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High Static Gain DC-DC Converter with Improved Regulation Using Magnetic Coupling

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ABSTRACT: A high static gain dc-dc converter based on the modified SEPIC converter is presented in this scheme. The preferred topology presents low switch voltage with high efficiency for low input and high output voltage applications. The configuration of this converter with magnetic coupling and output diode voltage clamping is presented and analyzed. The magnetic coupling allows to elevate the static gain maintaining a reduced switch voltage. In order to reduce the problem of overvoltage at the output diode, inclusion of a secondary voltage multiplier is made mandatory. This voltage multiplier increases the static gain of the converter and also acts as a non-dissipative clamping circuit for the output diode. The simulation is done using MATLAB/SIMULINK and results are investigated in order to validate the performance of the converter.

KEYWORDS: SEPIC converter, magnetic coupling, high static gain, voltage multiplier.

I.INTRODUCTION

The development of high step-up conversion technique is widely used in the renewable energy applications such as solar energy, wind energy, fuel cells etc [1]. The main features of these renewable energy sources are that they are clean as well as pollution free [2]. Since they are natural resources, there will be having some significant variations on the level of voltage and power, such that power electronics technology become more prior to improve the characteristics of steady-state and transient of these systems. Furthermore, the output of such systems may be very insufficient at times. Therefore it is very mandatory to increase the output of the renewable energy systems. Thus step up converters introduce an important application in this scheme. Conventional boost converter employed in these applications have several advantages such as simple structure, continuous input current, and reduced switch voltage stress, but it is very difficult to obtain high voltage conversion ratio and high efficiency simultaneously [3].This is due to the existence of parasitic resistances, which leads to inherent degradation in the step-up ratio and efficiency as the operating duty cycle increases.

As a result, the classical non-isolated dc–dc converters have limited step-up static gain $(q = V_0/V_i)$. The boost converter is the classical step-up dc–dc non-isolated converter with a duty cycle close to $D = 0.8$, where output voltage is around five times the input voltage. So three static gain ranges are considered in this scheme. A dc–dc converter operating with a static gain range, $q = 5$ is considered as a standard static gain, a static gain range higher than $q = 10$ is considered as high static gain solution and static gain higher than $q = 20$ is considered as a suitable static gain solution. In isolated dc-dc converters, turns ratio of transformer is used to increase the converter static gain [4]. But the usual problem of these converters is the efficiency degradation due to the transformer power losses and leakage inductance. The losses are due to the weight of the converter topology. Therefore, elimination of power transformer is the usual solution for improving efficiency and power density. Many techniques are developed on the basis of boost topology in order to achieve high static gain. The main techniques used are the switch capacitors and voltage multiplier cell, inductor magnetic coupling and also combination of these techniques [5]-[9].

In this paper, the topology employing magnetic coupling based on modified SEPIC is presented which increases static gain equal or higher than 20 times with reduced switch voltage. Fig.1 shows the classical SEPIC converter. Apart from the conventional topology the new topology have more desired characteristics. In the conventional topology hard switching operation is used. Due to several disadvantages of such operation, they cause extreme switching as well as conduction losses. By implementing soft switching techniques, such losses can be decreased significantly [10]. However, a very small leakage inductance is necessary in this converter in order to achieve ZCS turn-on commutation and thus to decrease the diodes reverse recovery current. Thereby the losses can be reduced and overall performance of the converter can be improved. Moreover, closed loop control of modified SEPIC converter enables better load regulation. Thereby, the suggested converter topology becomes digitalized. Using digitally controlled converters, better sensitivity can be enhanced with respect to the parameter variations [11]. The digitally controlled step up converters have the some features such as less sensitive to noise, temperature independent, better sensitivity to parameter variations. In this topology voltage mode control is employed. The advantages of voltage mode control is that there is a single voltage feedback path in which Pulse Width Modulation(PWM) technique is implemented by comparing the error signal with a constant ramp waveform. Thus a digital controlled modified SEPIC converter is introduced with better voltage regulation.

