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Applied Voltage Control Scheme for a DC Motor fed by a SEPIC based DC-DC Converter

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Abstract:- Recently, the researchers concentrate on the development of DC-DC converters with high voltage conversion ratio suitable for applications in nonconventional energy system based power generation. Two categories of DC-DC conversion schemes are available; transformer-based (isolated) and transformerless (non-isolated) configurations. Due to certain drawbacks present in transformer-based DC-DC conversion scheme, the non-isolated DC-DC converters are mostly preferred for applications that involve power generation using renewable energy sources. There are certain simple configured non-isolated high gain DC-DC conversion schemes with single control switch. This paper proposes the steady state analysis of a non-isolated high-gain single-switch DC-DC conversion scheme based on single-ended primary-inductor converter (SEPIC) topology with DC motor load. The proposed converter is operated in continuous conduction mode. The simulation analysis of the proposed SEPIC converter feeding a DC shunt motor is carried out using MATLAB / SIMULINK software tool. The no-load characteristics of the motor such as speed, torque, and armature current are validated by changing the converter output voltage through duty factor variation of the switch.

Keywords:- *Continuous inductor current mode; DC-DC SEPIC topology; DC shunt motor; Duty factor; MATLAB/SIMULINK; Performance characteristics.*

I. INTRODUCTION

The use of renewable energy system based power generation requires the development of both isolated and non-isolated DC-DC converter topologies with high voltage gain [1]-[6]. Due to the inherent issues such as the effect of leakage reactance of the transformer, complicated structure and control, and EMI present in the isolated topologies, the non-isolated high voltage gain converter structures find applications that involve electrical power generation by means of nonconventional energy sources [7]-[8].

The conventional boost, SEPIC, CUK, and ZETA topologies belonging to non-isolated DC-DC conversion schemes are not preferred for achieving high voltage gain since such traditional topologies need to be operated at extremely high duty ratios at which the losses occurring in the power switch are high and the power switch is subjected to high voltage stress. Hence, some researchers proposed modified structures of boost, SEPIC and CUK topologies with additional power switches, diodes, and passive devices for achieving high voltage conversion ratio [9]-[11]. The extra power switches lead to increased control complexity and converter losses. However, some researchers developed the non-isolated modified single-switch converter structures with additional passive components [12]-[14].

In this research article, a modified structure of transformer less DC-DC conversion based on SEPIC configuration with single-switch [14], feeding a DC motor load, is presented. The significance of using the modified converter structure is that high voltage conversion ratio can be obtained at low value of duty factor (D). The another advantage is that the suggested modified converter configuration has continuous input current. The power switch, diodes, inductors, and capacitors used in the converter are assumed to be lossless. The suggested converter feeds a 5 HP, 240 V, 22 A, DC shunt motor whose no-load performance characteristics such as speed, torque, and armature current are validated through the simulation of the proposed speed control scheme in MATLAB / SIMULINK environment.

The organization of the remaining sections of the proposed work is as follows: Section II explains the modes of operation of the modified DC-DC SEPIC topology and the various speed control methods for the DC shunt motor. The MATLAB / SIMULINK study of the proposed converter-fed DC motor is presented in Section III. The Section IV concludes the features of the research work proposed in this article.

II. PROPOSED NO-LOAD SPEED CONTROL METHOD FOR THE DC MOTOR FED BY A MODIFED SEPIC CONVERTER

The power circuit of the suggested continuous input current DC-DC SEPIC converter supplying a DC motor load is shown in Fig. 1. The modified SEPIC structure is operated at low value of duty factor (D) to achieve higher output voltage suitable for the given DC motor. It is assumed that the active and passive elements used in the speed control scheme are assumed to be ideal. The following section II-A explains the working of the modified SEPIC structure [14]:

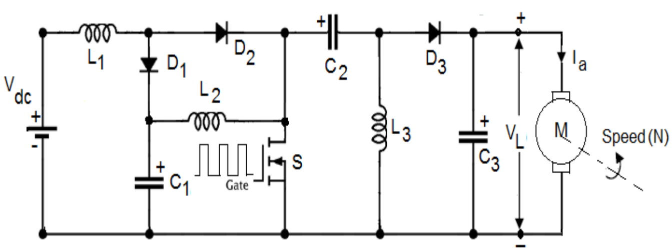

Fig 1:- Power circuit of the transformerless DC-DC SEPIC-fed DC motor

A. Operation of the modified SEPIC topology

The mode-I operation of the converter occurs between the time interval t_0 and t_1. During this period, a gate pulse is applied to the power switch S (MOSFET) to trigger it into conduction as shown in Fig. 1. The diode D_1 acts as short circuit due to forward-bias and the diodes D_2 and D_3 act as open circuit due to reverse-bias. The inductor L_1 gets charged to the supply voltage V_{dc}. The capacitors C_1 and C_2 charge the inductors L_2 and L_3 respectively. The load-side capacitor C_3 supplies the armature current (I_a) of the motor. The fundamental volt-second balance concept is applied for the three identical inductors in order to obtain the inductor voltage equations [14].

The mode-II operation of the converter occurs between the time interval t_1 and t_2. During this period, the power switch S is in non-conducting state and the diode D_2 too is not conducting. The diodes D_1 and D_3 act as short circuit due to forward-bias. The inductor L_1 discharges and charges the capacitor C_1. The capacitor C_2 gets charged by the capacitor C_1 along with the inductor L_2. The passive elements C_1 and L_2 supply the load current (I_a). The inductor L_3 also discharges through the load. The voltage equations for the three identical inductors are governed by the volt-second balance principle [14]. The input-output relationship for the modified continuous input current DC-DC SEPIC topology is obtained as [14]:

$$G = \frac{V_L}{V_{dc}} = \frac{D}{(1-D)^2} \qquad (1)$$

where, G – Voltage gain of the modified SEPIC topology; V_{dc} – DC source voltage to the SEPIC; V_L – DC output voltage of the SEPIC; D – Duty factor of the power switch S.

B. Speed control schemes of the DC motor

The speed (N) of a DC motor is expressed by the following equation [15]:

$$N = \frac{(V - I_a R_a)}{Z\phi}\left(\frac{A}{P}\right) = K\,\frac{(V - I_a R_a)}{\phi} \qquad (2)$$

Thus, the three factors such as flux/pole (Φ), armature resistance (R_a), and the applied armature voltage (V) influence the speed control of a DC motor. In field-flux (Φ) control method, the speed can be decreased by increasing the field-flux and vice versa. This method has the advantage that the speed can be varied above the rated value. But, there is a limitation to the maximum speed obtainable. The armature circuit resistance (R_a) and hence the armature voltage of the motor can be varied by means of a variable rheostat to control the motor speed below the rated value. In this method, the motor speed is approximately proportional to the armature voltage. This method has the disadvantage that the higher amount of power wastage in the variable rheostat leads to decreased motor efficiency.

In this work, the armature voltage control method is used for the speed control of the DC motor fed by the modified DC-DC SEPIC topology. The DC shunt motor is operated with no mechanical load at its shaft. The field current of the motor is kept constant. The desired value of armature voltage (V_L) is obtained by varying the input voltage (V_{dc}) for a fixed value of the duty factor (D). Accordingly, the speed control of the motor can be achieved. Thus, the duty factor (D) can be varied in order to obtain the variable speed for the different values of armature voltage (V_L).

III. MATLAB / SIMULINK STUDY OF THE CONVERTER-FED DC MOTOR AND THE RESULTS

The MATLAB / SIMULINK model of the suggested speed control scheme of DC-DC SEPIC converter-fed DC shunt motor model is shown in Fig. 2. The DC shunt motor is operated under no-load condition. The Sim Power System library is used to obtain the circuit components. Table I and Table II list the simulation model parameters and the specifications of the proposed speed control scheme of the DC motor. The 'ode 45' solver, a graphical user interface (GUI), and the sampling period $T_S = 4e^{-005}$ s are used for the simulation. The MOSFET switch S is triggered into conduction by applying a gate pulse as shown in Fig. 3. The waveforms of the converter input voltage (V_{dc}), output voltage (V_L), and output current ($I_L = I_a$) are depicted in Fig. 4, Fig. 5, and Fig. 6 respectively for the duty factor D = 0.59. The Fig. 7, Fig. 8, and Fig. 9 show respectively the field current (I_f), speed (N), and torque (T_e) characteristics of the motor.

