

Performance Analysis of Boost Fed Dc Drive under Load Uncertainties

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Abstract

Objectives: To design a new converter topology based on boost converter to obtain essential control characteristics of a DC drive. **Methods/Statistical analysis:** The developments in power electronics based industry/technology and development in new converter design strategies, the speed of DC motor can be maintained at required level by maintaining the voltage across armature. The closed loop control scheme with proportional plus integral (PI) controller takes speed reference and the actual speed of DC motor as input parameters and generates the pulses to control the boost converter output voltage. **Findings:** With this, the speed of DC motor can be maintained at the required speed. The effectiveness of closed loop control scheme with PI controller is compared with that of open loop control scheme. The analysis presented in this paper is mainly concentrated to obtain the suitable operational changes pertaining to various input and output parameters such as output voltage, input and output currents, speed, torque and output powers are analyzed for different load uncertainties. The complete design procedure of converter, analysis of load uncertainties is presented with supporting graphical and as well as numerical results. **Application/Improvements:** This converter design procedure can be applicable to control the speed of DC motor as per the application. With this procedure, the ripple factor and the converter losses can be decreased which results in improvement of converter efficiency.

Keywords: Boost Fed DC Drive, Closed Loop Operation, Converter Design, Converter Losses, Load Uncertainties

1. Introduction

Now a day, getting constant DC supply is one of the challenging tasks from the variable DC supply. For that, there are varieties of converter topologies equipped with multi-functional controllers. In practice, providing required voltage to an armature of DC drive to maintain required speed and control characteristics is one of the power handling problems of the converters. The efficiency of the converter depends on the mode of operation, the configuration of the circuit elements, an operation of the converter, the amount of load, etc.

The modern power system grid controlled operation requires DC supply because of decreased protection equipment, decreased maintenance cost with increased efficiency, lower harmonics, etc¹⁻³. The output voltage of boost converter can be increased in stage by stage in

geometric progression with increased transfer gain, efficiency, power density and decreased ripple in the output voltage and current⁴⁻⁸. Boost converters are widely used in power electronic based hybrid electric vehicles due to its simplicity in construction, high efficiency,⁹⁻¹³ onboard converter interfaced with energy storage systems¹⁴⁻¹⁵. A new control technique to control the output voltage of DC-DC converter is presented in¹⁶. An adaptive terminal sliding mode control strategy was introduced in¹⁷ to reduce ripple voltage in the output but the voltage recovery time is increased¹⁸. A neural adaptive dynamic surface control strategy based on finite time identifier was developed in¹⁹ to improve the dynamic response in two different modes for variations in input and connected load. A model predictive control strategy is developed in²⁰ for full bridge DC-DC converter. Most of the concentrated in analyzing the effect of the converter by varying

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the control strategies. But, it is one of the most warranted research thrusts to analyze the effect of converter for load uncertainties.

From the careful review of, it is identified that there is a research gap in analyzing the effect of load uncertainties on boost converter operation in controlling the speed of DC drive. In this paper, a new converter design procedure along with the ripple, converter losses and efficiency are presented. The designing procedure of converter enhances the converter efficiency under different load uncertainties. The load disturbance is obtained by applying step load on the DC drive. The boost converter operation is analyzed in terms of output voltage, input and output currents, speed, torque and output power along with the respective ripple content under load uncertainties. The input voltage to the boost converter is assumed to be 48 V and required speed from the DC drive is assumed to be 2300 RPM. The closed loop control scheme is presented using proportional plus integral (PI) controller, the efficiency of the converter is enhanced under load uncertainties. The graphical results as well as numerical results are presented for both open and closed control operations of the boost converter.

The remaining paper is organized as follows: configuration of boost converter along with modes of operation are presented in section-2, designing of boost converter which includes, calculation of ripple, converter losses, efficiency is presented in section-3, the analysis pertaining to open loop and closed loop operation of boost converter fed DC drive is presented in section-4. Observation and identifications are reported in section-5 in the form of conclusions.

2. Configuration of Boost Converter Fed DC Drive

DC motor is widely used in industrial control and automation. This motor is mostly preferred due to its control capabilities. In general, voltage of the armature is controlled to get required speed from the DC motor. The supply to this motor is controlled using the boost converter. Depending on the amount of voltage applied to the converter, the amount of voltage applied to the drive is changed. The gain of the converter is optimized so as to obtain the control performance with increased accuracy and precision. In this paper, new boost converter topology to get constant speed control of DC drive. The

simple block diagram of the proposed boost fed DC drive is shown in Figure 1.