II.REVIEW OF STATIC GAIN TOPOLOGIES

Fig: 1 shows the classical SEPIC converter. For wide range of input voltage applications, step up and step down static gain of this converter is an important characteristic. However, since the switch voltage is equal to the sum of the input and output voltages, the static gain is lower than the classical boost converter. In Fig: 2, SEPIC Converter with Magnetic Coupling converter topology, static gain is improved without increasing the duty cycle. The main aim is to insert a secondary winding in the L_2 inductor, which increases output voltage by the turns ratio (n). However, the overvoltage across the diode D_0 is due to the presence of the coupling winding leakage inductance. Because of reverse recovery current of the output diode D_0, the stored energy in the inductance results in voltage ring and high reverse voltage at D_0. This overvoltage cannot controlled with dissipative clamping.

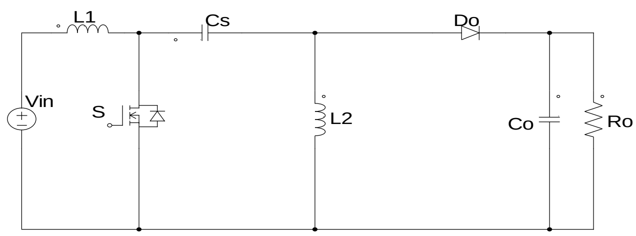

Fig.1. Conventional SEPIC converter

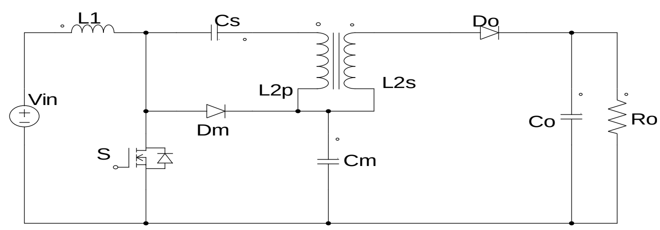

Fig.2. Modified SEPIC converter with magnetic coupling.

III.CIRCUIT DESCRIPTION

Fig: 3 shows the modified SEPIC converter with magnetic coupling and output diode voltage clamping. In order to reduce the overvoltage across the output diode D_0, a simple solution is the inclusion of a voltage multiplier at the secondary side. Therefore, the secondary voltage multiplier consists of diode D_{M2} and capacitor C_{s2}, which is a non-dissipative clamping circuit for the output diode. This voltage multiplier technique increases the static gain without any extreme duty cycle and reduces the voltage across the output diode D_0 lower than the output voltage. Thus the energy stored in the inductance is transferred to the output. The power switch turn-on occurs with zero current reducing the switching losses. Because of the existence of the coupling inductor leakage inductance, the current variation ratio (di/dt) presented by all diodes is limited. In case of single switch isolated dc-dc converters, the leakage inductance is a problem which results switch overvoltage. The stored energy in the leakage inductance must be dissipated through clamping circuits. However, the leakage inductance is needed in the preferred topology in order to achieve ZCS turn-on commutation and to alleviate the diode reverse recovery problems.

The classical boost converter with magnetic coupling or the integration of the magnetic coupling and the voltage multiplier can provide very high static gain and better performance as discussed. As the magnetic coupling is inserted with the input inductor in the boost-based techniques, correspondingly ripple current at input side is increased with respect to the inductor windings turns ratio. In order to obtain high efficiency, the solutions based on the integration of the SEPIC converter are illustrated. Thus an isolated active clamp technique is accomplished in the SEPIC flyback converter. However, this topology presents pulsating current, and the active clamp technique with additional switch leading to converter complexity. The integration of the boost converter with a SEPIC converter is also suggested. While comparing the previous topologies, preferred topology has some advantages are the ZCS switch turn-on obtained with a resonant stage, reducing commutation losses and switch voltage, higher static gain considering the same transformer turns ratio.

