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The recycled Power Multiplexed Control in Single Inductor Multiple Output Converter for Military Applications

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Abstract

In addition to the primary power circuit, auxiliary circuits are used in most domains these days, including plug-in hybrid automobiles, industries, telecommunication, and so on. DC-DC converters with single inductor multiple outputs (SIMO) play a key part in such systems, making their research worthwhile. The single inductor triple output buck converter (SITO) can be controlled by a recycled power multiplexed control system for military uses. The different modes of operation are explained. Efficiencies are improved as a result of reduced cross-regulation. For a wide range of loads, it is a versatile converter. MATLAB is used to simulate the behavior of the converter. Simulation results confirm the converter's functionality.

Keywords: Single inductor multiple output converter, recycled power multiplexed control, cross-regulation, DC-DC switching converter, military application.

Introduction

Over the last few decades, linear regulators have been utilized to generate step-down voltages. The disadvantage is that the efficiency is just 60% and applies only to lighter loads. Switched mode power supply has been introduced to be used for heavier loads. However, it only provides one voltage, and because these are merely step down regulators, the noise is extremely high. Single inductor single output converters (SISO) are used to generate the step up voltages. In everyday life, the necessity for several voltages for the same system grows. For the same system, having too many SISO converters increases the space and cost of the converters.

SIMO (single inductor multiple output) converters have been introduced to the market to address the converters' shortcomings. The energy of a single inductor is spread among many outputs. SIMO converters are used in military applications, electric cars, mobile phones, and computers, among other things. Cross regulation, or the variation of one output over the other outputs, is the fundamental disadvantage of the SIMO converter. To this day, many control techniques are utilized to control cross regulation. One switching cycle is divided into n slots, each of which is dedicated to generate one output, as recommended by time multiplexing control (TMC) Ma [1]. Inductor current freewheel separates the slots. In the heavy load situation, discontinuous mode (DCM) experiences a large peak current. Cross regulation is caused by continuous conduction mode (CCM) under heavy loads. Dongsheng [2] explains the pseudo-continuous conduction mode which is proposed to suppress cross regulation. For each switching cycle, the inductor current is set to the same value using a dc offset current. To determine the dc offset current value under various load conditions, a sophisticated technique is required. To compensate for unbalanced loads, separate freewheel currents are required explained by Zhang [3].

Jing [4] introduces the converter which automatically switch from one frequency to another based on the entire load's energy transfer. A complex controller is required. The last few trailing outputs are cross-regulated due to fixed time slots. Voltage overshoot and voltage drop have an impact on the system. To regulate the various freewheeling switching currents, a complex approach is required. To achieve the N outputs, the inductor is charged once and dispersed one by one to the outputs. The structure's adaptability is restricted. The N-1 outputs are controlled by a comparator, whereas the last output is PI controlled by an error amplifier. The Nth output is subjected to cross regulation as a result of load change in the preceding N-1 outputs [5-9]. Wang [10] explains under DCM operation, the pulse-train (PT) and time multiplexing (TM) control techniques are used. The number of current sensors are high, and the control method is complicated. Only under light load conditions delete can the converter can operate, resulting in substantial current ripple, high switching noise, and high switching device dissipation.

Goh [11] offers a converter that does not require an initial energizing phase. The SIMO converter uses hysteresis control for all outputs. The high side switch is activated during the energizing phase, while the low side switch is activated during the recycling phase. During the inductor's rising phase, all outputs are charged. During load transients, there are no overshoots or undershoots. The converter in DCM does not support lighter loads. Due to fully hysteresis control, each output should be charged back to back without any discontinuous phase. Jiang [12] tells that the dual frequencies play a vital role in feeding numerous outputs within a specific switching period. It has a quick dynamic response and minimal cross-regulation. The dual frequencies decouple the pace of power conversion from the rate of power distribution. Huang introduces power multiplexed control with a short dead time period to avoid output shot through. Excess inductor energy is wasted and not properly utilized by Huang [13]. The proposed technique has the recycling switch, which has its applications in military and mobile phones, is used in this study to recycle excess inductor energy back to the input. The recycled power multiplexed (RPM) control technique is proposed, in which the inductor energy is used effectively to charge the battery while also reducing the cross regulation problem

Recycled power multiplexed control

The proposed control method is applied to a wide range of multi-output designs based on typical converter topologies such as boost, buck, and buck-boost converters [15].

