Speed Control of DC Motor Using Non-isolated Boost Converter

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Abstract ***—*** *The use of DC-DC converter with voltage boosting capability in power conversion application is increasing nowadays. Non-isolated converters are commonly used becauseof its smaller size, low cost and easier methods to control. Among non-isolated converters, those that have greater fixed output voltage than input voltage is obtained byusing voltage lift techniques. The converter can be operated in both CCM and DCMmode. The boost converter is used for regulating the speed of DC motor. DC motor*
is the key element of mobile robots and autonomous systems. There is a set of variousapplications where it is necessary to control the speed of the DC motor subject to theload variations over a speed range. The topology is simulated in MATLAB/SimulinkR2017a software. The switching pulse for the switch is generated using dsPIC30F2010.Hardware of DC-DC converter is implemented and results are verified.

Keywords **—***Non-isolated DC-DC converter, VL technique, Speed regulation.*

I. INTRODUCTION

DC-DC converters with higher voltagecapability are extensively used inlarge number of power conversion applications. The application includes computer systems, LED lighting systems,medical equipment, servo-motors, power factor correction, communication systems, hybrid vehicles auxiliary equipment, portable electrical equipment such as mobile phones and portable computers, uninterrupted power supplies and green energy systems such as systems fuel cell, photovoltaic systems and wind turbine systems [1]. These types of power electronic converters are controlled using pulse width modulation (PWM).

The converters in which switching is controlled by PWM technique are classified into two; isolated and non-isolated groups. In the structure of isolated dc-dc converters such as fly back, forward, half bridge, full bridge and push pull, a high-frequency transformer is used and high voltage is achieved by changing the number of turns of transformer. However, high-frequency transformers lead to high switching voltage and considerable losses due to transformer leakage inductance [2]. This increases the price and size of the converters and complicates the control process. To reduce this problem, non-dissipative snubber circuits or active clamp circuits are used. In the structure of non-isolated dc-dc converters such as buck, boost, buck-boost, CUK, and SEPIC converters, there is no high-frequency transformer and as a result, non-isolatedDC-DC converters have lower price, lower switching losses, smaller size and high efficiency.

DC-DC converter uses various type of voltage boost technique to get desired higher voltage. The switched capacitor technique, in which it consists of, a number of switches and capacitors with minimum inductor achieving a higher output voltage than the input voltage is easily possible [3]. However, this topology increases the complexity due to number of power switches and increases the current stress of switching. To eliminate thecurrent stress, coupled inductor is used which increases the size and cost of the converter and is not very popular. Because of thecost, increased size, complexity of control it is not optimised design [4].

VL technique is a popular and eff ective technique for increasing the output voltage gain that has been used extensively in the power electronics circuits. Using this technique, characteristics of conventional non-isolated boost dc-dc converters are well improved. Using this method, the input voltage increases step to step to transfer high voltage gain to load. The performance of VL technique is based on energy storage elements (inductor and capacitor). High power density, high efficiency, simple structure and cheapness compared to other techniques and small output voltage ripple, especially for high voltage values are the features of this technique. In addition, the lack of additional switches that lead to the complexity of the control system of a dc-dc converter is an important feature of this technique [5].

The boost converter is used for regulating the speed of the DC motor. It has the capability of energy conversion either from electrical energy to mechanical energy or vice versa. It has a very fine speed control characteristics and so are widely used in various industrial applications. DC motors are extensively employed in various fields like steel and aluminium rolling mills, power shovels, electric elevators, rail road locomotives, robotics and large earth-moving equipment. These motors provide efficient, reliable, long-lasting service and require little maintenance. It has various advantages like high starting torque, wider range speed control and high degree of flexibility.

A new structure for non-isolated dc-dc boost converters using VL technique is introduced. The higher voltage can be achieved. The output voltage of the converter is negative with respect to input ground. Least elements are used compared with other boost DC-DC converter. This boost converter is used for the speed regulation of DC motor and kept constant for various applications.