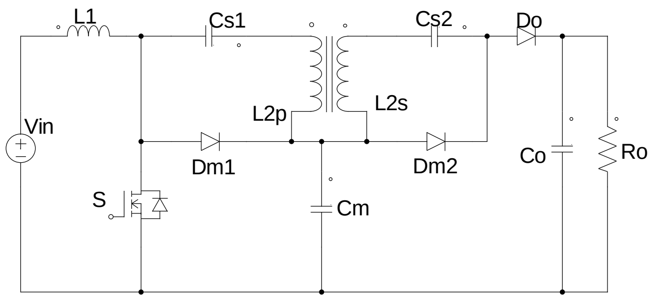

Fig.3. Modified SEPIC converter with magnetic coupling and output diode clamping.

IV.OPERATING PRINCIPLE

The main aim of this scheme is to elevate the converter static gain double than that of conventional topology and thereby reduce the switch voltage. But to attain such features, it becomes necessary to operate the converter in continuous conduction mode (CCM) at a duty cycle greater than 0.5. The continuous conduction mode of modified SEPIC converter consists of five operation stages in a single switching cycle, corresponding modes are represented by Fig.3.The detailed analyze of operational characteristics are following below. Following assumptions are done in the theoretical analysis order to simplify the suggested circuit.

1) All semiconductors are considered to be ideal.
2) All capacitors are assumed as a voltage source.

In mode 1 ($t_0 – t_1$), the switch S is conducting and the inductor L_1 stores energy. The capacitor C_{S2} is charged by the secondary winding $L_{2S}$and diode D_{M2}.The leakage inductance reduces the current and the energy transference happens in a resonant way. The output diode is blocked, and the maximum diode voltage is equal to $V_0 - V_{CM}$. At the instant t_1, the energy transference to the capacitor C_{S2} is completed and D_{M2} is blocked. In mode 2 ($t_1 – t_2$), the switch S is turned-OFF at the instant t_1, and the diodes D_{M2} is blocked and the inductors L_1 and L_2 store energy and the currents linearly increase. In mode 3 ($t_2 – t_3$), the energy stored in the inductorL_1 is transferred to the capacitor C_{S2}. Also, there is the energy transference to the output through the capacitors C_{S1}, C_{S2}, inductor L_2 and output diode D_0.In mode 4 ($t_3 – t_4$), the energy transference to the capacitor C_M is completed at the instant t_3 and the diode D_{M1} is blocked. The energy transference to the output is maintained until the instant t_4, when the switch is turned ON. In mode 5 ($t_4 – t_5$) the switch is turned ON at the instant t_4, the current at the output diode Do linearly decreases and the di/dt is limited by the transformer leakage inductance, reducing the diode reverse recovery current problems. When the output diode is blocked, the converter returns to the first operation stage.

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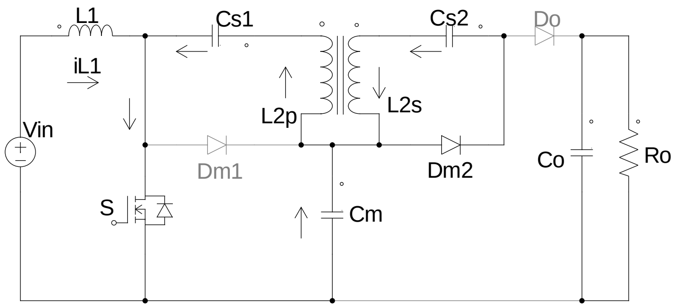

