Design of Bridgeless SEPIC Converter for Speed Control of PMDC Motor

K.K. Dinesh kumar, K.B. Naresh kumar, S. ManiKandan and S. Venkatanarayanan

***Abstract:** The bridgeless SEPIC converter design is used for the speed control of permanent magnet DC motor. This paper focuses the design of Bridgeless SEPIC topology having reduced switching and conduction losses with improved power factor, It is designed to work in Discontinuous Conduction Mode (DCM) to achieve the speed control of DC motor by varying the input supply to the armature. This converter is investigated theoretically and the performance comparisons of this proposed converter is verified with MATLAB simulation. The design example of a low voltage and PMDC Motor is developed.*

Keywords: **Bridgeless, Conduction, converter, SEPIC, speed, switching.**

I. INTRODUCTION

The SEPIC stands for single ended primary inductor converter. It is a one type of DC-DC converter which is used in many other applications like mobile phone battery charger, electronic ballast, telecommunications and DC power supplies etc, In this converter the output voltage is maybe buck or boost or same voltage as that of the supply voltage. The converter have been developed a new ZVS PWM SEPIC topology. it has low switching and conduction losses due to zero voltage switching and synchronous rectifier operation[1]. The SEPIC have been designed to increases the power factor correction in ac system, in order to achieve the high power factor [2]. The SEPIC input current and input voltage have been used to a certain extent, reducing the amount of lower order harmonics and resulting high power factor[3]. A new bridgeless PFC SEPIC converter have been designed for high power factor under universal input voltage condition[3]. A novel PFC topology have been developed by the valley-fill circuit into the DCM SEPIC derived converter, by implementing this topology. The solved the bus capacitor voltage dependent on the output load issue and avoided high voltage stress in light load[4]. Two new single–phase bridgeless rectifiers with low input current distortion and low conduction losses have obtained by implemented SEPIC compressed with CUK PFC converter. The size of inductor was reduced and obtained efficiency of SEPIC converter have been improved[5].Single switch bridgeless SEPIC converter have been developed and gave low switching loss compared to bridgeless double switch converter also efficiency[6].

K.K. Dinesh kumar, K.B. Naresh kumar, S. ManiKandan, S. Venkatanarayanan AP (S G), Email id: kkdinesheee05@gmail.com, nrshkmr325@gmail.com, manikandan0721@gmail.com, venjeyeee@gmail.com

In this proposed work the bridgeless SEPIC converter is developed for the speed control of PMDC motor. The Bridgeless SEPIC converter is designed for the energy elements of Inductors and capacitors. The values obtained are used in simulation. The conduction and switching losses are verified. The power factor improvement is verified with MATLAB simulink. The speed of the motor is controlled 900RPM to 1500RPM. Since the switching time is reduced and the losses are minimized. This proposed converter carries full current in the coupling capacitor and hence this capacitor values to be selected to carry the full load current of the PMDC.

II. SEPIC CONVERTER

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The SEPIC stands for single ended primary inductor converter, which is used to buck or boost or same voltage as that of supply voltage. The SEPIC output is controlled by varying duty cycle to the power switches like MOSFET, IGBT, GTO etc. it is also similar to traditional buck-boost converter, it has one additional advantage the output is non-inverted(the output same polarity as the input). Using series capacitor the couple of energy from input to output and being capable of true shutdown. when the switch is turned off the capacitor voltage false to 0V. SEPIC converter is operated in two mode, one continuous conduction mode (CCM) and discontinuous conduction mode(DCM). The DCM mode operation means the inductor current falls to zero.