II. SPEED REGULATION OF DC MOTOR

DC motors have a very fine speed control characteristics and so are widely used in various industrial applications.Fig.1 presents block diagram for speed regulation of DC Motor using non-isolated boost DC-DC converter. The speed which is required for the specific application is set as reference speed. The speed of the motor is measured and compared with reference speed. The error signal is given to the controller which gives the required voltage to balance the speed variations, is referred as reference voltage. The actual output voltage of motor is measured and compared with this reference voltage. The error signal is given to the controller which generates the control pulses for the converter.

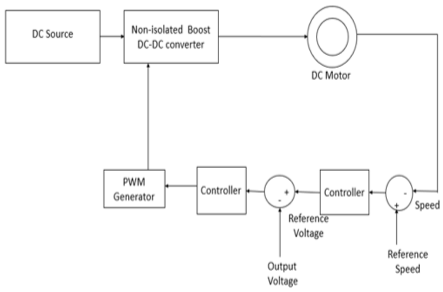

Fig .1: Block diagram for speed regulation of DC Motor.

Fig.2 shows a non-isolated DC-DC boost converter used in theabove block diagram. The circuit consists of two power switches, two inductors, three diodes and two capacitors are used. In this structure, the voltage boosting stage consists of one inductor, one capacitor, and two diodes.

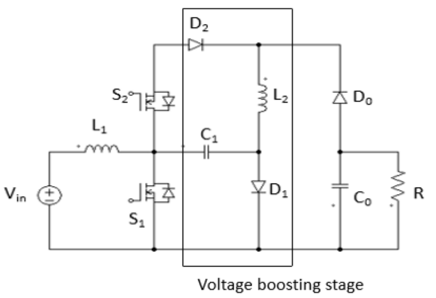

Fig 2: Non -isolated DC-DC Converter

The non-isolated dc-dc converter can operate in both continuous conduction mode (CCM) and discontinuous conduction mode (DCM). The CCM or DCM is dependson the value of the critical inductance.

A. CCM Operation

When the inductor value is greater than the critical value then the converter is working in continuous conduction mode (CCM). In CCM operation, the operating mode of the non-isolated converter can be divided into two operating modes over one switching period.

*1) **Mode 1:*** In this mode, switches S_1 is ONand S_2 in OFF state, inductor L_1 charges through input voltage source. Also, the D_0 diode is forward biased, and the diodes D_1 and D_2 are reverse biased. Therefore, the inductor L_2 and capacitor C_1 are connected in series and provides the currents to the load and charges the capacitor C_0. Also, the stored energy of the inductor L_2 and capacitor C_1 are gradually decreased.

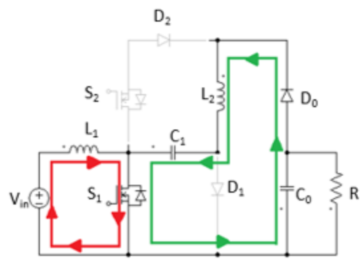

Fig 3: Mode 1

*2) **Mode2:***In this mode**,** the switch S_1 is OFF and the switch S_2 is ON state, the diodes D_1 and D_2 are forward biased and the diode D_0 is reverse biased. Here, the inductor L_2 and capacitor $C_1$are charges.The capacitor C_0 discharges and provides the load current.

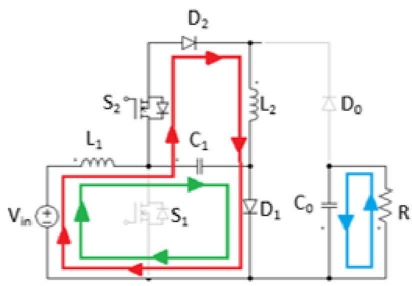

Fig 4: Mode 2

B. DCM Operation

When the inductor value is greater than the critical value then the converter is working in discontinuous conduction mode (DCM).There are four modes of operation, those are explained below.

*1)**Mode 1:***This mode is same as that of mode 1of CCM operation. Here switches S_1 is ON and S_2 in OFF state. Inductor L_1 charges. Also, inductor L_2 and capacitor C_1 is discharges.

2)**Mode 2:** when the switch S_1 is turned ON and the switch S_2 is turned OFF, the inductor L_1 is still connected directly to V_{in} and its current is linearly increased to its maximum value. During this time interval, the current of inductor L_2 is zero. As result, all the diodes are reverse biased and the voltage of capacitor C_1 and its stored energy remains unchanged.