Fig.4. Mode 1

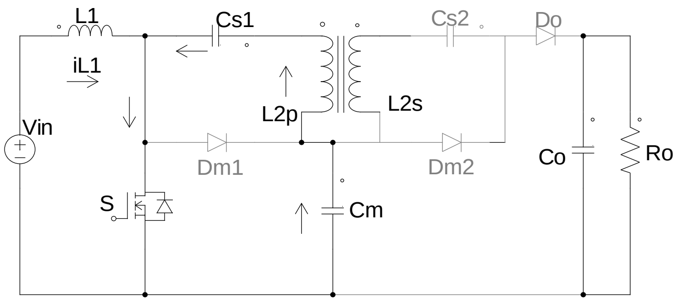

Fig.5. Mode 2

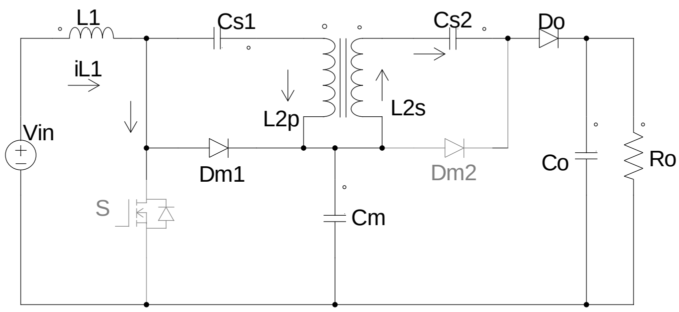

Fig.6. Mode 3

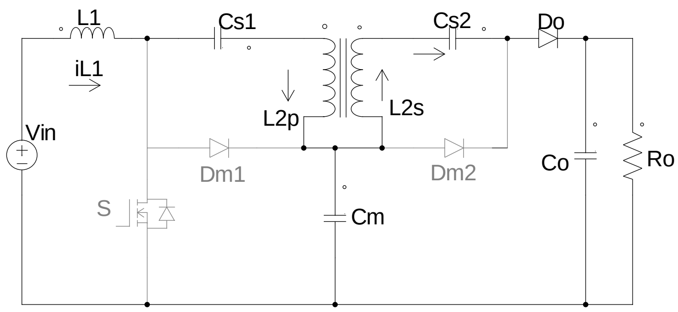

Fig.7. Mode 4

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V. ANALYSIS AND DISCUSSION

The voltage gain of the suggested converter is given by

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

The switch voltage, V_S is equal to the voltage of the capacitor C_M and the voltage across the diode, which is calculated as

$$V_S = \frac{V_i}{1-D} \qquad (2)$$

The average current of the diodes I_{DM} and I_{D0} is equal to the output current of the converter, which is given by

$$I_0 = \frac{P_0}{V_0} \qquad (3)$$

The preferred converter topology is simulated using MATLAB SIMULINK model. In order to clarify the performance of the converter, digital control are selected in order to obtain regulated output voltage and ZCS. Here the output power is taken at 100W. The waveforms of the input voltage is 15V and corresponding output voltage is 300V for obtaining 24 kHz switching frequency are shown in below.

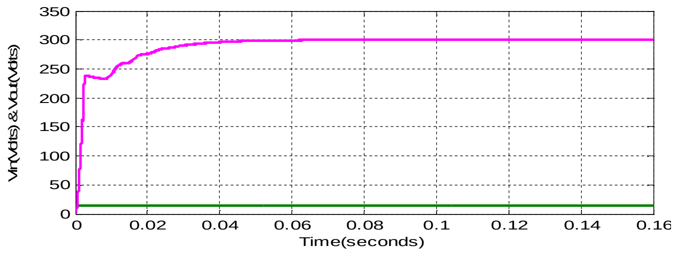

Fig.8.Waveforms of input voltage, $V_{in} = 15V$ and output voltage, $V_0 = 300V$

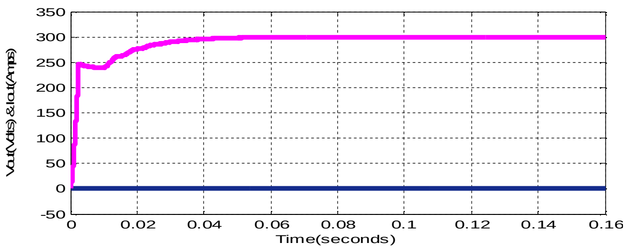

Fig.9.Waveforms of rated output voltage, $V_0 = 300V$ and output voltage,$I_0 = 0.33$A

