International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 8 (2018) pp. 6110-6117

Analyzing the Effect of Ramp Load on Closed Loop Buck Boost Fed DC Drive with PI Controller

G. Ramu[1], Umme Salma[2], C Dharma Raj[3]

[1,2] Department of Electrical and Electronics Engineering, GITAM (Deemed to be University), Visakhapatnam, India.
[3] Department of Electronics and Communication Engineering, GITAM (Deemed to be University), Visakhapatnam, India.

Abstract

In order to achieve good power management for simple applications can be achieved by using complete voltage range. The regulated voltage as per the load requirement can be efficiently and accurately transforms the battery voltage using buck-boost converter. This converter is designed and verified with a control range of 48-64 Volts and the ripple content is calculated. This ripple content is analyzed with closed loop operation of converter with PI controller when compared to open loop operation. The obtained graphical and numerical results show the effectiveness of the converter.

Keywords: Buck-Boost converter; Ripple factor; Load uncertainties; PI controller.

INTRODUCTION

Thyristorised power controllers are now widely used in the industry. Conventional controllers involving magnetic amplifiers, mercury arc amplifiers, rotating amplifiers, resistance controllers etc. have been replaced by thyristorised power controllers. A.C. and D.C. drives in rolling mills, paper mills and textile mills, traction vehicles, mine winders, cranes etc., widely used are thyristorised power controllers. By using microcontroller to generate and control the triggering angle, we can generate pulses of accurate width.

There are several types of voltage buck-boost converters are available [1-3]. Achieving high efficiency over input voltage range is key issue for the DC-DC converter. In this the buck-boost converters applied as pre stage DC-DC converter because of their simple structure [4-5]. Buck or boost converter cannot achieve high efficiency over wide range of input voltage range [6]. Isolated buck-boost converter design is presented in [7], but the efficiency of this converter design is low because of high voltage/current stresses on the components. The two switch buck-boost converter is proposed in [8], this is used to power factor correction applications [9, 10]. Improper designing of buck – boost converter is that both the input current and the output current feeding the output stage are highly discontinuous which leads to large external filtering requirements [11].

The rest of the paper consist configuration of buck-boost converter along with continuous and discontinuous modes of operation followed by its design aspects. At last, the effectiveness of the developed converter is analyzed on the DC drive in terms of ripple in various parameters such as output voltage, input and output currents, speed, torque and output power. The effect of PI controller in closed loop operation is compared with the open loop operation.

CONFIGURATION OF BUCK-BOOST CONVERTER FED DC DRIVE

Very frequently DC drives are preferable due to its control characteristics. Most commonly armature voltage control method is employed to get required speed below the rated speed. In this paper, this operation is achieved by performing closed loop operation with PI controller. The gain parameters are tuned in such a way that, the required speed is obtained from the given drive. The voltage supplied to the drive is controlled by changing the voltage supplied to the converter. The complete block diagram of buck-boost fed DC drive is shown in Fig.1.

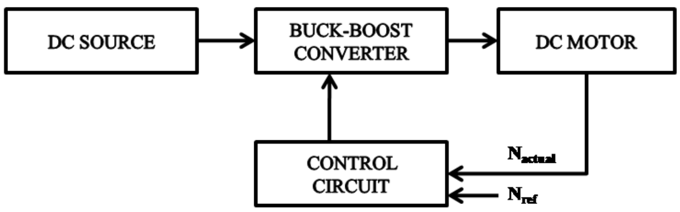

Figure 1. Block diagram of proposed buck-boost fed DC drive

The speed of DC motor is fed back to the control circuit. This value is compared with the reference speed input and the difference between them is processed and pulses are generated by the control circuit. These generated pulses drives the buck-boost converter so as to maintain the required speed.

The basic circuit consist two charging elements such as one capacitor and one inductor connected in parallel in series with a diode is shown in Fig.2.. This converter consist two MOSFET switches and three diodes.

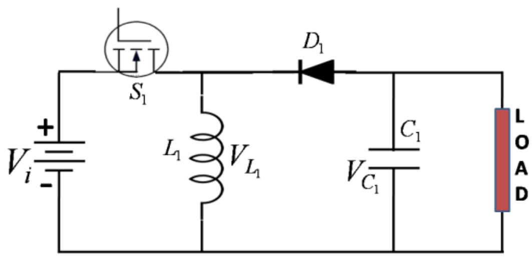

Figure 2. Basic circuit diagram of proposed buck-boost converter

The schematic diagram of the buck-boost fed DC drive is shown in Fig.3.

