Analysis of SEPIC for PV-Applications using PI Controller and Current Mode Control

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Abstract—A SEPIC (single-Ended Primary Inductor Converter) DC-DC converter is capable of operating in either step-up or step-down mode and widely used in battery-operated equipment. This paper presents two various closed loop techniques of SEPIC Converter, namely current mode control and PI control using PV panel. For PI controller voltage is taken as reference, for current mode controller current has taken as reference, by using the current mode controller chaos has also controlled.
Keywords: SEPIC Converter, PI controller, Current Mode control, PV panel, coupling capacitor

I. INTRODUCTION

In modern electronic devices, DC-DC converters are widely used, where battery is used as a source. The battery is used as an input to the converter and corresponding output voltage is obtained from the converter depending on the load requirement. The voltage range will depends on the charge level. In order to supply constant range, over the entire battery range the converter need to operate in buck as well as in boost mode. This can be done by the basic converter topologies such as CUK and SEPIC and etc., converters. But buck boost and CUK converters will produce output voltage which is in reverse polarity to the input. The above problem can be solved by including isolating transformer, but because of this the cost will be increased. So in order to solve this problem SEPIC converter is introduced which can be able to operate in both step up mode and step down mode with its output voltage in same polarity with the input voltage, so this converter is advantageous when compared to others. [1].

In section II operation and design of SEPIC has been done. In section III modelling of PV module has been done, In section IV control strategy has been done, there are current mode controller and PI controller have been designed. In section V simulation results have done

II. OPERATION

A Single ended Primary Inductor Converter (SEPIC) is a dc-dc converter, whose output voltage can be controlled by the duty cycle of the switching device.

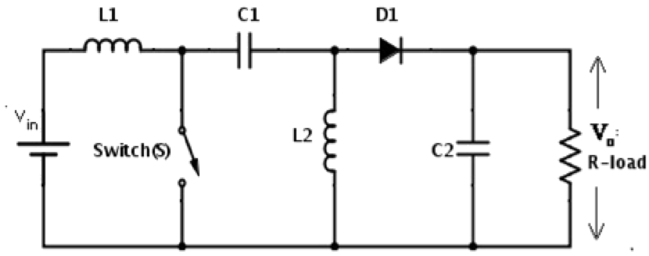

Fig. 1: Circuit diagram of the SEPIC Converter

The circuit diagram of SEPIC(single ended primary inductor converter) is shown in Figure(1).The SEPIC converter consists of a Switch (S) with duty cycle (α),a diode (D1), two inductors (L1 and L2),two capacitors(C1 and C2) and a resistive load (R).All the elements are assumed as ideal.

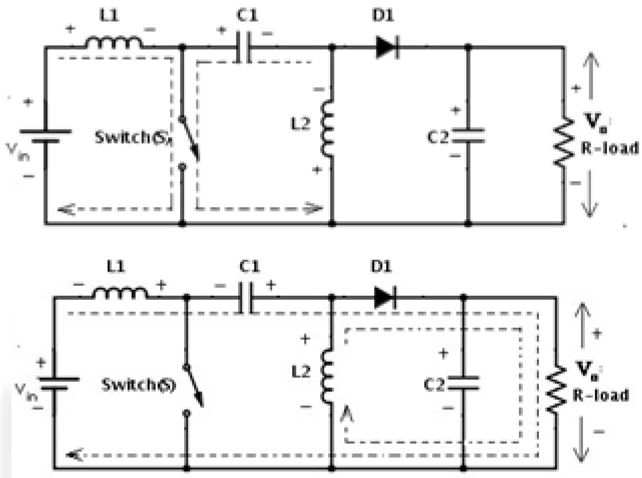

Fig. 2: Equivalent Circuit diagram of the SEPIC Converter when the Switch is ON and OFF

When switch is (S) turns ON, the energy is stored in the inductor L1. At this time the inductor voltage equals to the input voltage, and the energy stored in capacitor C1 will be transferred to inductor L2. The load is supplied by capacitor C2, When S turns OFF, the energy stored in inductor L1 is transferred to C1.The energy stored in L2 is transferred to C2 through D1 and supplying the energy to load. The equivalent circuits during on and off states are shown in Figure (2) for analysis, the converter with following parameters is chosen:

parameters	Symbol	Value	unit
Input voltage	v_{in}	12	V
Switching frequency	f_s	40	KHz
Rated output power	P_o	80	W
Output voltage	V_o	18	V
Input inductance	L_1	40	μH
Inductor	L_2	175	μH
Coupling capacitor	C_1	10	μF
Output capacitor	C_2	10	μF