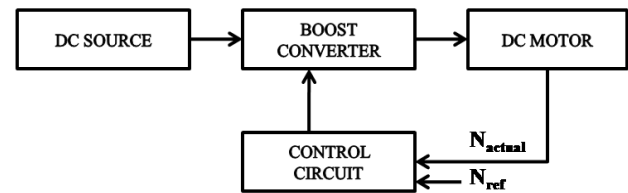


Figure 1. Block diagram of proposed boost fed DC drive.

In closed loop control, the boost converter takes the control input from the control circuit, which is driven based on the reference speed input and actual speed output from the DC motor. The basic circuit of boost converter is shown in Figure 2. It consists, two charging elements such as one inductor connected in series with the supply and one capacitor connected in parallel to the supply. This converter consists one MOSFET based switch connected in parallel and one diode connected in series with the supply.

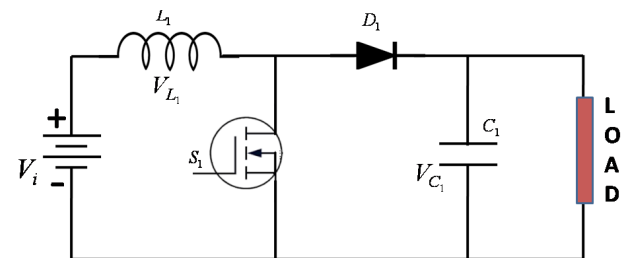


Figure 2. Basic circuit diagram of proposed boost converter.

The schematic diagram of the boost fed DC drive is shown in Figure 3.

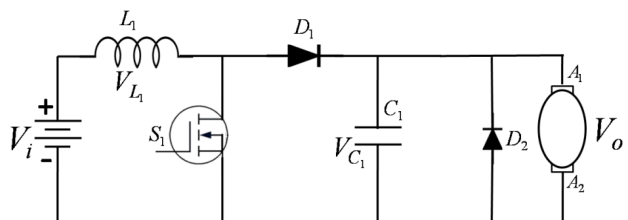


Figure 3. Schematic diagram of boost converter fed DC drive.

Based on switch operation, there are two working configurations for this boost converter. First configuration is, when switch is closed, the inductor tries to charge through the supply with positive polarity. The next con-

figuration is, when switch is opened, the energy stored in inductor discharges to the drive through diode and capacitor is charged with negative polarity. The schematic diagrams of the two configurations are shown in Figure 4. And Figure 5.

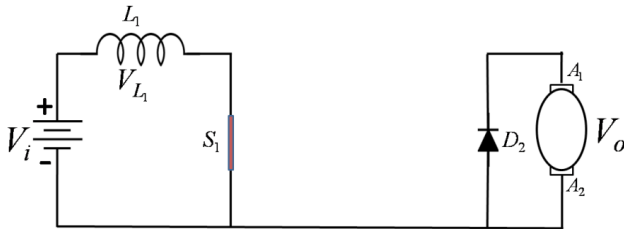


Figure 4. Configuration of boost fed DC drive when switch is closed.

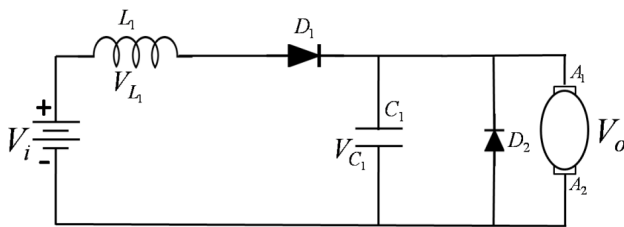


Figure 5. Configuration of boost fed DC drive when switch is opened.

2.1 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

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

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

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2L_1 I_o} \quad (2)$$

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

3. Designing of Boost Converter

The basic boost converter consist one MOSFET (S_1) and one diode (D_1) and two charging elements (L_1 and C_1).