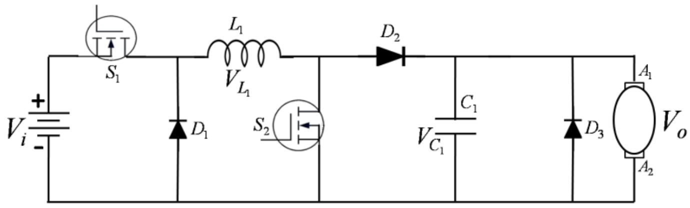

Figure 3. Schematic diagram of buck-boost converter fed DC drive

From Fig.3, this converter can be operated in the following three configurations.

- When switches S_1 and S_2 are closed as shown in Fig.4: In this configuration, the inductor starts charging.
- When switch S_1 is closed and S_2 is opened as shown in Fig.5: In this configuration, capacitor starts charging to double voltage i.e. source voltage plus inductor voltage.
- When S_1 and S_2 are opened as shown in Fig.6: In this configuration, capacitor stars discharging through the drive.

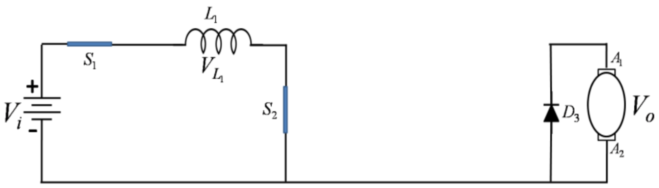

Figure 4. Configuration of buck-boost fed DC drive when switches S_1 and S_2 are closed

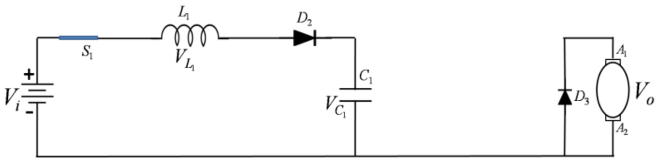

Figure 5. Configuration of buck-boost fed DC drive when switch S_1 is closed and S_2 is opened

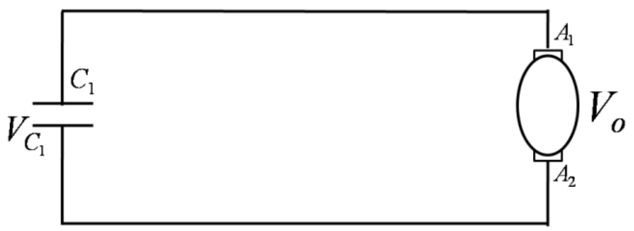

Figure 6. Configuration of buck-boost fed DC drive when switch S_1 and S_2 are opened

Modes of operation

For any DC drive, there are two modes of operation, one is continuous conduction mode for full load condition and other is discontinuous conduction mode for light load conditions. In continuous conduction mode, the relation between input (V_i) and output (V_o) voltages are given as

$$\frac{V_o}{V_i} = \frac{D}{1-D} \quad (1)$$

In discontinuous conduction mode, the relation between input and output voltage are given as

$$\frac{V_o}{V_i} = -\frac{V_i D^2 T}{2LI_o} \quad (2)$$

Where, 'T' is the total time period, 'D' is the duty ratio of the converter, I_o is the output current.

DESIGNING OF BUCK-BOOST CONVERTER

The basic buck-boost converter consist two MOSFETs (S_1 and S_2) and two diodes (D_1 and D_2) and two charging elements (L_1 and C_1). To design buck-boost converter, the following parameters are assumed:

Input voltage (V_i) = 48 V

Output voltage (V_o) = 64 V

Load resistance I = 0.04 Ω

Allowable current ripple limits (ΔI) = up to 20% of the full load current

From Eqn (1), the duty ratio can be calculated as

$$D=0.5714 \quad (3)$$

From the fundamentals, the inductor value can be calculated as

$$L = \frac{(1-K)R}{2f} \quad (4)$$

In the same way, the capacitor value can be calculated as

$$C = \frac{K}{2fR} \quad (5)$$

Ripple calculation

The amount of ripple in various input and output parameters can be calculated as

$$\%\,\text{Ripple} = \frac{\text{Change in parameter value}}{\text{Mean parameter value}} \times 100 = \frac{\text{Max. value} - \text{Min. value}}{\text{Mean value}} \times 100 \quad (6)$$

Angular velocity and Torque calculation

Similarly, angular velocity (ω) of the motor can be expressed as

$$\omega = \frac{2\pi N}{60} \quad (7)$$

Where, N is the speed in rpm.

The torque (T) developed by the motor can be expressed as

$$T = \frac{P_m}{\omega} \quad (8)$$

RESULTS AND ANALYSIS

To show the effect of load uncertainties on open loop and closed loop control actions in controlling the speed of DC drive, the entire analysis is performed for the following two cases

Case-1: Open loop control.

