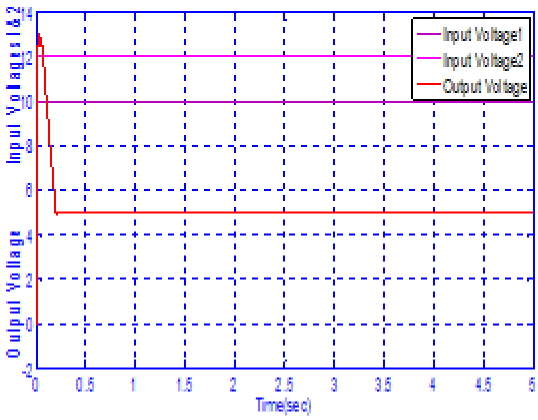

Figure 6: Output voltage of DIBB with Super-twisting control during buck operation

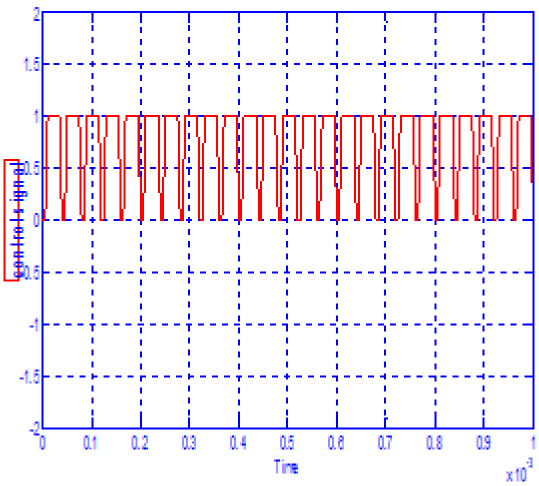

Figure 7: Super-twisting control signal

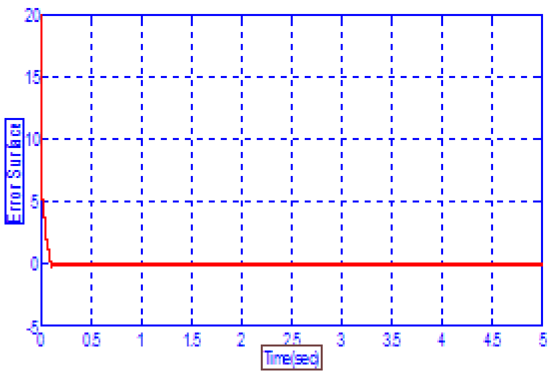

Figure 8: Error surface

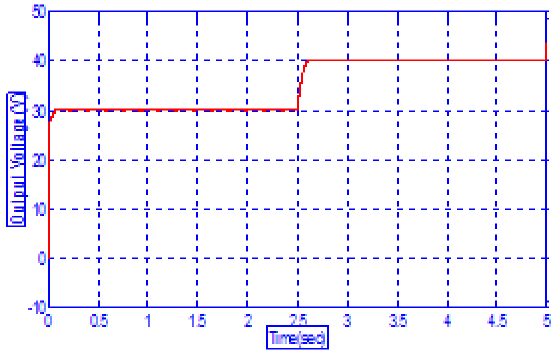

Figure 9: Output voltage of DIBB with Super-twisting control when reference is changed from 30V to 40 V at 2.5 sec

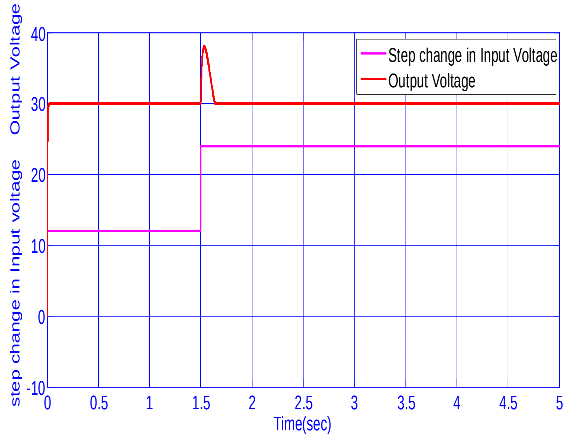

Figure 10: Output voltage of DIBB with Super-twisting control. one of the input voltage changes from 12V TO 24 VM at 1.5 sec