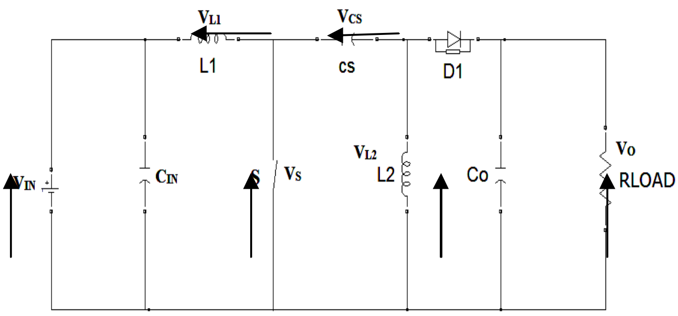

Fig.1. Schematic diagram of conventional SEPIC converter.

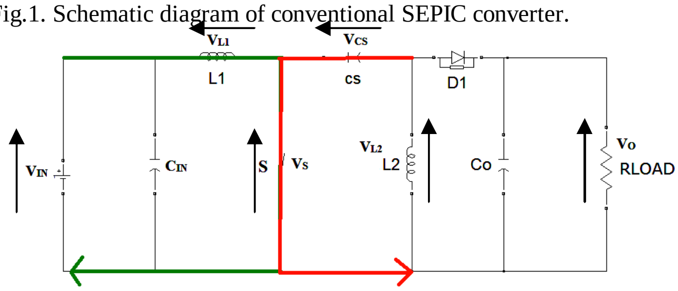

Fig.2: Current flows during switch is turn on condition

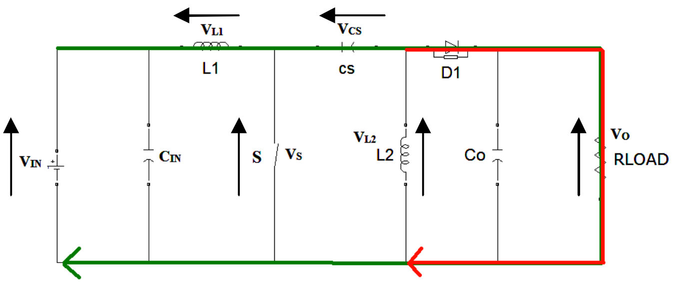

Fig.3: Current flows during switch is turn off condition.

A SEPIC said be in continuous-conduction mode means if the current through the inductor never falls to zero. During SEPIC steady state operation While switch S1 is turned on current IL1 increases and the current IL2 current increase in negative direction. The energy to increase the current IL1 comes from the input supply since S1 is a short while closed and the instantaneous voltage VC1 approximately VIN , the voltage VL2 is approximately –VIN. Therefore, the capacitor C1 supplies the energy to increase the magnitude of the current in IL2 and thus increase the energy stored in L2.

When the switch S1 is turned off , the current IC1 becomes the same as the current IL1, since inductors do not allow instantaneous change in current. The current IL2 will continue in the negative direction, in fact it never reverses direction. It can be seen from the fig.3 that a negative IL2 will add to the current IL1 to increase the current delivered to the load.

III. PERMANENT MAGNET DC MOTOR

Permanent magnet DC motor is similar to an ordinary dc shunt motor except that its field is provided by permanent magnet instead of salient pole wound structure. There are three types of permanent magnet used for such motors, (i.e.) Alnico, ferrite and rare-earth magnets. These materials has high residual flux density and high coercivity, The armature consist of slots to the accommodated armature winding. In this type of motor field speed control is not possible but armature speed control is only possible in order to vary the input supply to the armature winding the motor speed is varying as much we desired value. In this type of motor below speed control only possible because of field having permanent magnet, suppose we increase the voltage above rated voltage means the motor insulation will become into failure and motor windings will be short circuited.