Case-2: Closed loop control.

Case-1 (Open loop control)

In this section, the effect of load uncertainties on open loop control system of DC drive fed from buck-boost converter is analyzed. The entire analysis is presented for 5 sec. A ramp load of 5% and 10% is applied on the DC drive at 1 sec. The simulink diagram of the open loop system is shown in Fig.7.

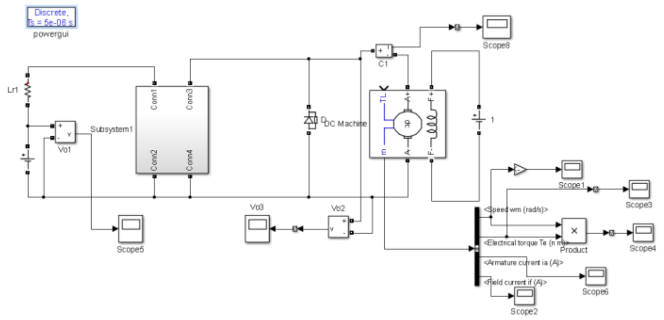

Figure7. Simulink diagram of the open loop buck-boost fed DC drive

The simulation result of the input and output voltages are shown in Figures 8 and 9. From this it is noticed that, the input voltage of 48 V is boosted up to more than 54 V. It is also observed that, the output voltage is increased as the load on the motor is increasing from without load to with 10% of ramp load. It is noticed that, output voltage is 53.406 V without load, 55.374 V with 5% ramp load and 57.73 V with 10% ramp load. From this it is observed that, the proposed converter increases output voltage as the load is increased. It is also noticed that, the ripple content in output voltage is zero due to effectiveness of the converter design. Due to effectiveness of the converter topology, the final steady state is obtained after 2 sec and the final steady error is zero.

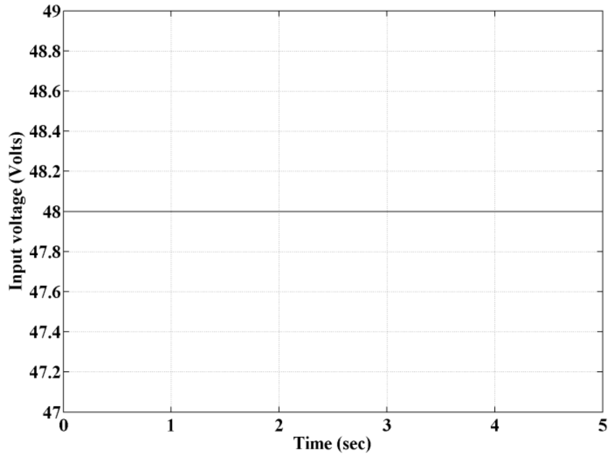

Figure 8. Simulation result of the input voltage for open loop buck-boost fed DC drive

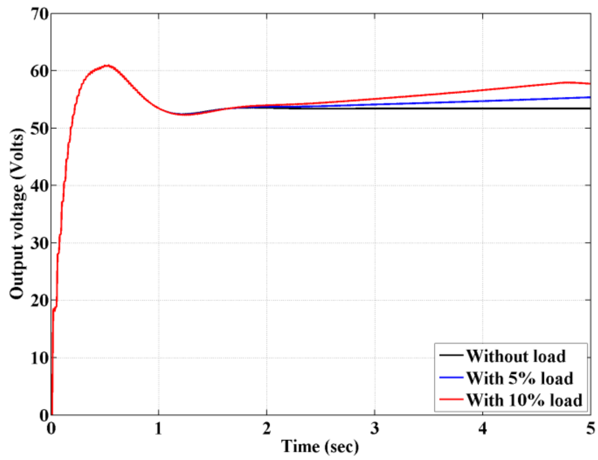

Figure 9. Simulation result of the output voltage for open loop buck-boost fed DC drive

The simulation result of the input and output currents are shown in Figures 10 and 11. From this, it is noticed that, without load, the input current of 15.188 A with the ripple 9.177% is reduced to be 11.236 A as output current with the ripple 10.756%, with 5% ramp load, the input current of 23.483 A with the ripple 0.023% is reduced to be 16.84 A as output current with the ripple 0.019% and with 10% ramp load, the input current of 30.519 A with the ripple 0.028% is reduced to be 22.519 A as output current with the ripple 0.019%. The input and output currents of the converter are increased as the load is increased. It is also the amount of current drop from input to output is also increased with the load. It is also noticed that, the ripple content in input and output currents is decreased as the load is increased due to effectiveness of the converter design. Due to effectiveness of the converter topology, the final steady state is obtained after 2 sec.