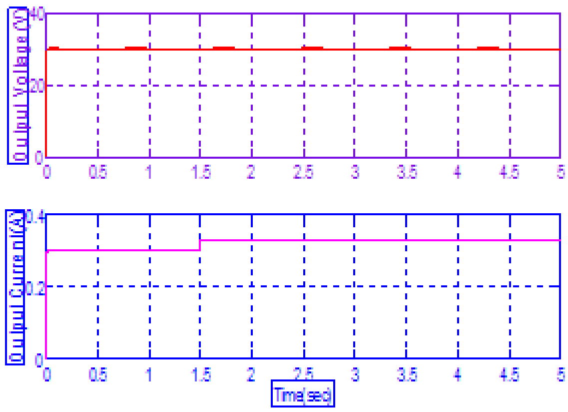

Figure 11: Output voltage of DIBB with Super-twisting control When load changes at 1.5 sec

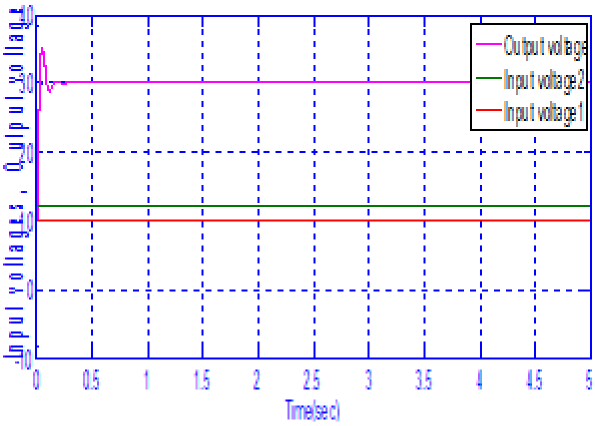

Figure 12: Output voltage of DIBB with conventional sliding mode control during boost operation

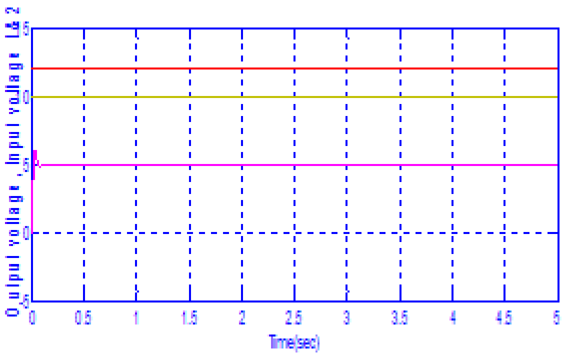

Figure 13: Output voltage of DIBB with conventional sliding mode control during buck operation