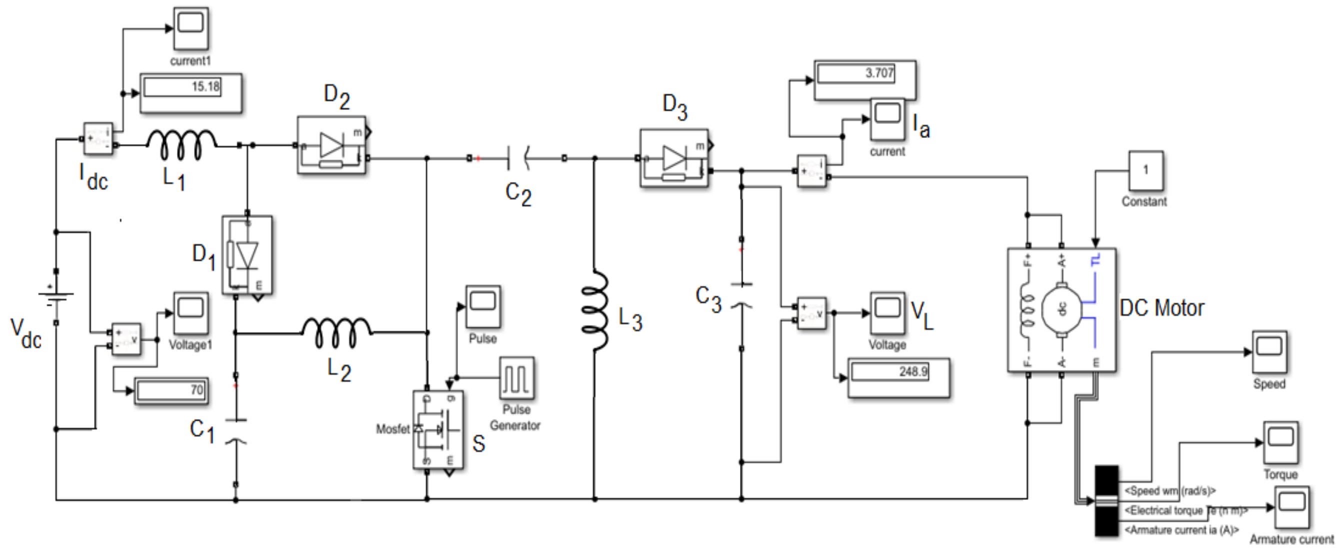

Fig 2: MATLAB / SIMULINK model of the suggested DC-DC SEPIC-fed DC motor

Circuit components	Values
Inductors (L_1, L_2, L_3)	1mH each
Capacitors (C_1, C_2, C_3)	220 µF each
Armature Resistance (R_a)	1 Ω
Duty ratio (D) of the switch S	0.59

Table 1: Parameters used in MATLAB / SIMULINK model of the proposed DC motor speed control scheme

Specifications	Values
Converter source voltage (V_{dc})	70 V
Output DC voltage (V_L)	246 V
Switching frequency (f_s)	50 kHz
DC shunt motor of 5 HP power rating: Armature winding: 240 V, 22 A Field winding: 300 V, 1 A Speed: 1750 rpm	