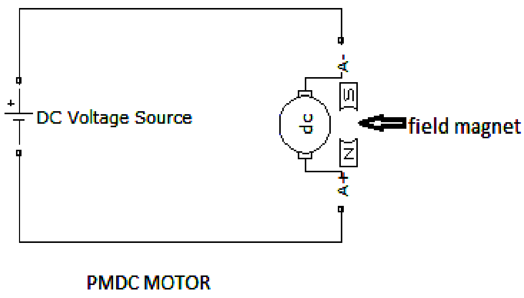

Fig.4.Permanent magnet DC motor

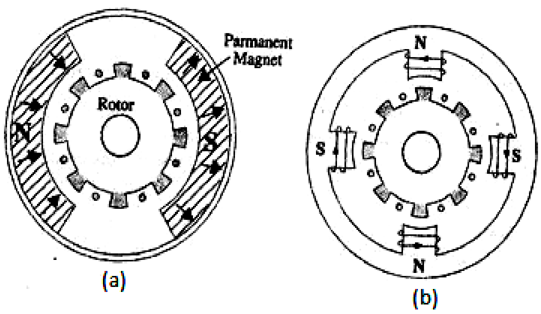

Fig.5.Construction of permanent magnet in PMDC.

The characteristics of PMDC motor is given below.

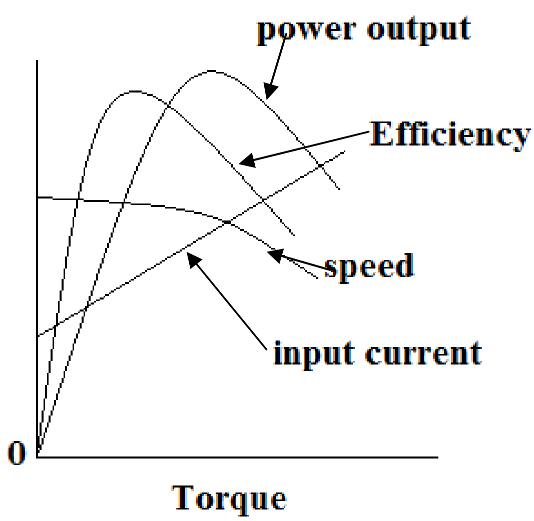

Fig.6.Charteristics of PMDC motor.

IV. BRIDGELESS SEPIC CONVERTER

A conventional AC-DC SEPIC converter had a bridge circuit in input because this circuit converts ac-dc. The converting process was done by means of diodes. During positive half cycle couple of the diode was conducting and negative half cycle another couple of the diode was conducting due to this conduction loss also increases and also presence of power switches the switching loss is increase. It is an unavoidable one but conduction loss is avoidable one. A bridgeless SEPIC converter gives a low conduction loss and switching loss during switch turn on and turn off condition.

The bridgeless circuit also used to improve power factor in SEPIC converter during conversion of ac-dc. Here three identical inductor is used to reduce the ripple current and coupling capacitor is used to store the input voltage and boost voltage both capacitors are identical so that the voltage ripple also reduced. During positive half cycle all components will conduct except DS1, S2, C2, L3 and D02. During negative half cycle all components will conduct except DS2, S1, C1, L2 and DO1. Thus only eight components will be conducted at each half cycle compared to eleven in bridgeless SEPIC converter. In this circuit PID controller is used to vary the speed of the PMDC motor by varying pulse width to the SEPIC converter, we obtained the various voltage to the motor.

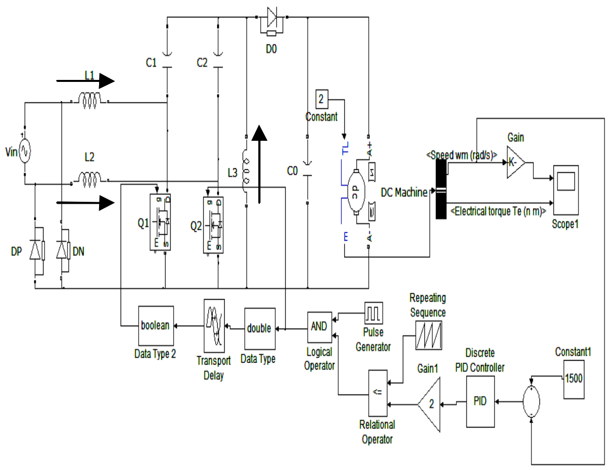

Fig.7.Bridgeless SEPIC converter circuit diagram.