The proposed technique is demonstrated and tested using a buck-derived SIMO converter in this study. SIMO converters with Recycled Power Multiplexed Control (RPMC) are introduced as a low-cross-regulation solution for a wide range of loads.

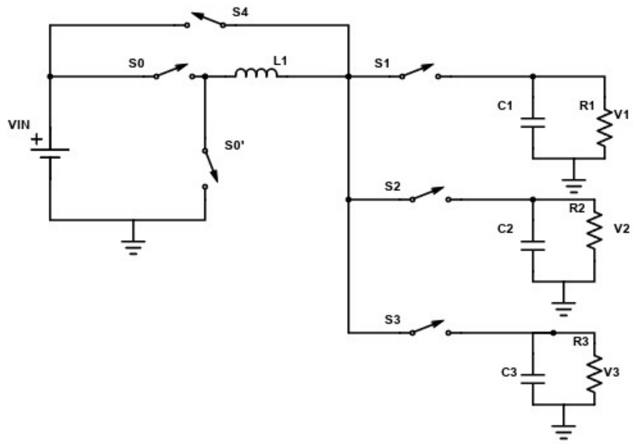


Fig. 1 Single inductor triple output converter (SITO)

The converter consists of three buck outputs V_1, V_2, and V_3 for the corresponding loads R_1, R_2 and R_3 respectively which is shown in the fig. 1

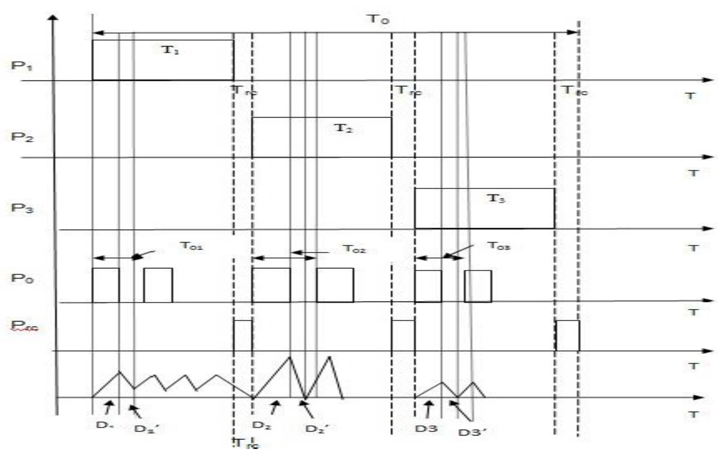


Fig. 2 Recycled power multiplexed control in DCM

In the proposed technique VIN is the battery voltage. The converter operates in two frequencies, with the input stage running at a greater frequency (f_s) than the output stage (f_0). Switches S_0, $S_{0'}$, S_4, and a power inductor L comprise the input stage. The output stage is made up of switches S_1, S_2, and S_3 that are connected to the output capacitors.

All of the converter's components are considered to be perfect, which means that all parasitic components, such as the inductor's DC resistance (DCR), the capacitor's equivalent series resistance (ESR), and the parasitic resistance and inductance of the PCB traces, are ignored. Over a switching cycle

$T_0=1/f_0$, the output switches S_1, S_2, and S_3 are turned on one at a time for a specific period T_1, T_2, and T_3, respectively. The timing diagram is shown in the fig 2.

