Design and Analysis of SEPIC Converter for Battery Charging Applications – Part I – Simulation Studies

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ABSTRACT – *In this paper, the design of sepic converter for battery charging applications is presented. The design procedure of sepic converter is analysed and its operation under varying input voltage is studied. A voltage regulation control circuit is added with PI controller and the results are studied with different reference voltages. The results of the proposed inverter is provided with MATLAB/Simulink software.*

I. INTRODUCTION

In past, the dc-dc converter topologies are designed for the microgrids, filters, electric vehicles, etc., are introduced. The most commonly used converter topologies are boost converter, buck converter, buckboost converters [1]. Among this, buckboost is preferred mostly due to the adaptability and also ability to provide both buck and boost operations. Also it provides path to the study of various converter structures in which the voltage sources are used for charging the passive elements such as inductors, capacitors, etc by providing the switching gate pulses in order to get the required output . In recent times, sepic converter replace the buckboost converters as the sepic converter is able to provide output continuous current even though at input side it is discontinuous[2]. Various passive elements such as inductor, capacitor, etc and active devices such as power electronic switches are used in designing the sepic converter. Lower ESRs (Equivalent Series Resistors), Non inverted load voltage and current, ripple minimization etc, are few advantages of sepic converter. The variations in the input voltage leads to the variation in load voltages which affects the loads. This causes the need of voltage regulation circuit which provides constant output voltage irrespective of the changes in the input voltages[3]. A voltage mode control loop with PI controller provides the regulation of output voltage under varying input voltage conditions.

In this paper, a sepic converter is designed and analysed for battery charging applications. A PI controller based voltage mode control loop is introduced to control the load voltage by providing variations in reference voltage[4]. The sepic converter is simulated in both open loop and closed loop conditions.

II SEPIC CONVERTER:

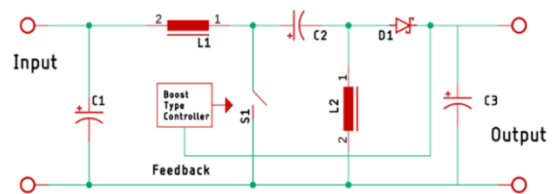The sepic converter circuit is shown in Fig 1 below:

Fig 1 Sepic Converter Circuit

SEPIC converter is similar to buck boost converter topology with non inverting output. It is comprised of two inductors connected with a coupling capacitor and a switch. The sepic converter's operational modes are provided below:

Mode 1:

In this mode, the power electronic switch is turned ON and both L1 and L2 are getting charged and the coupling capacitor C2 is discharging. The equivalent circuit for mode 1 of sepic converter is shown in Fig 2 below:
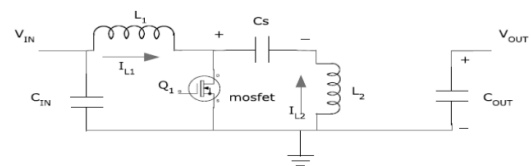

Fig 2 Sepic converter Mode 1 operational circuit

The voltage equation for this mode is provided below[5]:

$$V_{IN} = V_{L1} + V_{Cs} + V_{L2}$$

Because the average voltage of V_{Cs} is equal to V_{IN} [6]

$$V_{L1} = -V_{L2}$$

Mode 2:

In this, the power electronic switch is turned ON and both the inductors L1 and L2 are getting discharged and the coupling capacitor C2 starts charging. The equivalent circuit for mode 2 of sepic converter is shown in Fig 3 below:
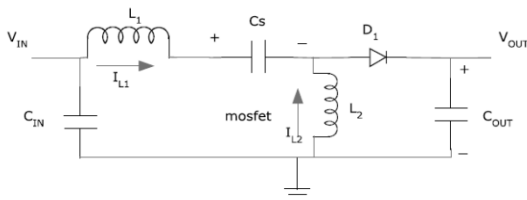

Fig 3 Sepic converter Mode 2 operational circuit

The output voltage for mode2 is provided below:

$$V_{OUT} = V_{Q1} - V_{IN}.$$

The duty ratio of the sepic converter is calculated by

$$D = \frac{V_{OUT} + V_D}{V_{IN} + V_{OUT} + V_D}$$

The inductors are calculated by:

$$L1 = L2 = L = \frac{V_{IN\,(min)}}{\Delta I_L \times f_{sw}} \times D_{max}$$

The ripple current calculation of the inductors are provided below:

$$\Delta I_L = 0.2 * \frac{Vo}{V_{in}} * I_o$$

The coupling capacitor is designed with the equation provided below:

$$\Delta V_{Cs} = \frac{I_{OUT} \times D_{max}}{Cs \times f_{sw}}$$

The load side capacitor value is designed as follows:

$$Cout \geq \frac{I_{OUT} \times D}{V_{ripple} \times 0.5 \times f_{sw}}$$

The ripple voltage of load side capacitor is provided by the following equation:

$$\Delta Voc = 2\% \; of \; Vo$$

III. CONTROL STRATEGY OF DC-DC CONVERTER

In this, the load voltage is controlled with the gate pulses generated by the control circuit (which is shown in Fig 4)

and provided to the sepic converter. The feedback voltage is measured from the load and compared with the reference voltage[7]. The error dc voltage is obtained as follows:

$$V_E = V^*_{dc} - V_{dc}$$

The generated load voltage error is provided to the voltage controller, which generates the duty ratio as shown below:

$$V_C(k) = V_C(k-1) + K_P$$
$$\{V_E(k) - V_E(k-1)\} + K_i V_E(k)$$

Where k is the sample time. The duty ratio output from controller is subjected to pwm by comparing it with carrier signal of higher frequency to generate the pulses[8].