To design boost converter, the following parameters are assumed:

| | | |
|--|---|-----------|
| Input voltage (V_i) | = | 48 V |
| Output voltage (V_o) | = | 110 V |
| Load resistance I | = | 0.04 Ohms |
| Allowable current ripple limits (ΔI) | = | up to 20% |

of the full load current

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

$$D=0.5636 \quad (3)$$

From the fundamentals, the inductor value can be calculated as

$$L_1 = \frac{V_i D}{f \Delta I} \quad (4)$$

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

$$C_1 = \frac{D}{2f_r R} \quad (5)$$

3.1 Ripple Calculation

The ripple in the input and output parameters such as output voltage, input and output currents, speed, torque and output power can be calculated as

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

3.2 Converter Loss Calculation

Let, DC motor mechanical output power be P_m , the output current (I_o) can be calculated as

$$I_o = \frac{P_m}{V_o} \quad (7)$$

Losses due to internal resistance of Inductor L_1 can be expressed as

$$P_{\text{loss},L} = I_o^2 \times R_{\text{int}} \quad (8)$$

Where, R_{int} is the internal resistance of the inductors.

Losses due to conduction of MOSFET switch S_1 can be expressed as

$$P_{\text{loss},M} = D \times V_M \times I_o \quad (9)$$

Where, V_M is the voltage drop across the MOSFET.

Losses due to conduction of diode D_1 can be expressed as

$$P_{loss,D} = 0.5 \times V_d \times I_d \quad (10)$$

Where, V_d , I_d are the voltage drop across the diode and current flow through diode.

Total losses in the proposed CBQRCFDD can be calculated as

$$P_{losses} = P_{loss,L} + P_{loss,M} + P_{loss,D} \quad (11)$$

3.3 Converter Efficiency Calculation

The efficiency of the proposed system can be expressed as

$$Efficiency(\eta) = \frac{\text{output power}}{\text{input power}} = \frac{\text{output power}}{\text{output power} + P_{losses}} \quad (12)$$

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

$$\omega = \frac{2\pi N}{60} \quad (13)$$

Where, N is the speed in rpm.

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

$$T = \frac{P_m}{\omega} \quad (14)$$

4. 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.

4.1 Case-1 (Open Loop Control)

In this section, the effect of load uncertainties on open loop control system of DC drive fed from boost converter is analyzed. The entire analysis is presented for 6 sec. A step 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 Figure 6.

The simulation result of the input and output voltages are shown in Figure 7 and Figure 8. From this it is noticed that, the input voltage of 48 V is boosted up to more than 90 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 step load. It is noticed that,

output voltage is 92.451 V without load, 96.628 V with 5% step load and 99.174 V with 10% step 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.

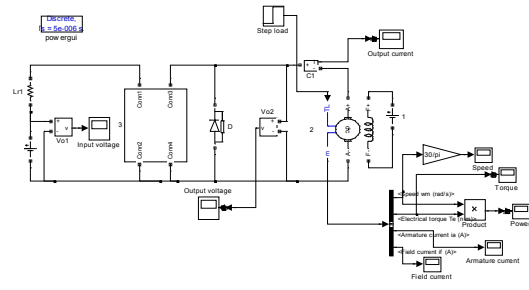


Figure 6. Simulink diagram of the open loop boost fed DC drive.

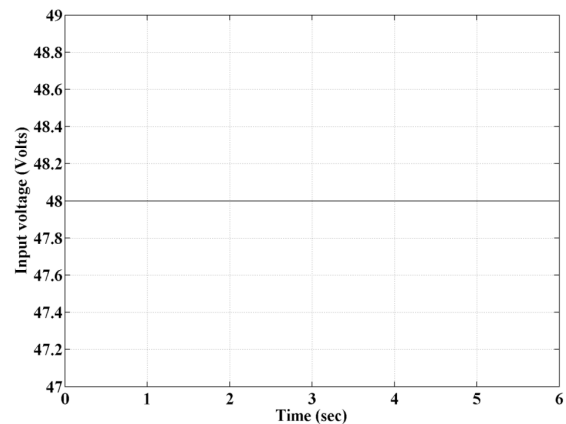


Figure 7. Simulation result of the input voltage for open loop boost fed DC drive.

The simulation result of the input and output currents are shown in Figure 9 and Figure 10. From this, it is noticed that, without load, the input current of 35.253 A with the ripple 2.972% is reduced to be 19.136 A as output current with the ripple 9.313%, with 5% step load, the input current of 63.422 A with the ripple 1.75% is reduced to be 34.709 A as output current with the ripple 9.247% and with 10% step load, the input current of 86.756 A with the ripple 1.385% is reduced to be 49.326 A as output current with the ripple 8.961%. 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.