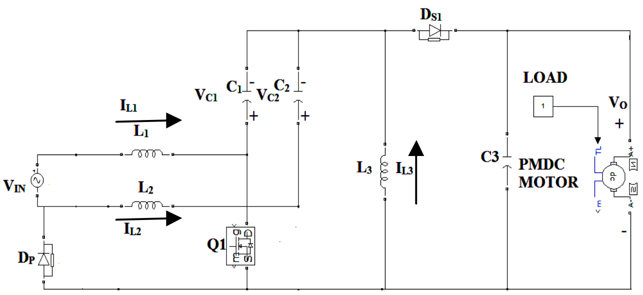

Fig.8.During positive half cycle, switch Q_1 turn on and Q_2 turn off condition.

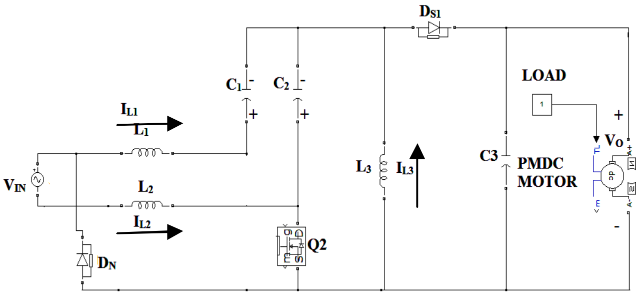

Fig.9.During negative half cycle, switch Q_2 turn on and Q_1 turn off condition.

V. CIRCUIT OPERATION

The operation of the converter will be explained assuming that the three inductors are working in DCM. Operating the SEPIC in DCM offers advantages over continuous-current mode (CCM) operation. Such as a near-unity power factor can be achieved naturally and without sensing the input line current. Also in DCM, both Q1 and Q2 are turned on at zero current. While the diode DS1 are turned off at zero current. Thus, the loss due to switching losses and the reverse recovery of the rectifier are considerably reduced.

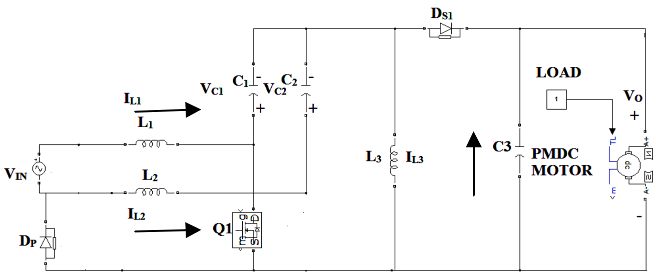

Fig.10(a).During positive half cycle, switch Q_1 turn on and Q_2 turn off condition.

(a) MODE 1: During the positive half-line cycle, the first dc-dc SEPIC circuit, L1-Q1-C1-L3-Do, is active through diode Dp, which connects the input ac source to the output ground. when the switch Q1 is turned on, diode Dp is forward biased by the sum inductor currents iL1 and iL2. As a result, diode DN is reversed biased by the input voltage. The output diode is reversed biased by the reverse voltage (Vac + Vo). In this stage, the three-inductor currents increase linearly at a rate proportional to the input voltage Vac.

(b) MODE 2: During the negative half-line cycle, the second dc-dc SEPIC circuit, L2-Q2-C2-L3-Do, is active through diode DN, which connects the input ac source to the output ground.