$T_0 = T_1+T_2+T_3+3T_{rc}$

Where T_1, T_2, and T_3 are the on-time switching period of switches S_1, S_2, and S_3, respectively. T_{rc} is the recycling time that totally de-energizes and recycles the inductor energy back to the input via the S_4 switch, which has found applications in mobile phones. At the start of each switching cycle of the output switches, the surplus inductor energy is totally de-energized to zero. It is vital to note that the input and output side switches must be synchronized at the start of each switching period. D_1 is the duty cycle of the switch S_0 when S_1 is turned on, D_2 is the duty cycle of the switch S_0 when S_2 is turned on, and D_3 is the duty cycle of the switch S_0 when S_3 is turned on. All the outputs can operate in different frequencies and wide range of loads.

Modes of Operation

The different modes of operation of the SITO converter using recycled multiplexed control are explained as follows and are shown in the fig 3.

Mode 1

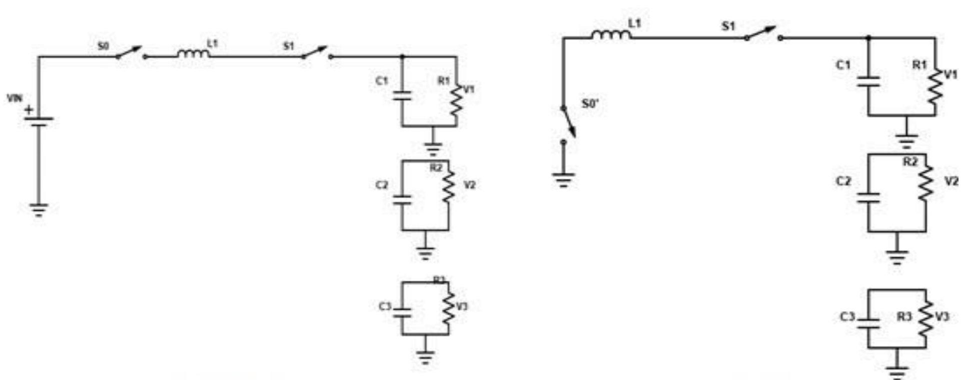
During this mode, switch S_1 and S_0 are turned on and the remaining switches have been deactivated. The inductor is energized and provides the output voltage V1. In the meantime, the output capacitors C2 and C3 supply energy to the load two and three respectively. The inductor current is given by,

$$\frac{di_L}{dt} = \frac{V_{IN}-V_1}{L}$$

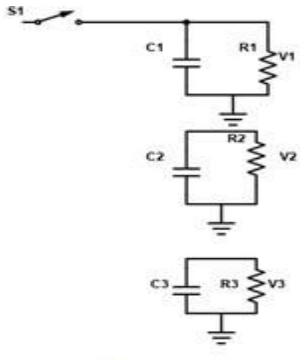
Mode 2

In this mode, $S_{0'}$ is switched on and S_1 continues to be turned on and the stored inductor energy is given to the first load. The remaining switches have been deactivated. In the meantime, the output capacitors C2 and C3 supply energy to the load two and three respectively. The inductor current is given by