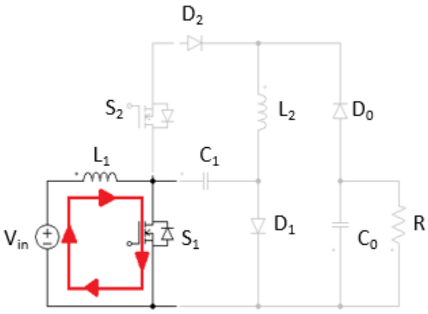

Fig 5: Mode 2

*3)***Mode 3:**This mode is same as that of mode 2of CCM operation. Here switches S_1 is OFF and S_2 in ON state. Inductor L_1discharges. Also, inductor L_2 and capacitor $C_1$are charges.

*4)***Mode4:**when the switch S_1 is turned OFF and the switch S_2 is turned ON, the current of inductor L_1 is zero and its stored energy is zero. As a result, the diodes $D_1$and D_0 are reverse biased. In this time interval, the inductor L_2 and capacitor C_1 are in parallel. During in this time interval, the load current is provided by the discharge current of capacitor C_0.

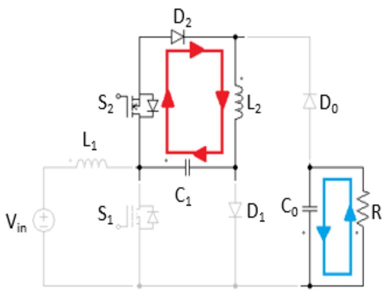

Fig 6: Mode 4

By applying the current-balancing law for capacitor C_1 inCCM mode, critical inductance L_{C1} obtained as

$$L_{C1} = \frac{D^3(1-D)^2R}{2f_s} \qquad (1)$$

By applying the current-balancing law for capacitor C_0inCCM mode,critical inductance L_{C2} obtained as

$$L_{c2} = \frac{D^2(1-D)R}{2f_s} \qquad (2)$$

If the value of inductors is greater than the critical inductance, the converter operates in CCM, and otherwise the converter in DCM.

Voltage gain of the converter in CCM mode is given by

$$\frac{V_O}{V_{IN}} = \frac{1}{D(1-D)} \qquad (3)$$

The value of capacitors C_1 and C_0 are obtained by using the following equations

$$C_1 = \frac{I_O}{f_s \Delta V_{C1}} \qquad (4)$$

Where

$$V_{C1} = \frac{V_{IN}}{(1-D)} \qquad (5)$$

$$C_O = \frac{I_O(1-D)}{f_s \Delta V_{CO}} \qquad (6)$$

where

$$V_{C0} = V_O \qquad (7)$$

III. SIMULATION AND EXPERIMENTAL RESULTS

In order to validate the performance of the non-isolated boost DC-DC converter and DC motor, MATLAB simulations and experiments are carried out. The designed parameters are listed in TABLE I.In this converter an input voltage of 12V is used and switching frequency is 10 kHz. The simulation results are shown below.

TABLE I
SIMULATION PARAMETERS

System Specification	Parameters
Input voltage	12 V
Switching Frequency (f_s)	10 kHz
Inductor L_1	2mH
Inductor L_2	4.5 mH
Capacitor C_1	68 µF
Capacitor C_0	50 µF
Armature resistance	0.9 Ω
Armature inductance	0.0023 H

A. Simulation Results

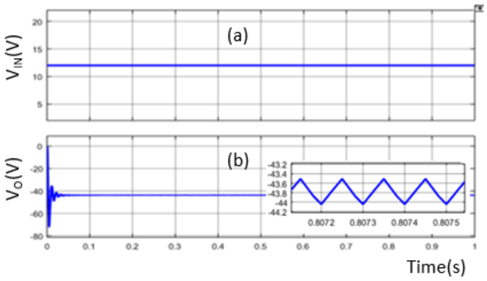

Fig 7: (a)Input Voltage(b)Output Voltage

Fig.7 shows input-output voltage waveforms. In the CCM mode for an input voltage of 12 VOutput voltage obtained as 44V. The voltage ripple is less than 1%.