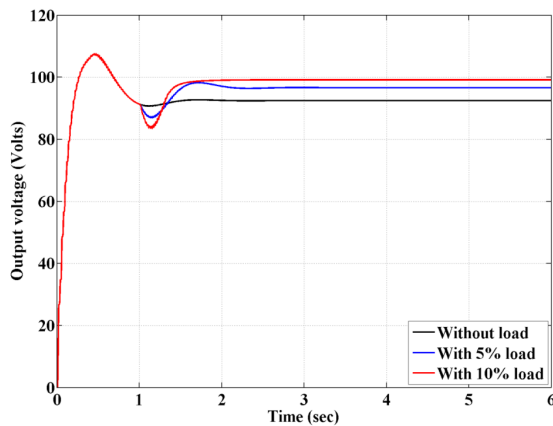


Figure 8. Simulation result of the output voltage for open loop boost fed DC drive.

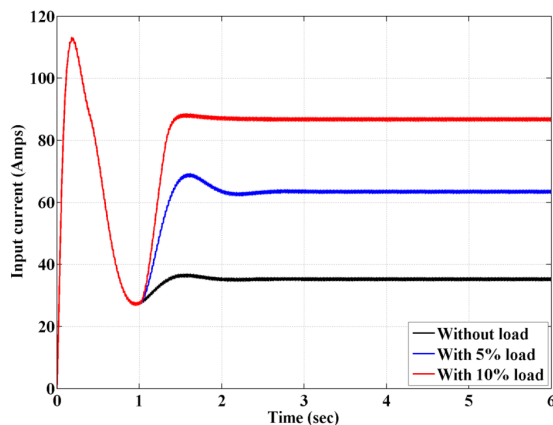


Figure 9. Simulation result of the input current for open loop boost fed DC drive.

The simulation result of the speed, torque and output power are shown in Figure 11, Figure 12 and Figure 13. From this, it is noticed that, without load, speed is 2571.521 RPM with the ripple of 0.28%, with 5% step load, speed is 2284.777 RPM with the ripple of 0.567%, with 10% step load, speed is 1905.609 RPM with the ripple of 0.925%. 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, torque is 1549.922 N-m with the ripple of 5.599%, with 5% step load, torque is 2497.975 N-m with the ripple of 5.558%, with 10% step load, torque is 2960.775 N-m with the ripple of 5.387%. 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, output power is 5.763 Watts with the ripple of 3.733%, with 5% step load, output power is 10.454 Watts with the ripple of 3.706%, with 10% step load, output power is 14.856 Watts with the ripple of 3.592%. 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.

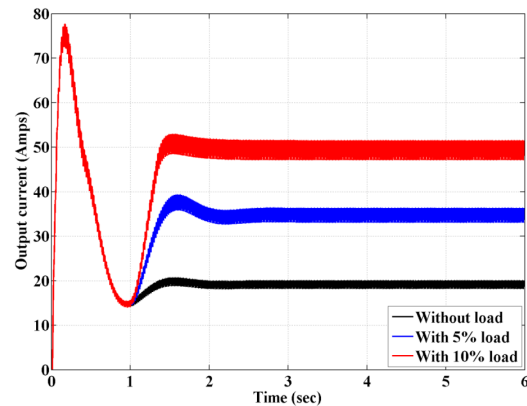


Figure 10. Simulation result of the output current for open loop boost fed DC drive.

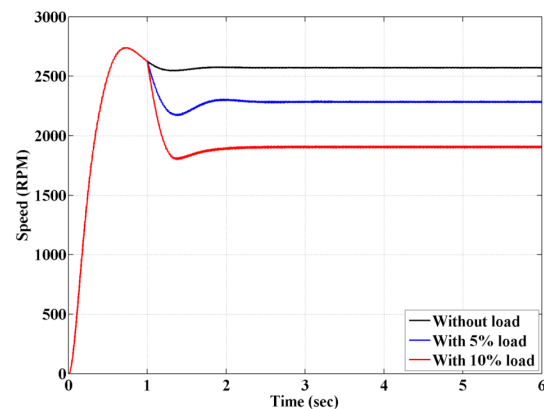


Figure 11. Simulation result of the speed for open loop boost fed DC drive.