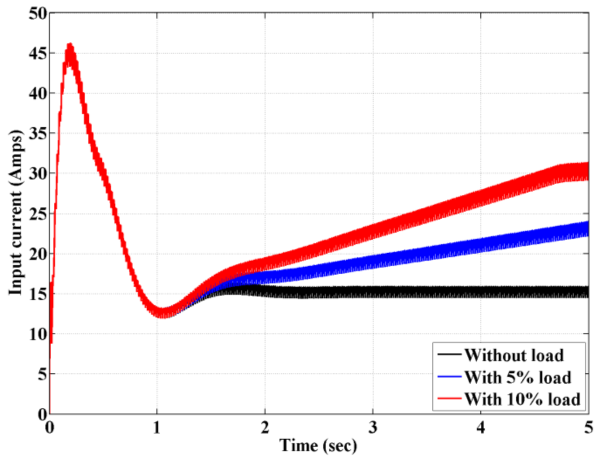

Figure 10. Simulation result of the input current for open loop buck-boost fed DC drive

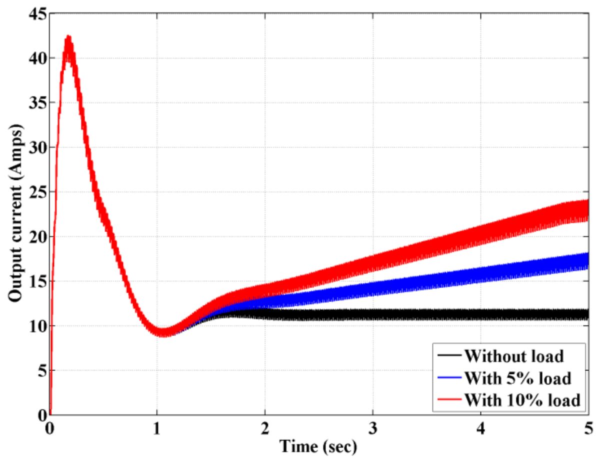

Figure 11. Simulation result of the output current for open loop buck-boost fed DC drive

The simulation result of the speed, torque and output power are shown in Figures 12, 13 and 14. From this, it is noticed that, without load, speed is 1463.169 RPM with the ripple of 0.346%, with 5% ramp load, the speed is 1341.082 RPM with zero ripple, with 10% ramp load, and the speed is 1217.664 RPM with zero ripple. It is also noticed that, speed of the motor is decreased and ripple content is increased as the load on motor is increased. It is noticed that, without load, the torque is 518.302 N-m with the ripple of 6.455%, with 5% ramp load, the torque is 724.235 N-m with the ripple of 0.012%, with 10% ramp load and the torque is 875.618 N-m with the ripple of 0.012%. It is also noticed that, torque of the motor is increased and ripple content is decreased as the load on motor is increased. Finally, it is noticed that, without load, the output power is 3.388 Watts with the ripple of 4.301%, with 5% ramp load, the output power is 5.176 Watts with the ripple of 0.008%, with 10% ramp load and the output power is 6.877 Watts with the ripple of 0.008%. It is also noticed that, output power of the motor is increased and ripple content is decreased as the load on motor is increased. Due to effectiveness of the converter topology, the final steady state is obtained after 2 sec.