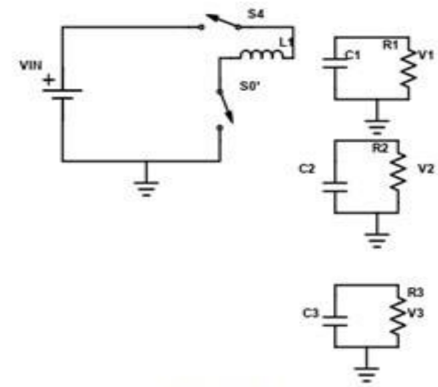
$$\frac{di_L}{dt} = \frac{-V_1}{L}$$



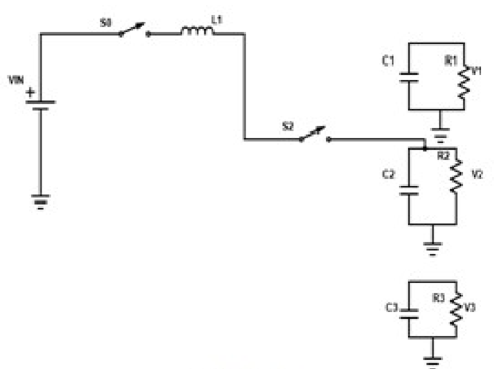
Mode 1 Mode 2



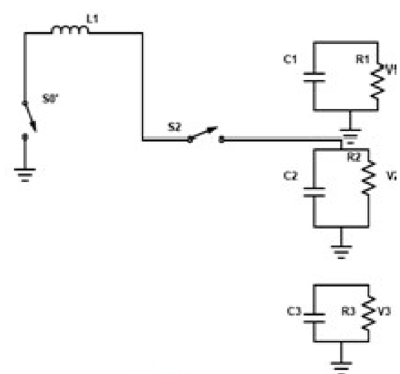
Mode 3



Mode 4



Mode 5



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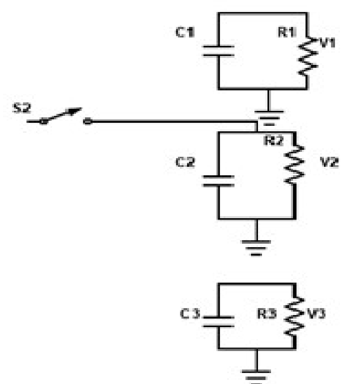
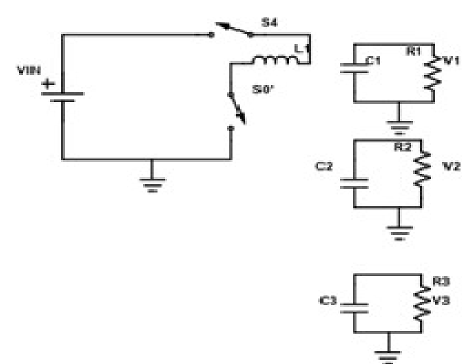
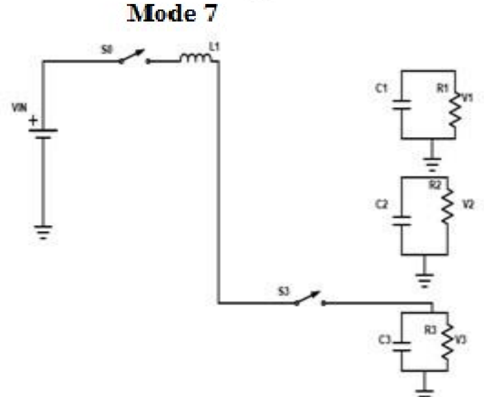