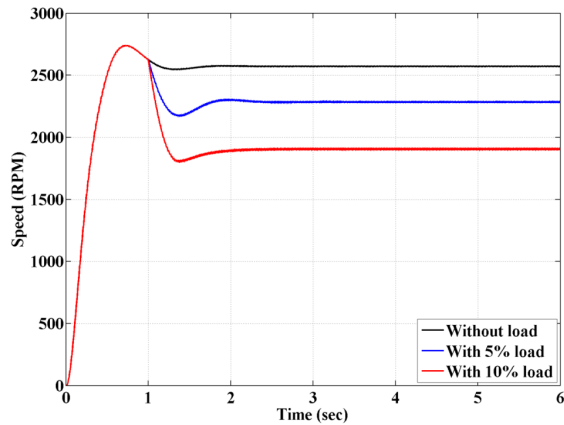


Figure 11. Simulation result of the speed for open loop boost fed DC drive.

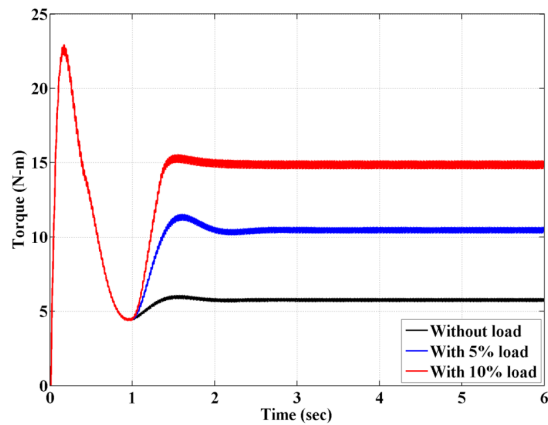


Figure 12. Simulation result of the torque for open loop boost fed DC drive.

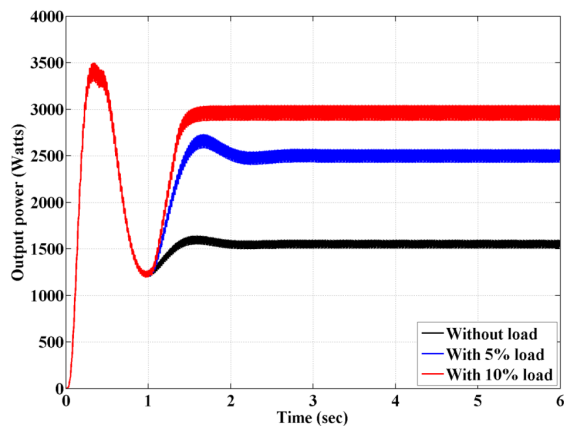


Figure 13. Simulation result of the output power for open loop boost fed DC drive.

To show the effectiveness of the developed converter topology, the numerical results pertaining to open loop control with different load are tabulated in Table 1, Table 2 and Table 3. From these tables, it is identified that, converter losses are decreased from without load to with 5% load and again these losses are increased from with 5% load to with 10% load. This is due to the effect of converter design parameters. Accordingly the converter efficiency is also varied.

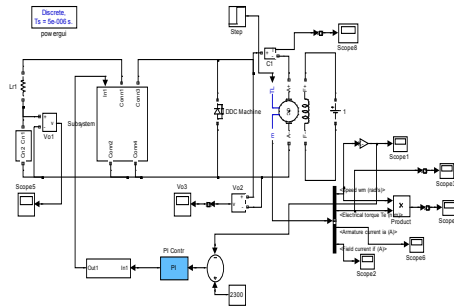


Figure 14. Simulink diagram of the closed loop boost fed DC drive.

4.2 Case-2 (Closed loop control)

In this section, the effect of load uncertainties on closed loop control system of DC drive fed from boost converter is analyzed. The entire analysis is presented for 6 sec. A step 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 Figure 14.

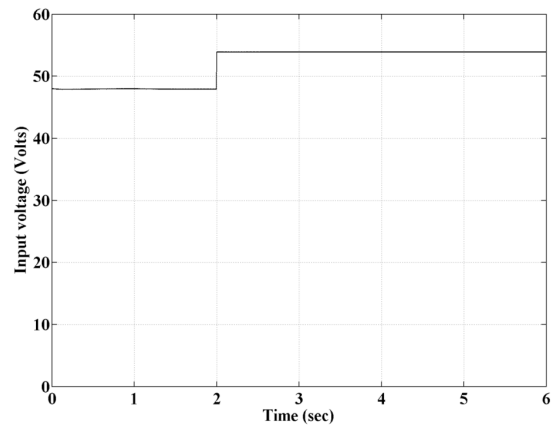


Figure 15. Simulation result of the input voltage for closed loop boost fed DC drive.