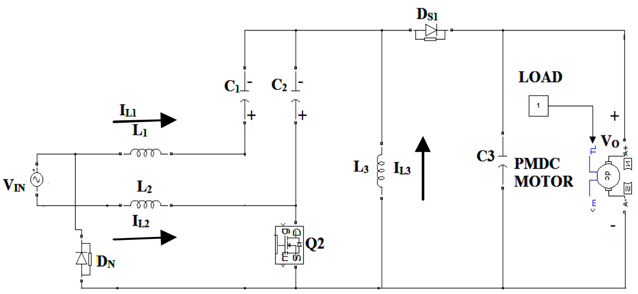

Fig.10(b).During positive half cycle, switch Q_1 turn on and Q_2 turn off condition

At the instant, switch Q1 is turned-off, diode Do is turned-on simultaneously providing a path for the three inductor currents. Diode Dp remains conducting to provide a path for iL1 and iL2. In this stage, the three inductor currents decrease linearly at a rate proportional to the output voltage, Vo.

(c)MODE 3: In this stage, both Q1 and Do are in their off-state. Diode Dp provides a path for iL3. The three inductors behave as current sources, which keep the currents constant. Hence, the voltage across the three inductors is zero. Capacitor C1 is charging up by iL1, while C2 is discharged by iL2.

Fig.11. shows the main theoretical waveforms during one switching period Ts. It should be mentioned here that if the two active switches Q1 and Q2 are implemented as standard MOSFET, then the body diode of Q2 will conduct during the first stage and the circuit will not function properly. In other words, there are reverse voltages applied to the active switches, so that the switches must have reverse blocking capability. Therefore, unidirectional current conducting device must be implemented for Q1 and Q2. In this case, turning ON or OFF Q2 during the first stage will not change the circuit operation mode. Accordingly, both of the switches, Q1 and Q2, can be driven by the same control signal, which helps in reducing the cost and complexity of the driving circuit.

The rate of increase of the three inductor currents are given by

$$\frac{d_{i_{Ln}}}{dt} = \frac{v_{ac}}{L_n}, \quad n = 0,1,2,3 \qquad (1)$$

The peak switch current I_{Q1-pk} is given by

$$I_{Q1,pk} = \frac{V_m}{L_e} D_1 T_s \qquad (2)$$

Where,

$$\frac{1}{L_e} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \qquad (3)$$

And D1 is the switch duty cycle. This intervals ends when Q1 is turned off, initiating the next subinterval.

VI. DESIGN PROCEDURE FOR BRIDGELESS SEPIC

A simplified design procedure is presented in this section to determine the components values of the proposed converter. Suppose we would like to design the SEPIC converter with the following power stages specification.

1) Input voltage Vac =12 Vrms at 50Hz
2) Output voltage = Vo=15Vdc
3) Output power = 30Watts
4) Switching frequency = 330KHz
5)Maximum input ripple currentΔi_{L1} = 20%% of fundamental current
6) Output voltage ripple $\Delta v_0 = \pm 1\% \, of \, Vo$

The voltage conversion ratio M is

$$M = \frac{15}{12 * \sqrt{2}} = 0.88 \qquad (4)$$

The value of K_{e-crit} is

$$K_e < K_{e-crit} = \frac{1}{2(M+1)^2} = 0.147 \qquad (5)$$

For values of $K_e > K_{e-crit}$, the converter operates in CCM; otherwise, the converter operates in DCM.
Inductance L_e value is

$$L_e = \frac{K_e R_L}{2 f_s} = 2.22 \mu H \qquad (6)$$

Inductances L_1,L_2 and L_3 value can be determined as follows,

$$L_1 = \frac{V_m D_1}{f_s \Delta i_{L1}} = 10mH, \qquad (7)$$

$$L_2 = L_3 = \frac{2 L_1 L_e}{L_1 - L_e} = 100mH \qquad (8)$$

The required output capacitance to maintain peak-peak output voltage ripple of 2% of Vo can be calculated as follows,

$$\Delta v_o = \frac{T_L V_o}{2 C_o} \left[\frac{1}{R_e M^2} \left(\frac{1}{\pi} + \frac{1}{2} \right) - \frac{1}{R_L} \right] \qquad (9)$$

And Co1, Co2 =1mF

The coupling capacitor C1 must be chosen such that its voltage Follows the shape of the input ac line voltage wave form with the lowest ripple as possible, C1 should not cause low-frequency oscillations with inductors L1,L2 and L3, based on three constraints , the value of C1=C2=10mF is chosen for this particular design.