Table 2: Requirements of the proposed DC motor speed control scheme

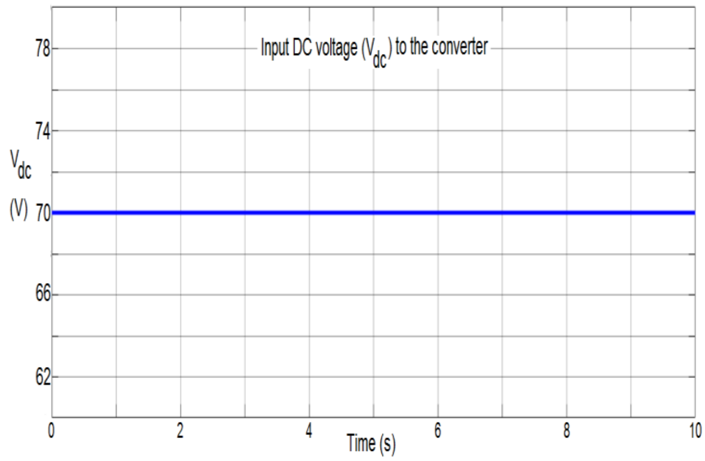

Fig 4: Input DC voltage waveform (V_{dc}) of the SEPIC topology

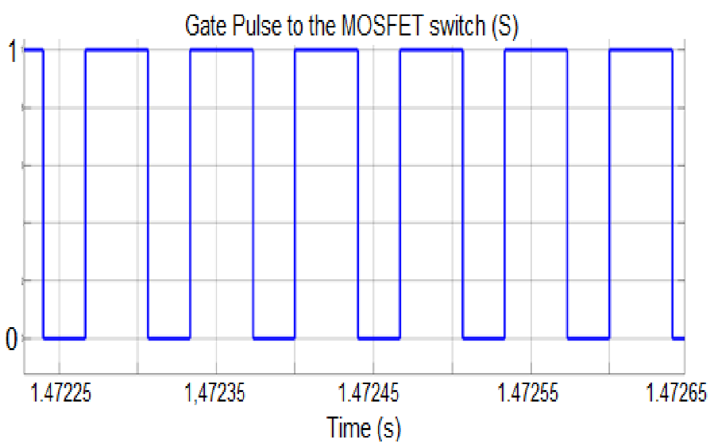

Fig 3:- Gate pulse waveform for the MOSFET switch (S)

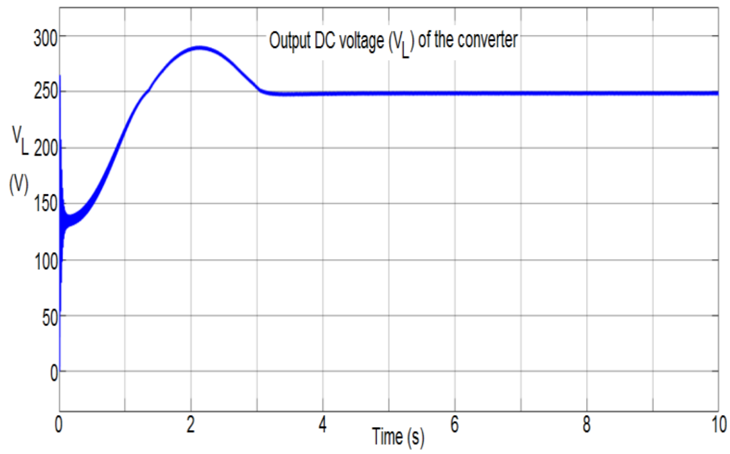

Fig 5: Output voltage waveform (V_L) of the SEPIC topology for duty factor D = 0.59

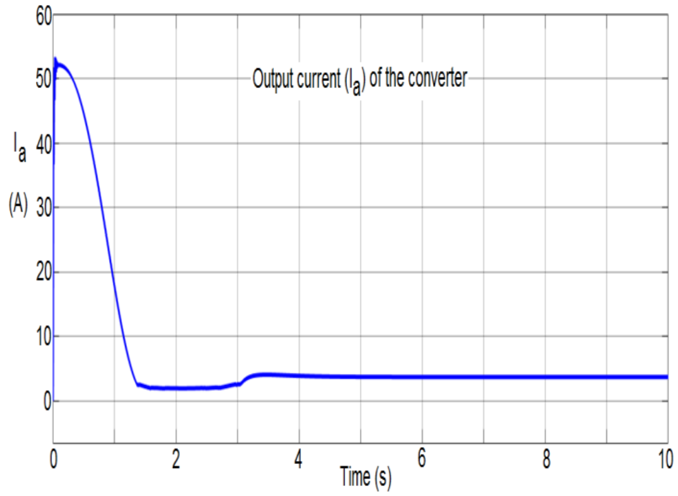

Fig 6: Armature current waveform ($I_L = I_a$) of the SEPIC topology for duty factor D = 0.59