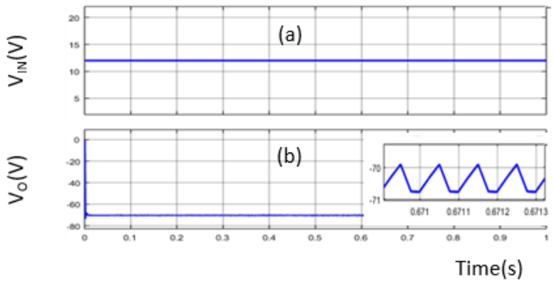

Fig 8: (a)Input Voltage(b)Output Voltage

Fig.8 shows input-output voltage waveforms.In theDCM mode for an input voltage of 12 V,outputvoltage obtained as 70V. Voltage ripple is less than1%.

TABLE III
COMPARISON BETWEEN CCM AND DCM MODE

Parameters	CCM mode	DCM mode
Input voltage	12 V	12 V
Output Voltage	-44V	-70V
Voltagestress across S_1	26V	38V
Voltage stress across S_2	46V	72V
Peak current through S_1	3A	13A
Peak current through S_2	1.5A	3A
Efficiency	89.6%	87%

From the above table, it is clear that theboost converter is working in CCM mode has better performance than when it works in DCM mode.

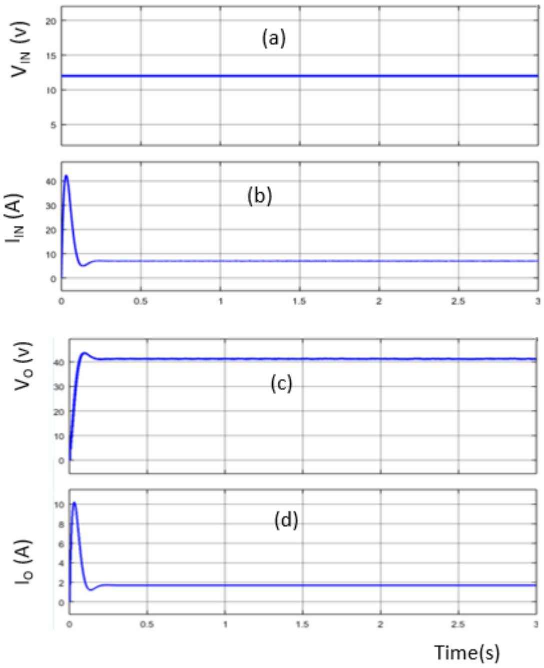

Fig 9: (a)Input Voltage (b)Input Current (c)Output Voltage (d)Output Current

Fig.9 shows input-output voltage and current waveforms, when converterconnected with motor in CCM mode. In closed loop, for an input voltage of 12 V,output voltage obtained as 44V.

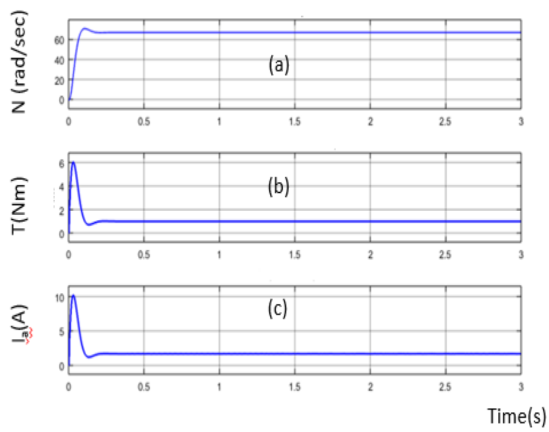

Fig.10: (a) Speed (b) Electromagnetic Torque (c) Armature current

Fig.10 shows waveforms of speed, electromagnetic torque, and armature current. The full load speed of the DC motor is obtained as 650 rpm.

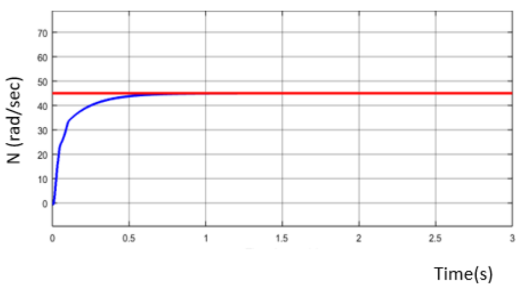

Fig.11: Speed of motor and reference speed

Fig. 11 shows waveforms of speed regulation of motor. In the speed graph, red line indicates the reference speed of motor as 45 rad/secs. The blue line shows the speed of the motor in closed loop. The speed of the motor increases from zero and after 0.6 seconds, its speed sets to required speed.