The inductor ripple current is,

$$\bar{\iota}_{L1} = \frac{D_1^2 T_s v_{ac}}{2 L_1} \left(1 + \frac{2 v_{ac}}{v_o} \right) + i_x \qquad (10)$$

$$\bar{\iota}_{c1} = \frac{D_1^2 T_s v_{ac}}{2} \left[\frac{2 v_{ac}}{v_o} \left(\frac{1}{L_e} - \frac{1}{L_2} \right) - \frac{1}{L_2} \right] - i_y \qquad (11)$$

The current i_x simply found by following expression,

$$i_x = \frac{v_{ac}}{R_e} \left[1 - \frac{L_e}{L_1} \left(1 + \frac{2 v_{ac}}{v_o} \right) \right] \qquad (12)$$

i_{c1} can be represented by,

$$\bar{\iota}_{c1} = C_1 \omega V_m \cos(\omega t) \qquad (13)$$

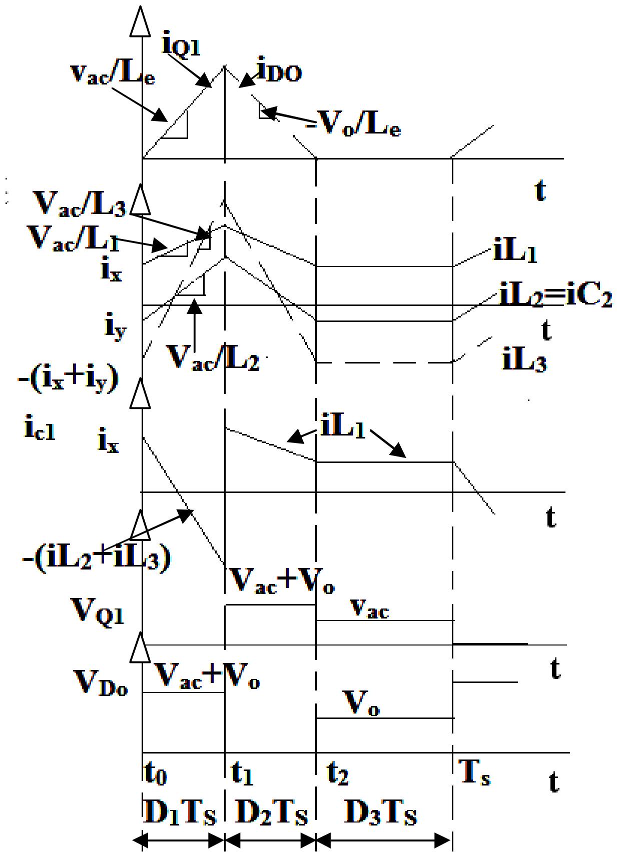

Fig.11. Theoretical waveforms in DCM of proposed converter

VII. SIMULATION

A simulation performed at bridgeless SEPIC converter inductors and capacitors values are taken above mentioned value, Supply voltage and switching frequency are also specified value. The bridgeless SEPIC converter simulated waveforms are shown in fig.

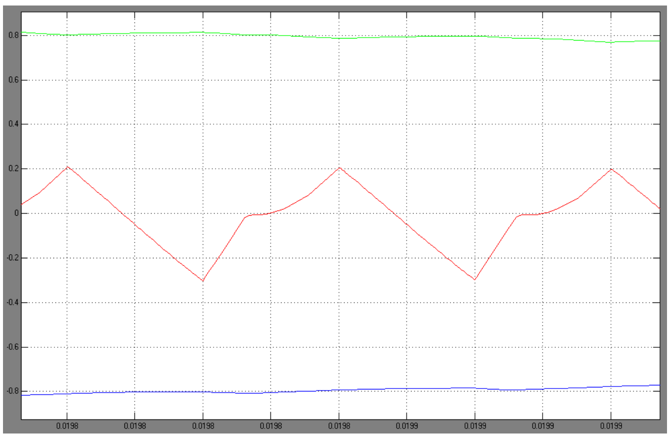

Fig.12.Inductors L_1, L_3 and L_2 current waveforms.