Table. 1: SEPIC Specifications And Design Parameters [2]

The average output voltage is

$$V_o = \frac{\alpha}{1-\alpha} V_{in} \tag{2.1}$$

The average input current is

$$I_{in} = \frac{\alpha}{1-\alpha} I_{out} \quad (2.2)$$

The ripple current in the inductor L2 is

$$\Delta I_1 = \frac{V_{in}\alpha}{f_s L_1} \quad (2.3)$$

The ripple current in the inductor L2 is

$$\Delta I_2 = \frac{V_S \alpha}{f L_2 (1-\alpha)^2} \quad (2.4)$$

The coupling capacitance is

$$C_1 = \frac{\alpha}{2fR} \quad (2.5)$$

The output capacitance is

$$C_2 = \frac{\alpha}{8fR} \quad (2.6)$$

III. MODELING OF PV MODULE

The PV module is a collection of cells assembled to generate an unstable electric current when it is exposed to light. A single cell can only generate a small voltage. The several cells have to be connected in series, called module [8]

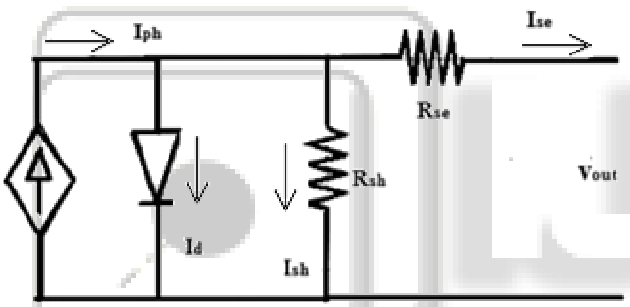

Fig. 3: Single diode equivalent circuit of a solar cell [8]

To generate a useful voltage for high power PV generators, several modules are connected in series and parallel to form the array. Using the single diode, equivalent circuit of a solar cell shown in Figure (3), current-voltage (I-V) characteristics depend on the radiation and temperature equations and P parallel string with S series cells per string is developed (2.7 to 11)

$$I_L = I_{Ph} - I_s \left[\exp\left(\frac{qV_d}{AK_bT}\right) - 1 \right] - \frac{V_d}{R_{sh}} \quad (2.7)$$

$$I_{Ph} = \left[I_{sc} + K_1 (T_c - T_{ref}) \right] G \quad (2.8)$$

$$I_s = I_{Rs} \left(\frac{T_c}{T_{Ref}}\right)^3 \exp\left[\frac{qE_b \left(\frac{1}{T_{Ref}} - \frac{1}{T_C}\right)}{K_b A} \right] \quad (2.9)$$

$$I_{Rs} = \frac{I_{sc}}{\exp\left(\frac{qV}{N_s K T_c A}\right) - 1} \quad (2.10)$$

$$I_L = N_p I_{Ph} - N_p I_s \left[\exp\left(\frac{qV}{N_s K T_c A}\right) - 1 \right] \quad (2.11)$$

Where I_{PH} is the photo-current; I_L is the net current at the output terminal; R_{sh} is the shunt resistance of the diode; R_S is the series resistance; I_s is the saturation current of the diode; q is the electron charge (1.6×10^{-19}C);A is the diode Ideality factor; K_B is the Boltzmann constant(1.38×10^{-23}J/^{o}K); T_c is the cell working temperature; V_d is the diode voltage in volts; I_{Sh} is the shunt leakage current; G is the solar insolation; I_{SC} is the short-circuit current at standard test condition 25^{o}C and 1000Wm;Klis the cell's short-circuit temperature coefficient; T_{ref} is the reference temperature of 25^{o}C;and I_{RS} is the reverse saturation current[3]

SPECIFICATIONS @ G=1000W/m^2 and T=25^{o}C	
Rated power (P_{max})	9W
Voltage at P_{max}(V_{mp})	3.45V
Current at P_{max}(I_{mp})	2.81A
Short circuit current(I_{sc})	3.8A
Open circuit voltage(V_{oc})	3.2V

Table 2: Pv Panel Specifications

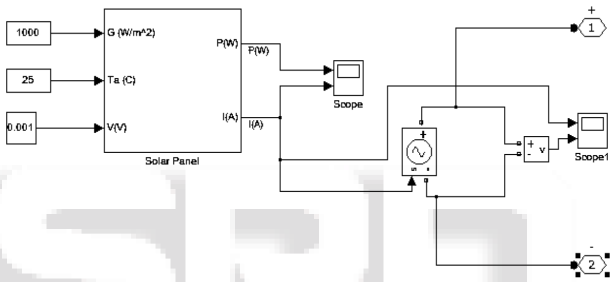

Fig. 4: Solar array block diagram

IV. CONTROL STRATEGY

PI controller using Ziegler-Nichols for SEPIC converter:

A. The schematic functioning diagram is shown in below

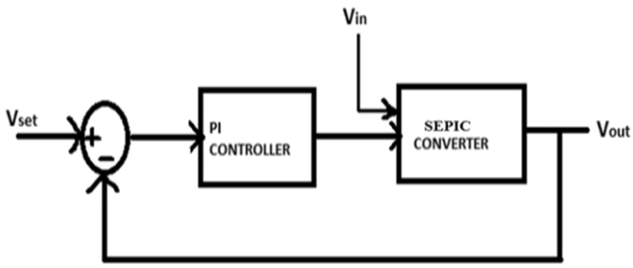

Fig. 5: Block diagram of PI controller SEPIC converter

The transfer function [9] is in the form of

$$G_P(s) = \frac{K_P}{1+ST_P} e^{-S\tau} \quad (2.12)$$

From the step response diagram three parameters have been obtained

Static process gain K_P

$$K_P = \frac{\Delta Y}{\Delta U} \quad (2.13)$$

Process transport delay τ

Process time constant T_P

From these parameters a constant a is computed;

$$a = \mu K_P \quad \text{Where} \quad \mu = \frac{\tau}{T_P} \qquad (2.14)$$

PI controller values can be find by

$K=0.9a$, $T_I=3\tau$

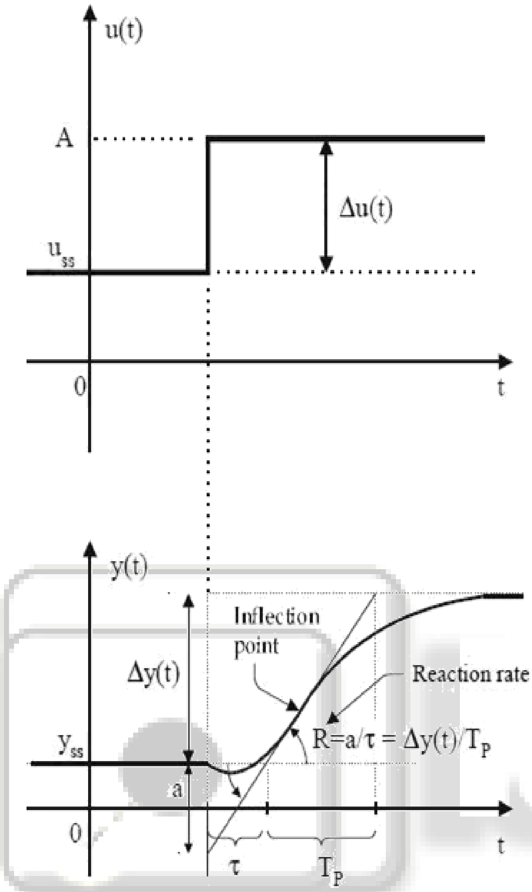

Fig. 6: Graph for PI controller

B. Current mode control of SEPIC converter:

The circuit diagram of the current controlled SEPIC topology is shown in figure 5.

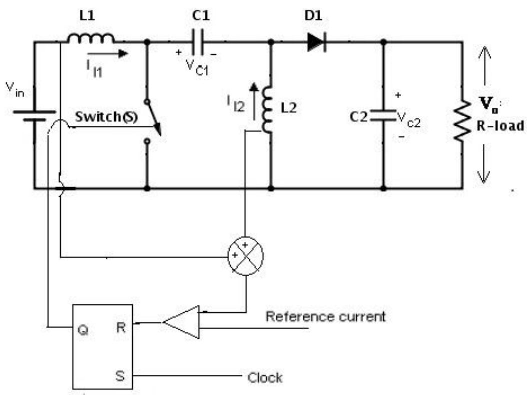

Fig. 7: Circuit diagram of current mode controlled SEPIC converter

In this converter method, the control signal is chosen as the Sum of the inductor currents, hence

$$I = I_{L1} + I_{L2} \qquad (2.15)$$

By comparing I with the reference current, the driving on, off signals for switch S is generated. At the beginning of the cycle the switch S is turned on. Switch current is increased until it reaches the values the reference current. I_{ref} and switch S is turned off and remains off until the next cycle begins.