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

| Parameters | Actual value | % ripple parameters | | |
|--------------------------|--------------|---------------------|------------|--------------|
| | | Min. value | Max. value | Ripple value |
| Output voltage (Volts) | 92.451 | 92.451 | 92.451 | 0 |
| Input current (Amps) | 35.253 | 34.729 | 35.777 | 2.972 |
| Output current (Amps) | 19.136 | 18.245 | 20.027 | 9.313 |
| Speed (RPM) | 2571.521 | 2567.922 | 2575.12 | 0.28 |
| Torque (N-m) | 1549.922 | 1506.529 | 1593.314 | 5.599 |
| Output power (Watts) | 5.763 | 5.655 | 5.87 | 3.733 |
| Converter losses (Watts) | 0.05195 | - | | |
| Efficiency (%) | 99.11 | - | | |

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

| Parameters | Actual value | % ripple parameters | | |
|--------------------------|--------------|---------------------|------------|--------------|
| | | Min. value | Max. value | Ripple value |
| Output voltage (Volts) | 96.628 | 96.628 | 96.628 | 0 |
| Input current (Amps) | 63.422 | 62.868 | 63.977 | 1.75 |
| Output current (Amps) | 34.709 | 33.104 | 36.314 | 9.247 |
| Speed (RPM) | 2284.777 | 2278.302 | 2291.252 | 0.567 |
| Torque (N-m) | 2497.975 | 2428.552 | 2567.398 | 5.558 |
| Output power (Watts) | 10.454 | 10.26 | 10.647 | 3.706 |
| Converter losses (Watts) | 0.0128 | - | | |
| Efficiency (%) | 99.88 | - | | |

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

| Parameters | Actual value | % ripple parameters | | |
|--------------------------|--------------|---------------------|------------|--------------|
| | | Min. value | Max. value | Ripple value |
| Output voltage (Volts) | 99.174 | 99.174 | 99.174 | 0 |
| Input current (Amps) | 86.756 | 86.156 | 87.357 | 1.385 |
| Output current (Amps) | 49.326 | 47.116 | 51.536 | 8.961 |
| Speed (RPM) | 1905.609 | 1896.798 | 1914.419 | 0.925 |
| Torque (N-m) | 2960.775 | 2881.022 | 3040.528 | 5.387 |
| Output power (Watts) | 14.856 | 14.589 | 15.123 | 3.592 |
| Converter losses (Watts) | 0.13062 | - | | |
| Efficiency (%) | 99.13 | - | | |

The simulation result of the input and output voltages are shown in Figure 15 and Figure 16. From this it is noticed that, the input voltage of 48 V is boosted up to more than 90 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 step load. It is noticed that, output voltage is 88.939 V without load, 104.126 V with

5% step load and 113.662 V with 10% step 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.

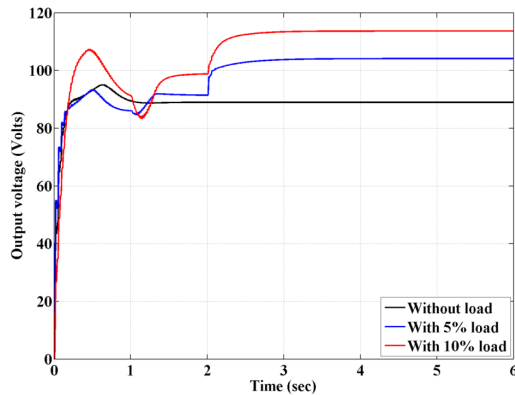


Figure 16. Simulation result of the output voltage for closed loop boost fed DC drive.

The simulation result of the input and output currents are shown in Figure 17 and Figure 18. From this, it is noticed that, without load, the input current of 31.549 A with the ripple 5.281% is reduced to be 19.359 A as output current with the ripple 12.637%, with 5% step load, the input current of 60.732 A with the ripple 5.085% is reduced to be 36.606 A as output current with the ripple 11.31% and with 10% step load, the input current of 95.012 A with the ripple 1.422% is reduced to be 52.465 A as output current with the ripple 9.189%. 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.