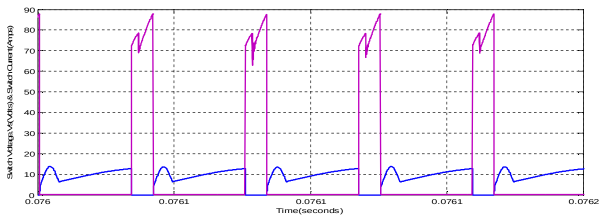

Fig.10.Switching waveforms of voltage and current

VI.APPENDIX

TABLE I

Parameter	Modified SEPIC converter
Input voltage, V_i	15V
Output voltage, V_0	300V
Output power, P_0	100W
Switching frequency, f	24kHz
Static gain, q	20
Duty cycle, D	0.82

VII.CONCLUSION

Modified SEPIC converter with magnetic coupling is the most advanced scheme in order to achieve a very high static gain for low input voltage and high output voltage applications. This converter structure can operate with static gain higher than 20 with low switch voltage. Inclusion of voltage multiplier cell at the secondary side will not affect the complexity of converter. Furthermore, it increases the converter static gain. The commutation losses of the suggested converter with magnetic coupling are reduced due to the existence of the transformer leakage inductance. Implementing voltage mode control, the circuit gets modified with better voltage regulation.

REFERENCES

C. W. Li and X. He, “Review of non-isolated high step-up DC/DC converters in photovoltaic grid-connected applications,”IEEE Trans. Ind.Electron., vol. 58, no. 4, pp. 1239–1250, Apr. 2011.

D. Meneses, F. Blaabjerg, O. Garcia, and J. A. Cobos, “Review and comparison of step-up transformerless topologies for photovoltaic AC-Module application,”IEEE Trans. Power Electron., vol. 28, no. 6, pp. 2649–2663,Jun. 2013.

K. Park, H.-W. Seong, H.-S. Kim, G.-W. Moon, and M.-J. Youn, “Integrated boost-SEPIC converter for high step-up applications,” in Proc.IEEE Power Electron. Spec. Conf. 2008 (PESC 2008), Jun. 2008, pp. 944–950K.

S. Kim, D.-K. Choi, S.-J. Jang, T.-W. Lee, and C.-Y. Won, “The active clamp SEPIC- flyback converter,” in Proc. IEEE 36th Power Electron. Spec. Conf., 2005 (PESC ‘05), Jun. 2005, pp. 1209–1212.

[5] M. Prudente, L. L. Pfitscher, G. Emmendoerfer, E. F. Romaneli, and R. Gules, “Voltage multiplier cells applied to non-isolated DC–DC converters,”IEEE Trans. Power Electron., vol. 23, no. 2, pp. 871–887, Mar.2008.

[6] E. H. Ismail, M. A. Al-Saffar, A. J. Sabzali, and A. A. Fardoun, “A family of single-switch PWM converters with high step-up conversion ratio,” IEEE Trans. Circuits Syst. I, Reg. Papers, vol. 55, no. 4, pp. 1159–1171, May 2008.

[7] B. Axelrod, Y. Berkovich, and A. Ioinovici, “SwitchedCapacitor/Switched-Inductor structures for getting transformerlesshybrid DC–DC PWM converters,”IEEE Trans. Circuits Syst. I, Reg.Papers, vol. 55, no. 2, pp. 687–696, Mar. 2008.

[8] L.-S. Yang, T.-J. Liang, and J.-F. Chen, “Transformerless DC–DC converters with high step-up voltage gain,”IEEE Trans. Ind. Electron.,vol.56,no. 8, pp. 3144–3152, Aug. 2009.

[9] Q. Zhao and F. C. Lee, “High-efficiency, high step-up DC–DC converters,”IEEE Trans. Power Electron., vol. 18, no. 1, pp. 65–73, Jan. 2003.

[10] G. Henn, R. Silva, P. Prac ¸a, L. Barreto, and D. Oliveira, “Interleaved boost converter with high voltage gain,”IEEE Trans. Power Electron., vol. 25,no. 11, pp. 2753–2761, Nov. 2010.

[11] M. K. Kazimierczuk and R. Cravens II, “Closed-loop characteristics of voltage-mode controlled PWM boost converter with an integral-leadcontroller,”J. Circuits, Syst. Comput., vol. 4, no. 4, pp. 429–458, Dec.1994.