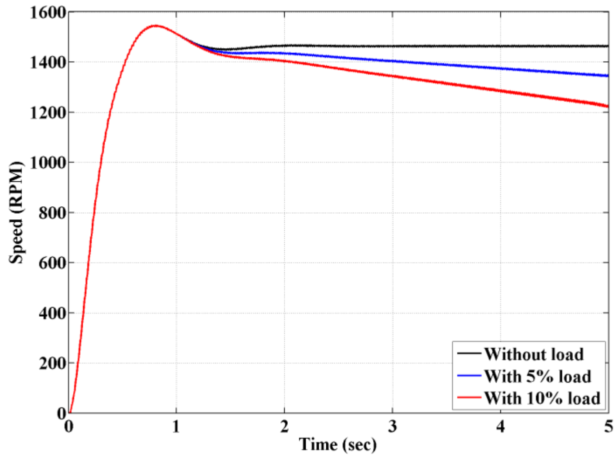

Figure 12. Simulation result of the speed for open loop buck-boost fed DC drive

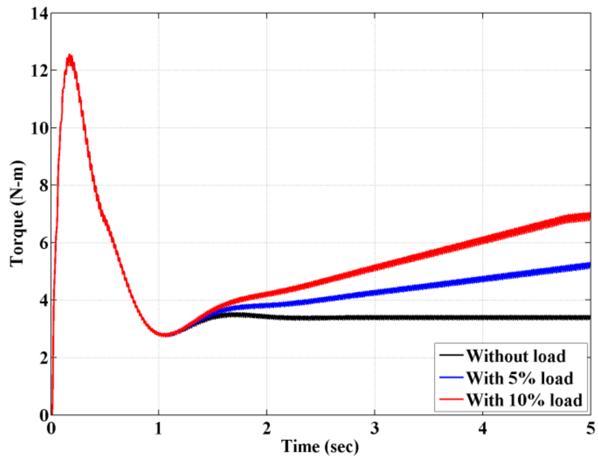

Figure 13. Simulation result of the torque for open loop buck-boost fed DC drive

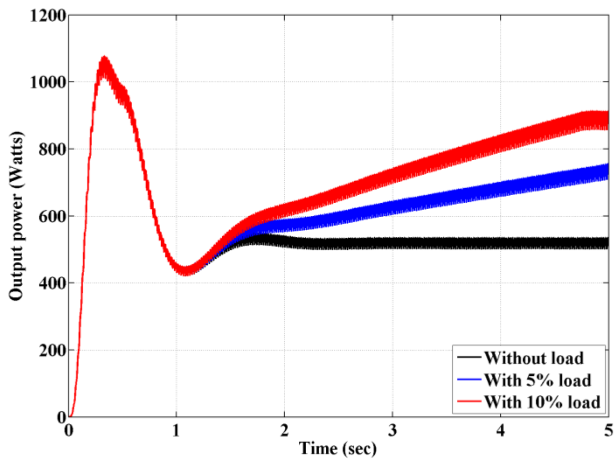

Figure 14. Simulation result of the output power for open loop buck-boost fed DC drive

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 8 (2018) pp. 6110-6117

To show the effectiveness of the developed converter topology, the numerical results pertaining to open loop control with different load are tabulated in Tables.1-3.

Table 1. Numerical results of open loop buck-boost fed DC drive without load

Parameters	Actual value	% ripple parameters		
		Min. value	Max. value	Ripple value
Output voltage (Volts)	53.406	53.406	53.406	0
Input current (Amps)	15.188	14.491	15.885	9.177
Output current (Amps)	11.236	10.632	11.84	10.756
Speed (RPM)	1463.169	1460.641	1465.698	0.346
Torque (N-m)	518.302	501.574	535.031	6.455
Output power (Watts)	3.388	3.315	3.461	4.301

Table 2. Numerical results of open loop buck-boost fed DC drive with 5% ramp load

Parameters	Actual value	% ripple parameters		
		Min. value	Max. value	Ripple value
Output voltage (Volts)	55.374	55.374	55.374	0
Input current (Amps)	23.483	23.481	23.486	0.023
Output current (Amps)	16.84	16.838	16.842	0.019
Speed (RPM)	1341.082	1341.08	1341.085	0
Torque (N-m)	724.235	724.192	724.278	0.012
Output power (Watts)	5.176	5.176	5.177	0.008

Table 3. Numerical results of open loop buck-boost fed DC drive with 10% ramp load

Parameters	Actual value	% ripple parameters		
		Min. value	Max. value	Ripple value
Output voltage (Volts)	57.73	57.73	57.73	0
Input current (Amps)	30.519	30.515	30.523	0.028
Output current (Amps)	22.394	22.392	22.396	0.019
Speed (RPM)	1217.664	1217.661	1217.666	0
Torque (N-m)	875.618	875.565	875.671	0.012
Output power (Watts)	6.877	6.877	6.877	0.008

Case-2 (Closed loop control)

In this section, the effect of load uncertainties on closed loop control system of DC drive fed from buck-boost converter is analyzed. The entire analysis is presented for 6 sec. A ramp load of 5% and 10% is applied on the DC drive at 1 sec. The simulink diagram of the closed loop system is shown in Fig.15.

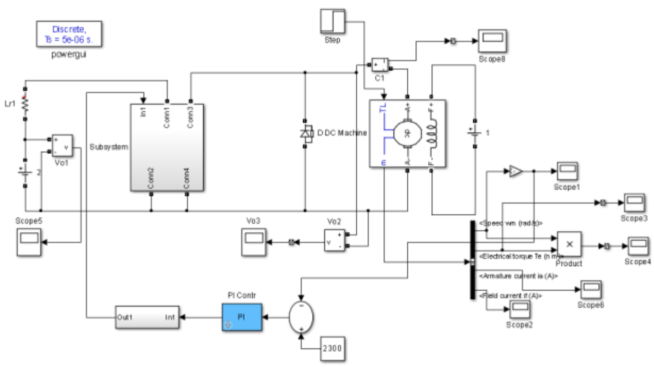

Figure 15. Simulink diagram of the closed loop buck-boost fed DC drive

The simulation result of the input and output voltages are shown in Figures 16 and 17. From this it is noticed that, the input voltage of 48 V is boosted up to more than 64 V. It is also observed that, the output voltage is increased as the load on the motor is increasing from without load to with 10% of ramp load. It is noticed that, output voltage is 53.406 V without load, 61.965 V with 5% ramp load and 64.55 V with 10% ramp load. From this it is observed that, the proposed converter increases output voltage as the load is increased. It is also noticed that, the ripple content in output voltage is zero for without load and this value is 0.542 for 5% load, 1.362 for 10% load due to effectiveness of the converter design. Due to effectiveness of the converter topology, the final steady state is obtained after 3 sec and the final steady error is zero.