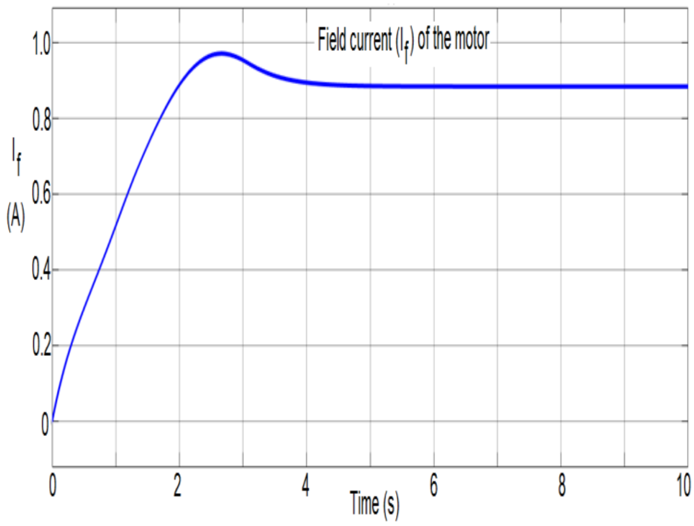

Fig 7: Field current (I_f) variation of the DC motor

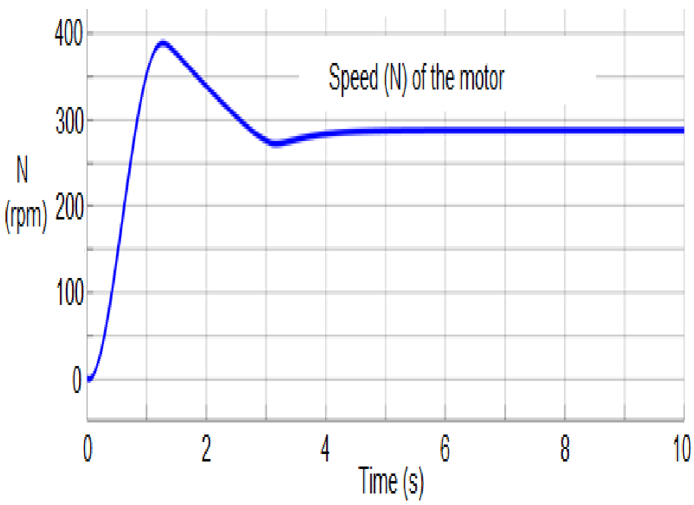

Fig 8: Speed (N) variation of the DC motor

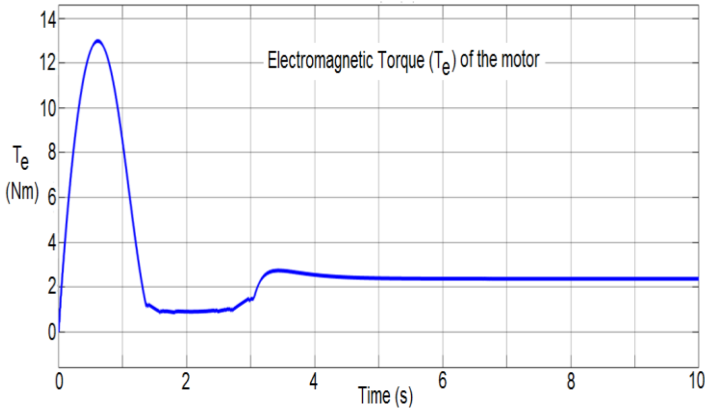

Fig 9: Torque (Te) variation of the DC motor

IV. CONCLUSION

This paper presents the no-load speed control scheme of a DC shunt motor fed by a transformerless modified DC-DC SEPIC topology. The speed control of the DC motor is achieved by the duty factor (D) variation based applied armature voltage control scheme. The motor speed is approximately proportional to the applied armature voltage. The performance of the proposed SEPIC-fed DC motor speed control scheme is validated through MATLAB/SIMULINK study. The no-load characteristics of the motor are obtained. The advantages of the suggested SEPIC-fed DC motor speed control scheme include: (i). In the single-switch converter configuration, the power switch S is made to conduct by applying the conventional Pulse Width Modulated signal. (ii). The switching and conduction losses of the switch are low, thereby improving the converter efficiency. (iii). The single control switch is subjected to low voltage-current stress. (iv). The converter has continuous input current. (v). Moreover, the low duty factor (D = 0.59) itself is enough to produce the sufficient armature voltage for the DC motor.

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