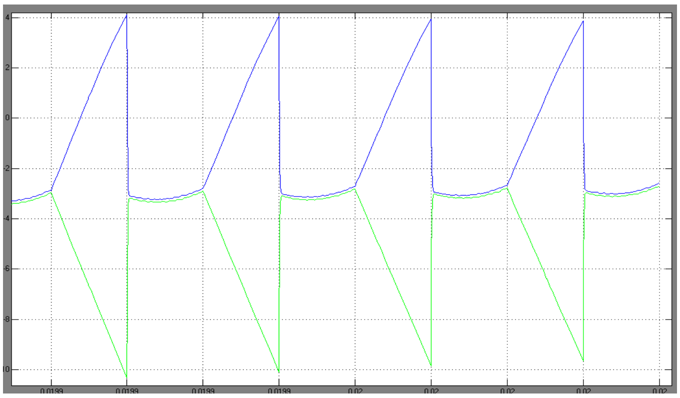

Fig.13.Capacitors C_1 and C_2 voltage waveforms.

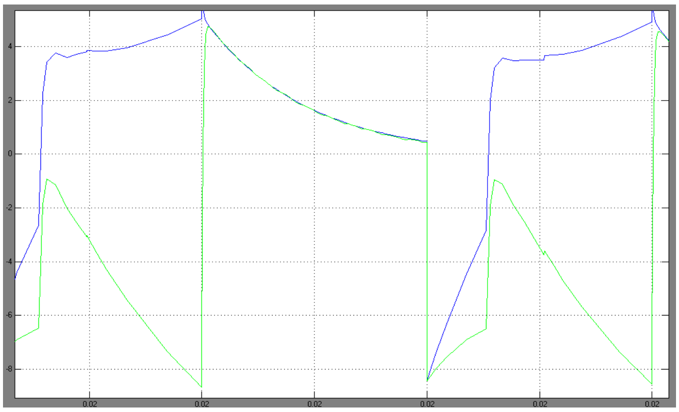

Fig.14.Inductors L_1 and L_2 voltage waveforms.

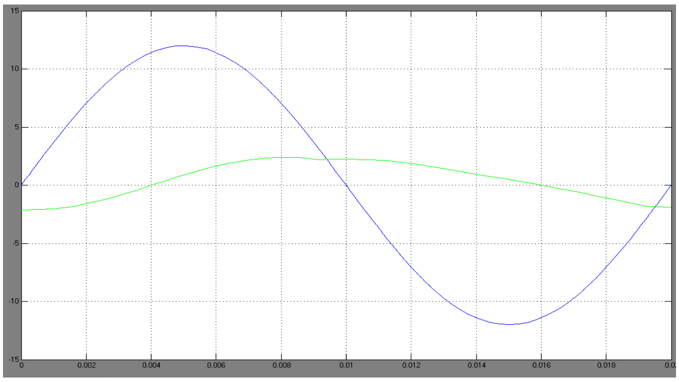

Fig.15. Input voltage and current waveforms.