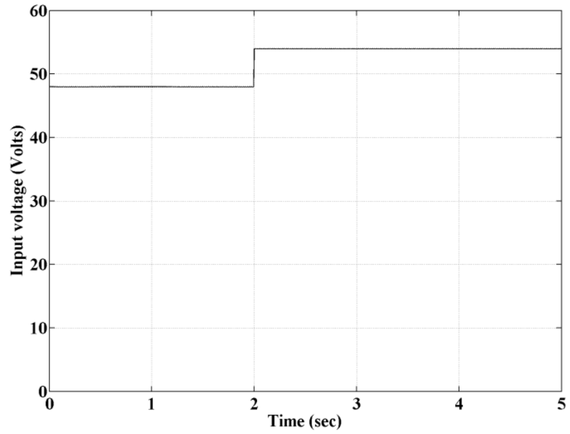

Figure 16. Simulation result of the input voltage for closed loop buck-boost fed DC drive

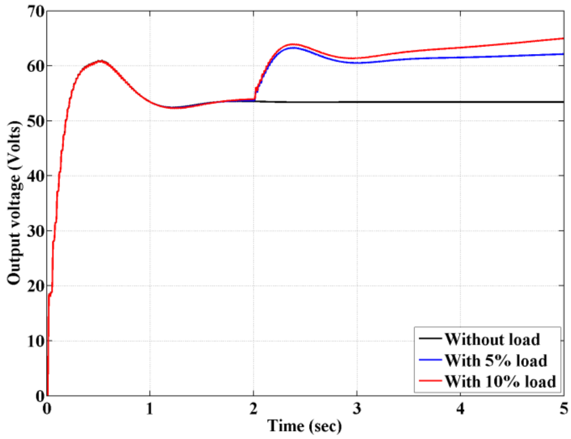

Figure 17. Simulation result of the output voltage for closed loop buck-boost fed DC drive

The simulation result of the input and output currents are shown in Figures 18 and 19. From this, it is noticed that, without load, the input current of 15.429 A with the ripple 0.002% is reduced to be 11.236 A as output current with the ripple 10.756%, with 5% ramp load, the input current of 24.665 A with the ripple 4.216% is reduced to be 18.342 A as output current with the ripple 14.74% and with 10% ramp load, the input current of 32.014 A with the ripple 6.495% is reduced to be 24.025 A as output current with the ripple 16.832%. The input and output currents of the converter are increased as the load is increased. It is also the amount of current drop from input to output is also increased with the load. It is also noticed that, the ripple content in input and output currents is decreased as the load is increased due to effectiveness of the converter design. Due to effectiveness of the converter topology, the final steady state is obtained after 3 sec.

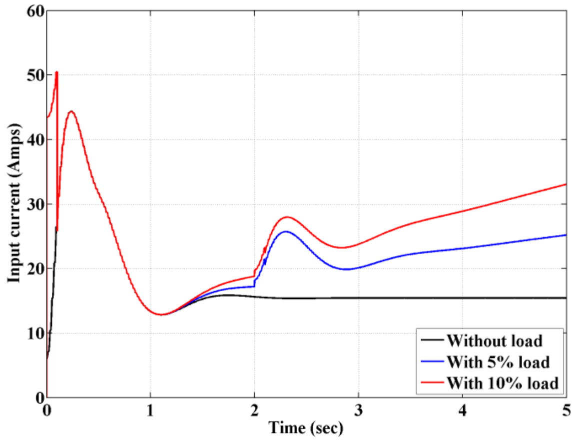

Figure 18. Simulation result of the input current for closed loop buck-boost fed DC drive