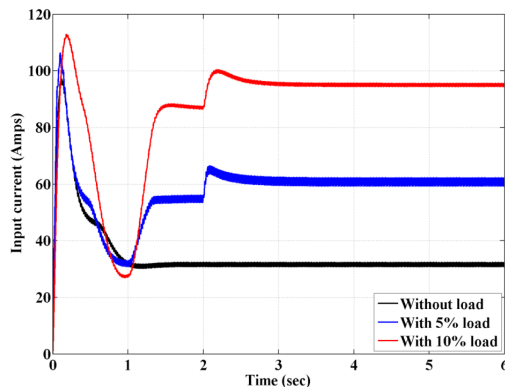


Figure 17. Simulation result of the input current for closed loop boost fed DC drive.

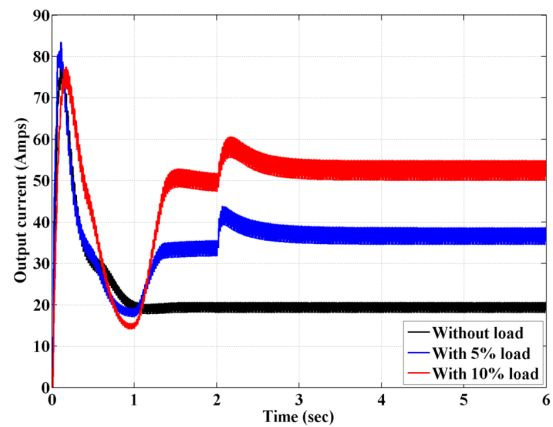


Figure 18. Simulation result of the output current for closed loop boost fed DC drive.

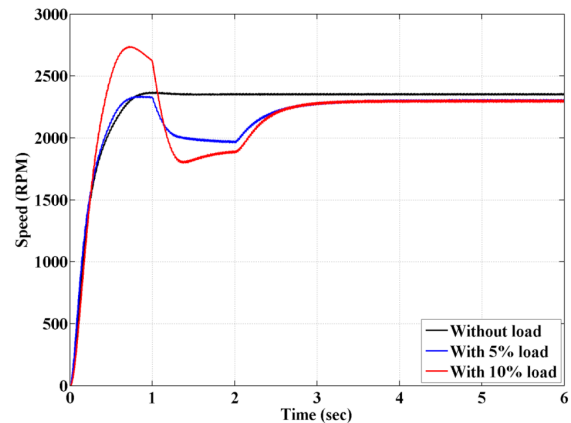


Figure 19. Simulation result of the speed for open loop boost fed DC drive.

The simulation result of the speed, torque and output power are shown in Figure 19, Figure 20 and Figure 21. From this, it is noticed that, without load, speed is 2351.394 RPM with the ripple of 0.472%, with 5% step load, speed is 2300.889 RPM with the ripple of 0.771%, with 10% step load, speed is 2296.87 RPM with the ripple of 0.845%. 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, torque is 1438.313 N-m with the ripple of 7.548%, with 5% step load, torque is 2656.684 N-m with the ripple of 6.778%, with 10% step load, torque is 3795.914 N-m with the ripple of 5.523%. 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, output power is 5.857 Watts with the ripple of 5.017%,

with 5% step load, output power is 11.047 Watts with the ripple of 4.515%, with 10% step load, output power is 15.802 Watts with the ripple of 3.683%. 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.

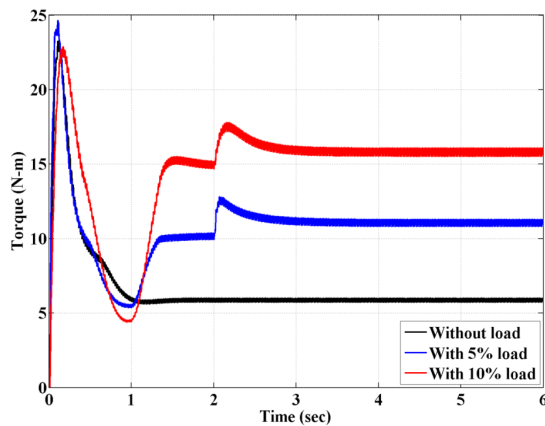


Figure 20. Simulation result of the torque for open loop boost fed DC drive.