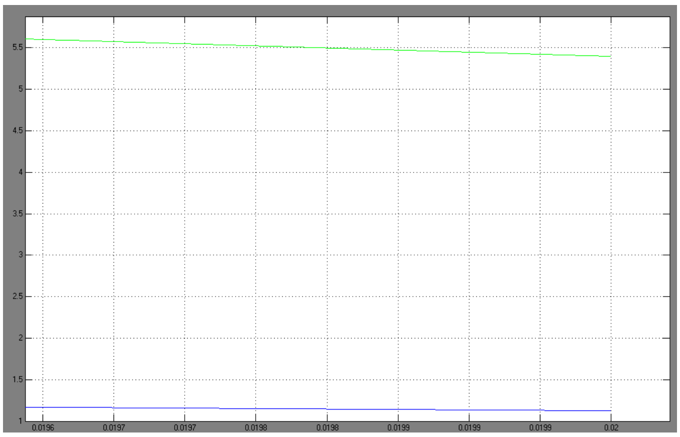

Fig.16. Output voltage and current waveforms.

b. Motor specifications

Sl.no.	Parameter	Value
1.	Ra, La	0.5Ω, 0.01H
2.	Torque constant	1.8 N.m/A
3.	J	0.05 Kg.m^2
4.	Bm	0.02 N.m.s
5.	Tf	0 N.m

Torque constant (N.m/A)
J-total inertia in Kg.m^2
Bm-viscous friction coefficient in (N.m.s)
Tf-coulomb friction torque in (N.m)

Where,
Ra-armature resistance in Ω
La-armature inductance in H

	INPUT			OUTPUT			%EFFICIENCY	Power factor Cosφ
	VOLTAGE (volts)	CURRENT (A)	POWER (watts)	VOLTAGE (volts)	CURRENT (A)	POWER (watts)	Output power/input power	
1	12.0	2.60	31.20	14.23	1.75	24.902	79.8%	0.80
2	12.5	2.55	31.87	14.23	1.85	26.325	82.6%	0.85
3	13.0	2.50	32.50	14.23	1.85	26.325	82.6%	0.85
4	13.5	2.50	33.75	14.24	1.95	27.768	82.2%	0.88
5	14.0	2.50	35.00	14.24	1.95	27.768	82.2%	0.88
6	14.5	2.45	35.50	14.24	1.95	27.768	82.2%	0.88
7	15.0	2.40	36.00	14.24	1.95	27.768	82.2%	0.88

VIII. CONCLUSION

The bridgeless SEPIC converter designed used for the speed control of permanent magnet DC motor. This paper Bridgeless SEPIC topology is used and having reduced switching and conduction losses with improved power factor, It is designed to work in Discontinuous Conduction Mode (DCM) to achieve the speed control of DC motor by varying the input supply to the armature. This converter is developed in MATLAB simulink and Performance are verified. The efficiency of this converter is obtained about 82.2%. The further improvement can be done in DSP controllers.

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K.K. DINESH KUMAR was born in India, Madurai in 1992 is pursuing in K.L.N. college of engineering, madurai as final year student in the department of EEE. His area of interest is converter control, Power Electronics, DC-DC converters, Power supplies, Power factor correction etc

S. MANIKANDAN was born in India, Madurai in 1992 is pursuing in K.L.N. college of engineering, madurai as final year student in the department of EEE. His area of interest is converter control, SEPIC converter and Power Electronics,DC-DC converters.

K.B. NARESH KUMAR was born in India, Madurai in 1992 is pursuing in K.L.N. college of engineering, madurai as final year student in the department of EEE His area of interest is converter control, DC-DC converters, Power supplies, Power factor correction.

S.VenkatanarayananAP(S.G) was born in India ,Vandary,Madurai in 1969, He Received BE Degree in 1998 at Madurai Kamaraj University Madurai , ME in 2008 at Annauniversity Chennai, Also he is have MBA and MPhil ,Presently pursuing his part time Ph.D at Annauniversity .He is working as Assistant Professor (Sr.Gr) at K.L.N. college of engineering, Pottapalayam, Sivagangai District in the department of EEE. His area of interest is converter control, SEPIC converter and Power Electronics,DC-DC converters, Power supplies, Power factor correction etc and development of prototypes of converters