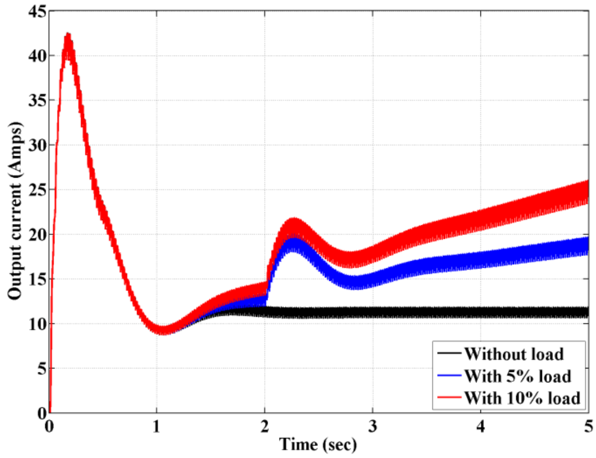

Figure 19. Simulation result of the output current for closed loop buck-boost fed DC drive

The simulation result of the speed, torque and output power are shown in Figures 20, 21 and 22. From this, it is noticed that, without load, the speed is 1463.169 RPM with the ripple of 0.346%, with 5% ramp load, the speed is 1538.654 RPM with the ripple of 1.461%, with 10% ramp load and the speed is 1426.926 RPM with the ripple of 2.761%. It is also noticed that, speed of the motor is decreased and ripple content is increased as the load on motor is increased. It is noticed that, without load, the torque is 518.302 N-m with the ripple of 6.455%, with 5% ramp load, the torque is 889.364 N-m with the ripple of 9.598%, with 10% ramp load and the torque is 1079.89 N-m with the ripple of 10.675%. It is also noticed that, torque of the motor is increased and ripple content is decreased as the load on motor is increased. Finally, it is noticed that, without load, the output power is 3.388 Watts with the ripple of 4.301%, with 5% ramp load, the output power is 5.528 Watts with the ripple of 8.363%, with 10% ramp load and the output power is 7.239 Watts with the ripple of 10.491%. It is also noticed that, output power of the motor is increased and ripple content is decreased as the load on motor is increased. Due to effectiveness of the converter topology, the final steady state is obtained after 3 sec.

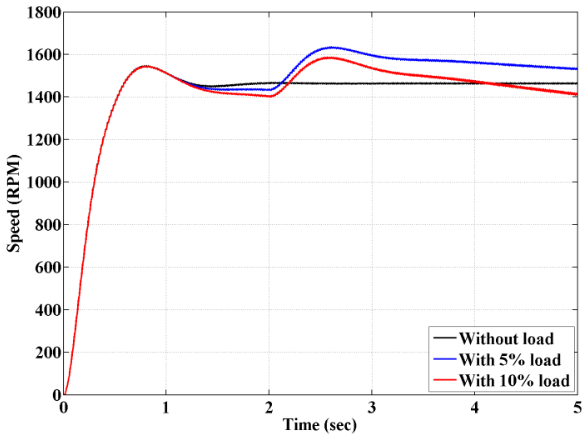

Figure 20. Simulation result of the speed for open loop buck-boost fed DC drive

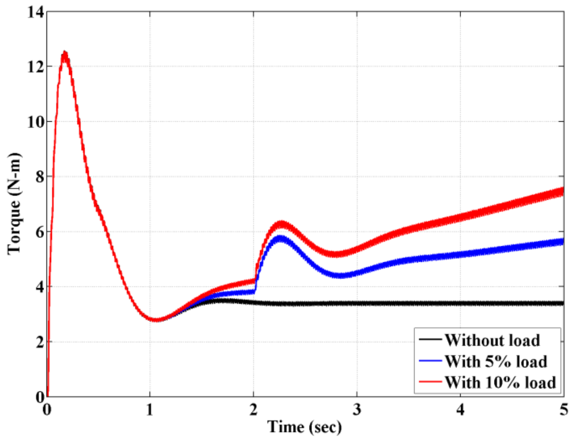

Figure 21. Simulation result of the torque for open loop buck-boost fed DC drive

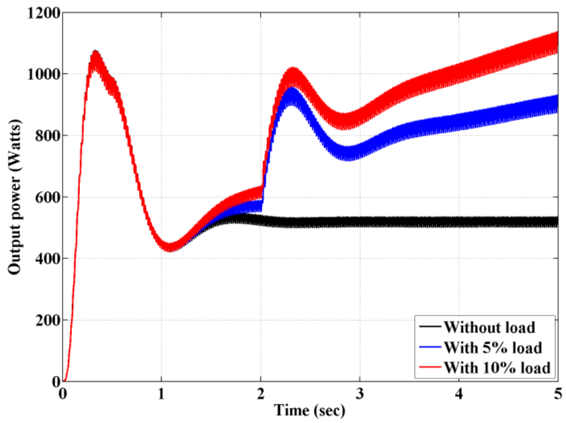

Figure 22. Simulation result of the output power for open loop buck-boost fed DC drive

To show the effectiveness of the developed converter topology, the numerical results pertaining to open loop control with different load are tabulated in Tables.4-6. From this, it is identified that, the closed loop operation increases the accuracy and decreases the ripple content in various parameters when compared to open loop operation.