When $M_C < V_C$, switch is turned ON
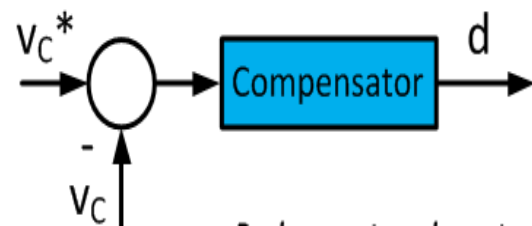
When $M_C \geq V_C$, switch is turned OFF

Fig 4 Control loop for the dc-dc converter

IV. SIMULATION RESULTS

The sepic converter with openloop pulse generation is shown below in Fig 5:
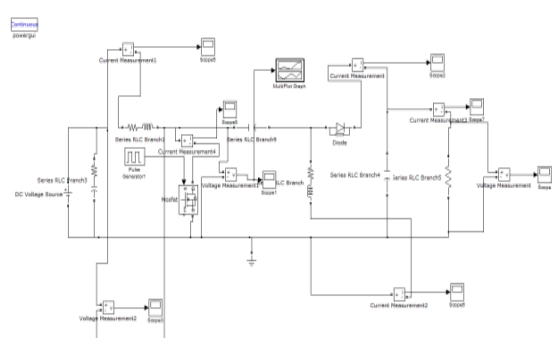

Fig 5 Simulation circuit for open loop sepic converter

In this, the dc voltage source of 12V provides supply to the load of 8-14V using sepic converter with switching frequency of 30KHz.

A resistance of 100Ω is provided as load. The pulses are generated based on the duty ratio provided as 0.5. The load voltage in Fig 6 is as follows:
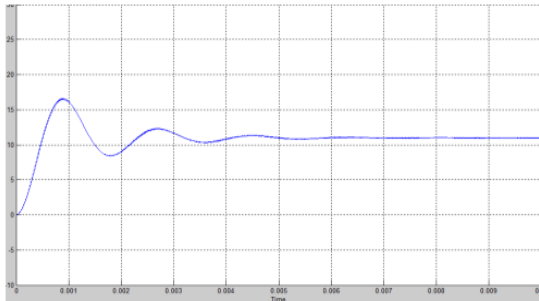

Fig 6 Open loop output voltage

The sepic converter with closed loop pulse generation in Fig 7 is as follows:
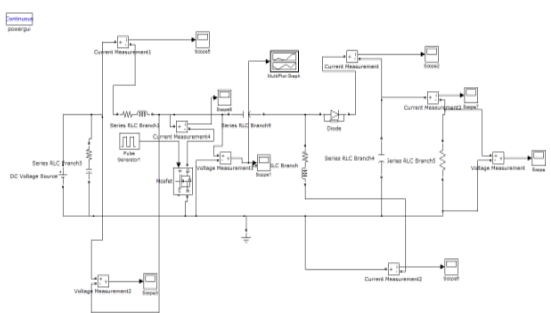

Fig 7 Sepic converter with closed loop control

In this, the dc voltage source of 12V provides supply to the load of 8-14V using sepic converter with switching frequency of 30KHz.

The pulses are generated based on the duty ratio generated by PI controller. The load voltage in Fig 8 is as follows:
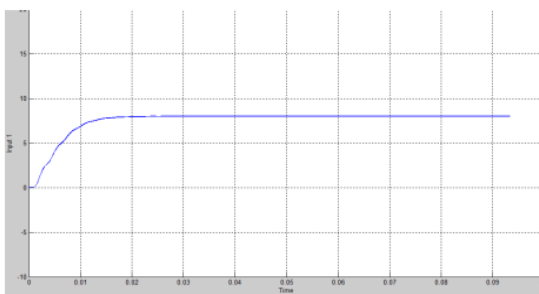

Fig 8 Output voltage with reference 8V

In this, the sepic converter is functioning as buck converter. The reference voltage is varied to 14V and the load voltage measured in Fig 9 is as follows:
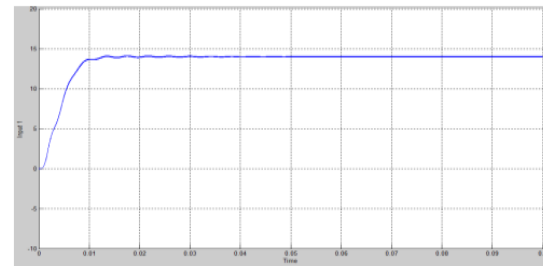

Fig 9 Output voltage with reference 14V

In this, the sepic converter is functioning as boost converter.

V. CONCLUSION

A sepic converter is designed and analysed for battery charging applications and presented. The simulation work is carried out for both open loop and closed loop. A PI controller based voltage mode control loop is introduced to control the load voltage by providing variations in reference voltage in the range of 8-14V with the input voltage of 12V. The sepic converter is simulated in both buck and boost mode operations.

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