V. SIMULATION DIAGRAMS AND RESULTS

A. Open loop control of SEPIC:-

The figure 8 shows the simulation diagram of open loop SEPIC converter and the also shows the voltage and current waveforms of SEPIC converter

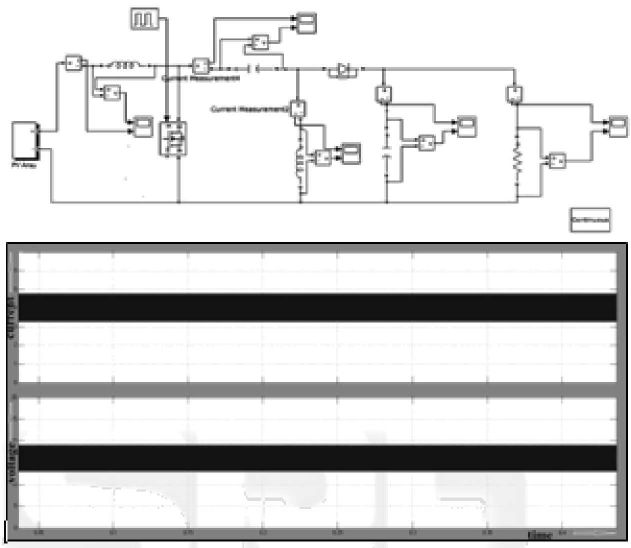

Fig.8 Simulation Diagram and Result of Open Loop SEPIC

B. Closed loop control of SEPIC:-

1) Current mode control:- The figure shows the results of current mode control, this figure contains voltage and current wave forms at the load, operating 4.5A as the reference current

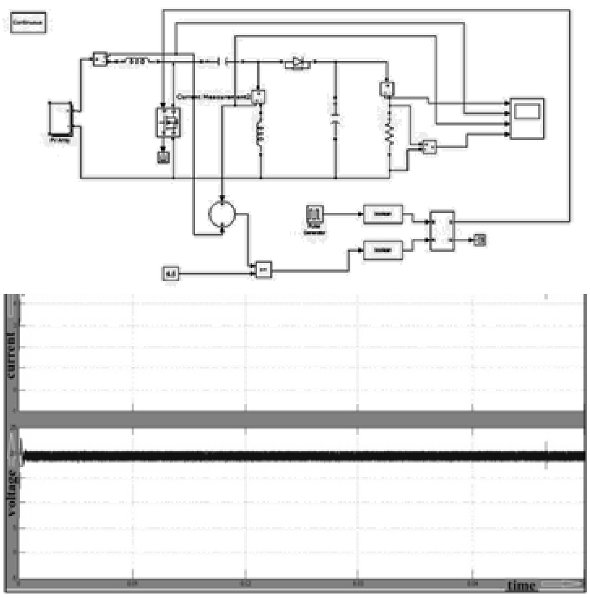

Fig. 9: Simulation Diagram and Result of Current Mode Control of SEPIC

2) PI controller:- The figure shows the results of PI controller, which is designed by Ziegler-Nichols, and also shows voltage and current wave form of PI controller, the KP=0.0001,Ki=2

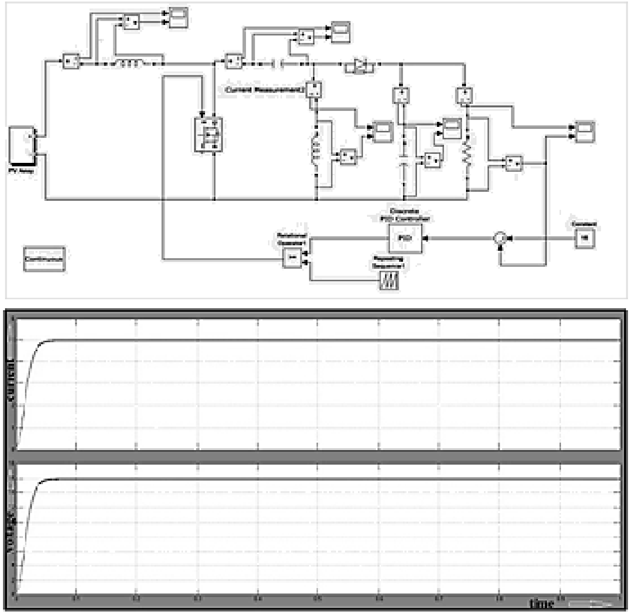

Fig. 10: Simulation Diagram and Result of PI Controller of SEPIC Converter

VI. CONCLUSION

By using SEPIC (single ended primary inductor converter), we can efficiently operate the converter depends on the applications. In the current mode control, current has been controlled. The reference current has limitations, taken current should be in stable [2], sometimes because of the current system may go to unstable region

In the PI controller, voltage has taken as reference, but current mode controller gives the better result compares to the PI controller.

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