Table 4. Numerical results of closed loop buck-boost fed DC drive without load

Parameters	**Actual value**	**% ripple parameters**		
		Min. value	**Max. value**	**Ripple value**
Output voltage (Volts)	53.406	53.406	53.406	0
Input current (Amps)	15.429	15.428	15.429	0.002
Output current (Amps)	11.236	10.632	11.84	10.756
Speed (RPM)	1463.169	1460.641	1465.698	0.346
Torque (N-m)	518.302	501.574	535.031	6.455
Output power (Watts)	3.388	3.315	3.461	4.301

Table 5. Numerical results of closed loop buck-boost fed DC drive with 5% ramp load

Parameters	**Actual value**	**% ripple parameters**		
		Min. value	**Max. value**	**Ripple value**
Output voltage (Volts)	61.965	61.797	62.133	0.542
Input current (Amps)	24.665	24.145	25.185	4.216
Output current (Amps)	18.342	16.991	19.694	14.74
Speed (RPM)	1538.654	1527.416	1549.892	1.461
Torque (N-m)	889.364	846.682	932.045	9.598
Output power (Watts)	5.528	5.297	5.759	8.363

Table 6. Numerical results of closed loop buck-boost fed DC drive with 10% ramp load

Parameters	**Actual value**	**% ripple parameters**		
		Min. value	**Max. value**	**Ripple value**
Output voltage (Volts)	64.55	64.111	64.99	1.362
Input current (Amps)	32.014	30.975	33.054	6.495
Output current (Amps)	24.025	22.003	26.047	16.832
Speed (RPM)	1426.926	1407.229	1446.622	2.761
Torque (N-m)	1079.89	1022.253	1137.527	10.675
Output power (Watts)	7.239	6.859	7.619	10.491

CONCLUSIONS

The effects of load uncertainties have been analyzed in this paper using buck-boost converter. For this, the converter parameters have been designed in such a way that, the closed loop operation with PI controller yields better results when compared to open loop operation. The speed of the motor can be maintained by varying armature voltage. From the results, it has been identified that, the effectiveness of the converter has been improved with buck-boost converter when loadings are increased. The entire analysis has been presented with supporting numerical and graphical results.

REFERENCES

[1]. R. W. Erickson and D. Maksimovic, Fundamentals of Power Electronics, 2nd ed. Norwell, MA: Kluwer, 2001.

[2]. N. Mohan, T. M. Undeland, and W. P. Robbins, Power Electronics, 2nd ed. New York: Wiley, 2003.

[3]. F. L. Luo, "Positive output Luo converters: Voltage lift technique," Proc.Inst. Elect. Eng.—Elect. Power Appl., vol. 4, no. 146, pp. 415–432, Jul. 1999

[4]. G. R. Walker, P. C. Sernia, "Cascaded DC-DC converter connection of photovoltaic modules," IEEE Transactions on Power Electronics, vol. 19, no. 4, pp. 1130-1139, 2004.

[5]. N. Femia, G. Lisi, G. Petrone, G. Spagnuolo, M. Vitelli. "Distributed maximum power point tracking of photovoltaic arrays: Novel approach and system analysis," IEEE Transactions on Industrial Electronics, vol. 55, no. 7, pp. 2610-2621, 2008.

[6]. X. Ren, X. Ruan, H. Qian, M. Li, Q. Chen. "Three-mode dual-frequency two-edge modulation scheme for four-switch buck-boost converter," IEEE Transactions on Power Electronics, vol. 24, no. 2, pp. 499-509, 2009

[7]. J. A. Sabaté, V. Flatkovic, R. B. Ridley, F. C. Lee, and B. H. Cho, "Design considerations For high-voltage high-power full-bridge zero-voltage-switched PWM converter," in Proc. APEC'90, 1990, pp. 275–284

[8]. R. Morrison and M. Egan, "A new single transformer, power factor corrected UPS design," in Proc. APEC'98, vol. 1, 1998, pp. 237–243.

[9]. S. Korotkov, V. Meleshin, R. Miftakhutdinov, A. Nemchinov, and S. Fraidlin, "Integrated AC/DC converter with high power factor," in Proc. APEC'98, vol. 1, 1998, pp. 434–440.

[10]. M. C. Ghanem, K. Al-Haddad, and G. Roy, "A new single phase buckboost converter with unity power factor," in Proc. IAS'93, vol. 2, 1993, pp. 785–792

[11]. Mohan Ned., Undeland T.M. and Robbins W.P., "Power Electronics: Converters Applications and Design", John Wiley and Sons, New York, U.S.A., 1989, pp.161-196