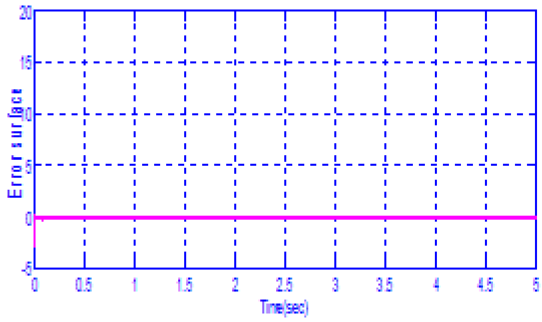

Figure 14: Error surface

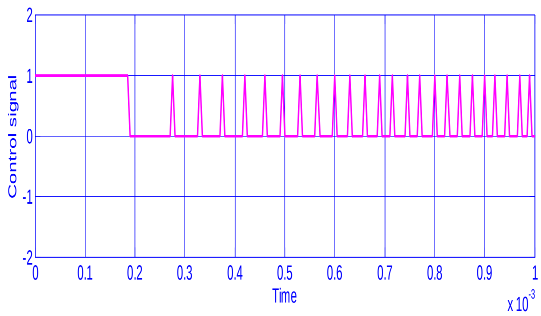

Figure 15: conventional sliding mode control signal

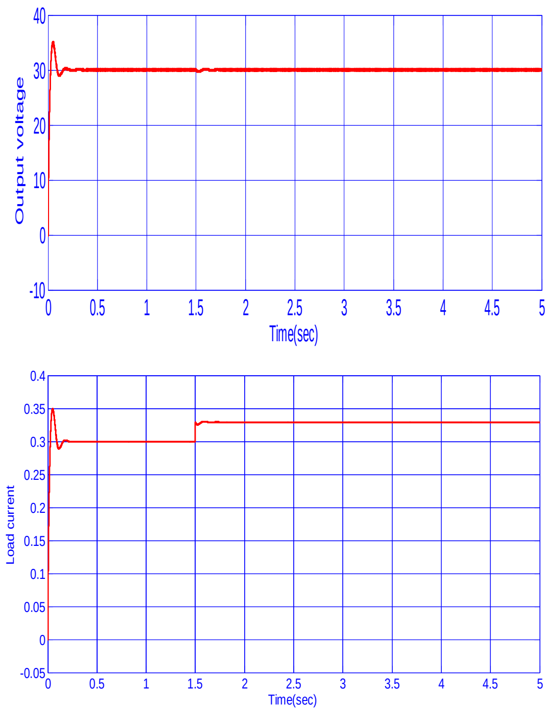

Figure 16: Output voltage of DIBB with conventional sliding mode control When load changes at 1.5 sec

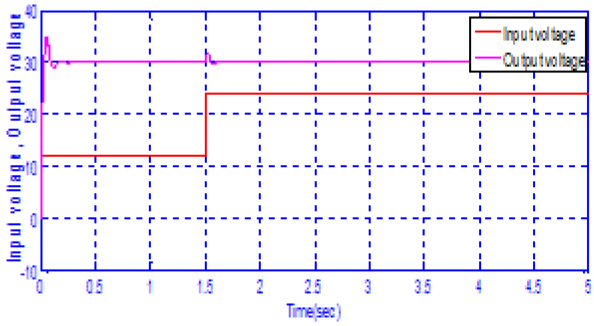

Figure 17: Output voltage of DIBB with conventional sliding mode control. one of the input voltage changes from 12V TO 24 VM at 1.5 sec.

Table 1: Comparison

	Performance of DIBB with super- twisting controller	*Performance of DIBB with conventional sliding mode controller*
Chattering in output	±0.045	±0.002
Switching in control signal	High frequency switching. The switching signal cannot be applied in real time.	Switching at designed frequency. The switching signal can be applied in real time.
Initial Transient	No overshoot for boost operation, Small Overshoot for buck operation The settling time is 0.1 second.	Overshoot for buck and boost operation. The settling time is 0.25 second.
Dynamic Response (line Regulation)	Small change in the output voltage at the time when a change in input voltage occurs and attains steady value with in 0.2 second	Small change in output voltage to changes in input voltage and attains steady value in 0.1 second
Dynamic Response (Load Regulation)	Output voltage is insensitive to a change in load current occurs.	Small change in the output voltage at the time when a change in load current occurs and attains steady value in 0.2 second.

5. Conclusion

Application of super-twisting control in dual input buck boost converter is the main contribution of this work. The output voltage of the Dual input buck boost converter (DIBB) is regulated using super-twisting control. The output voltage is insensitive to the changes in the input voltages and also to the variation in the load current. The transient performance criterion like settling time and chattering effect has also been reduced when super-twisting control is used.

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