B. *Analysis of the Converter*

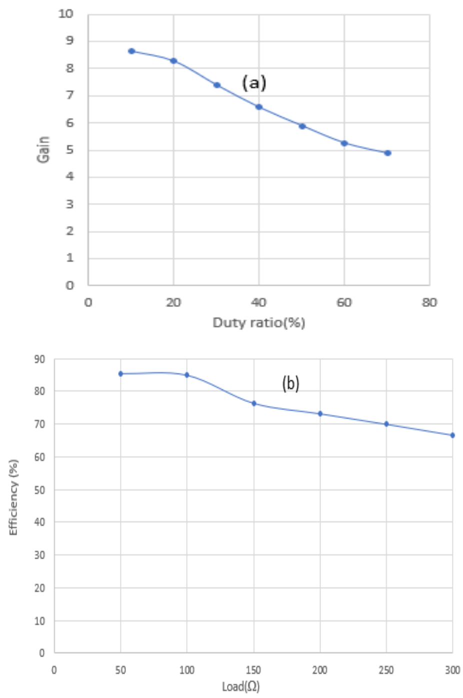

Fig.12(a) Gain Vs Duty ratio (b) Efficiency Vs Load

Analysis is done with input voltage of 12V for continuous mode. The variation of duty ratio with gain and the variation of load with efficiency is shown in Fig.12. When the duty ratio is increases, the gain is decreasing. When load increases, effciency is decreasing**.**

IV. EXPERIMENTAL RESULTS

Inorder to verify the performance of the converter and motorthe experimental setup is implemented. The prototype with the parameters given in TABLE III was built. The power supply consists of astep-down transformer, full bridge diode rectifier, filter capacitor and a regulator IC (7812). IRF3205 MOSFET is used as switches. TLP250 driver isused to drive the MOSFET. To generate the switching signal dsPIC30F2010 was programmed in the laboratory and necessary waveforms are obtained. The switches are working in 10kHz frequency.12V DC motor is used as load. An output voltage of 10.6V is obtained for an input of 4.5V.The experimental test setup is presented in Fig. 13 and results are given in Fig. 14.

TABLE IIII
COMPONENTS USED FOR PROTOTYPE

Components	**Ratings**
Input voltage	4.5 V
Switching Frequency (f_s)	10 kHz
Inductor L_1	14 μH
Inductor L_2	45 μH
Capacitor C_1	68μF
Capacitor C_0	120 μF

Fig 13: Experimental Setup

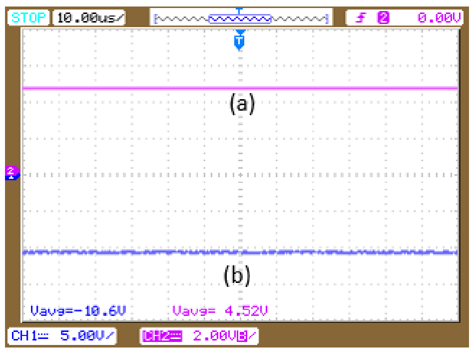

Fig 14: (a) Input Voltage (b)Output Voltage

V. CONCLUSIONS

The non-isolated boost converter has simple structure, since it uses lessnumber of passive components. The topology gives step up voltage of -44V(CCM) and -70V(DCM) with an input of 12V. Voltage gain in CCM is 3.5 and that of DCM is 6. The converter can benefit from high step-up ratio, a wide voltage-gain range and avoiding of the extreme duty cycles. In addition, this converter has the advantages of the low voltage stress of power switches. Voltage stress across switch of the converter in CCM is less compared with DCM and the output voltage ripple is less than 1%. The non-isolated boost converter is implemented to regulate the speed of DC motor. For an input of 12V speed of the DC motor can be controlled up to 650rpm. The experimental prototype of theconverter and motor is implemented and output voltages are verified.

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