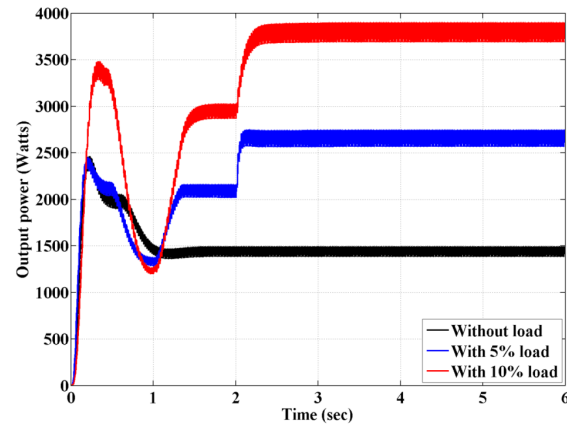


Figure 21. Simulation result of the output power for open loop boost fed DC drive.

To show the effectiveness of the developed converter topology, the numerical results pertaining to open loop control with different load are tabulated in Table 4, Table 5 and Table 6. From these tables, it is identified that, the converter losses are increased as the load is increasing, in the same way, due to effectiveness of the converter with PI

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

| Parameters | Actual value | % ripple parameters | | |
|--------------------------|--------------|---------------------|------------|--------------|
| | | Min. value | Max. value | Ripple value |
| Output voltage (Volts) | 88.939 | 88.939 | 88.939 | 0 |
| Input current (Amps) | 31.549 | 30.716 | 32.383 | 5.281 |
| Output current (Amps) | 19.359 | 18.136 | 20.582 | 12.637 |
| Speed (RPM) | 2351.394 | 2345.85 | 2356.937 | 0.472 |
| Torque (N-m) | 1438.313 | 1384.033 | 1492.592 | 7.548 |
| Output power (Watts) | 5.857 | 5.71 | 6.004 | 5.017 |
| Converter losses (Watts) | 0.0505 | - | - | - |
| Efficiency (%) | 99.144 | - | - | - |

Table 5. Numerical results of closed loop boost fed DC drive with 5% step load

| Parameters | Actual value | % ripple parameters | | |
|--------------------------|--------------|---------------------|------------|--------------|
| | | Min. value | Max. value | Ripple value |
| Output voltage (Volts) | 104.126 | 104.126 | 104.126 | 0.001 |
| Input current (Amps) | 60.732 | 59.188 | 62.276 | 5.085 |
| Output current (Amps) | 36.606 | 34.536 | 38.676 | 11.31 |
| Speed (RPM) | 2300.889 | 2292.02 | 2309.758 | 0.771 |
| Torque (N-m) | 2656.684 | 2566.648 | 2746.72 | 6.778 |
| Output power (Watts) | 11.047 | 10.798 | 11.296 | 4.515 |
| Converter losses (Watts) | 0.0906 | - | - | - |
| Efficiency (%) | 99.186 | - | - | - |

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

| Parameters | Actual value | % ripple parameters | | |
|--------------------------|--------------|---------------------|------------|--------------|
| | | Min. value | Max. value | Ripple value |
| Output voltage (Volts) | 113.662 | 113.662 | 113.662 | 0 |
| Input current (Amps) | 95.012 | 94.336 | 95.687 | 1.422 |
| Output current (Amps) | 52.465 | 50.055 | 54.876 | 9.189 |
| Speed (RPM) | 2296.87 | 2287.16 | 2306.58 | 0.845 |
| Torque (N-m) | 3795.914 | 3691.087 | 3900.741 | 5.523 |
| Output power (Watts) | 15.802 | 15.511 | 16.093 | 3.683 |
| Converter losses (Watts) | 0.1248 | | | |
| Efficiency (%) | 99.216 | | | |

controller, the converter efficiency is also increased as the load is increased.

5. Conclusions

In this paper, a new boost converter design has been presented to analyze the effect of load uncertainties on the performance of the DC drive. The effectiveness of closed loop control system with PI controller has been analyzed and compared with that of the open loop control system. It has been observed that required speed of DC motor can be maintained by varying the armature voltage. The effectiveness of proposed converter is also analyzed in terms of ripple content in different output parameters such output voltage, input and output currents, speed, torque and output power. The variation of converter losses and thereby the converter efficiency has been also presented. From the entire analysis, it has been identified that the converter losses are reduced in closed loop operation when compared to open loop system. The entire analysis has been presented using graphical and as well as numerical results. There is a scope to extend this type work using different types of converters such buck converter, cascaded buck-boost converter with PI and Fuzzy controllers also.

6. References

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