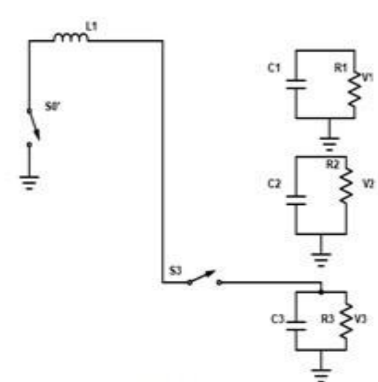
Mode 7



Mode 8



Mode 9



Mode 10

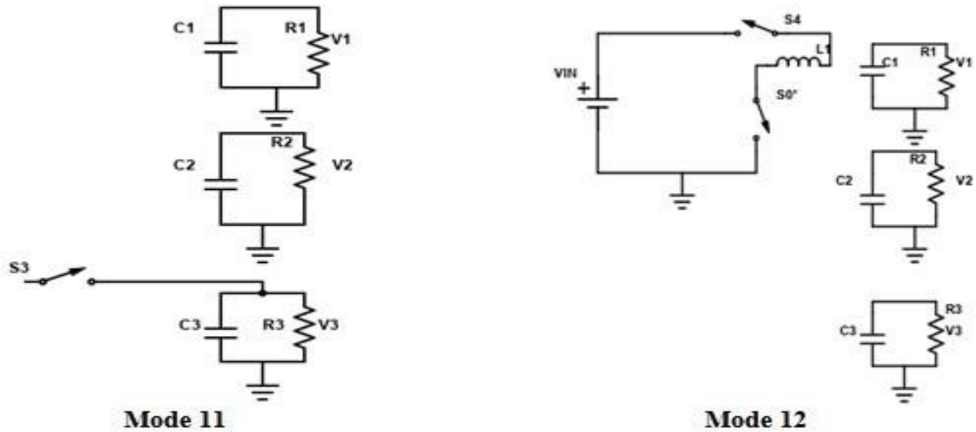


Fig. 3 Modes of operation of SITO converter

Mode 3

During this mode, S1 continues to be turned on and the switch $S_{0'}$, S_0, S_2, S_4, and S_3 are turned off. The inductor de-energizes the stored energy to load one .In the meantime, the output capacitor C2 and C3 supplies energy to the load two and three respectively .

Mode 4

In this mode, the switch S_0, S_1, S_2, and S_3 are tuned off. S_4, S_0' are turned on. The inductor recycles the excess stored energy to load one. The inductor current value remains at zero. The output capacitor C1 supplies energy to the load one while the output capacitor C2 supplies energy to the load two and output capacitor C3 supplies to load three. The inductor current is given by

$$\frac{di_L}{dt} = \frac{V_L - V_{IN}}{L}$$

Where VL is the voltage across the inductor. The modes 5 and mode 9, mode 6 and mode 10, mode 7 and mode 11, mode 8 and mode 12, continue to operate as modes 1, mode 2, mode 3, and mode 4 respectively for the other outputs 2 and 3. The inductor energy is completely discharged before the beginning of each switching period of the switches. The control signal is obtained by taking the duty cycle of the buck outputs and compared with the reference duty cycle signal.

Results and discussion

The duty cycle of the outputs are taken and compared with the reference value and the duty cycles D_1, D_2, and D_3. The duty cycles of the SITO converter are compared with the reference values and given to the PI controller and is produced to PWM block and the duty cycles are obtained and is given to the SITO converter which is shown in the fig. 4.

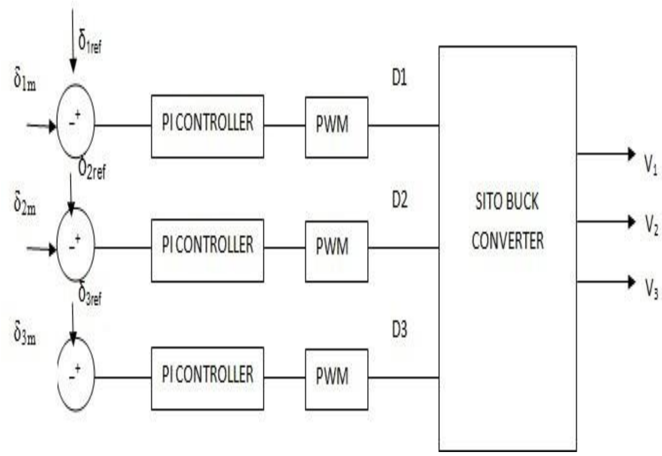


Fig. 3 Closed loop control of SITO converter

In tab. 1, the table parameters are taken from the datasheet [14] which is used for military applications. The input voltage is given as VIN = 270 V and the value of the inductor is given by L1=350mH. The SIMO converter parameters are tested in MATLAB and the preliminary results are obtained for the above-mentioned table parameters. The duty cycle of the output one is compared with the reference value and D_1 is obtained.

Tab. 1 SITO converter in military application

Parameters	Output 1	Output 2	Output 3
Voltage	3.3V	5V	28V
Current	210 A	285A	8.93A
Power	693 W	1425W	250W
Resistance	0.0157Ω	0.017 Ω	3.13 Ω
Capacitance	186mF	253mF	476µF

The fig.5 shows the voltage V1=3.3V and current = 210A

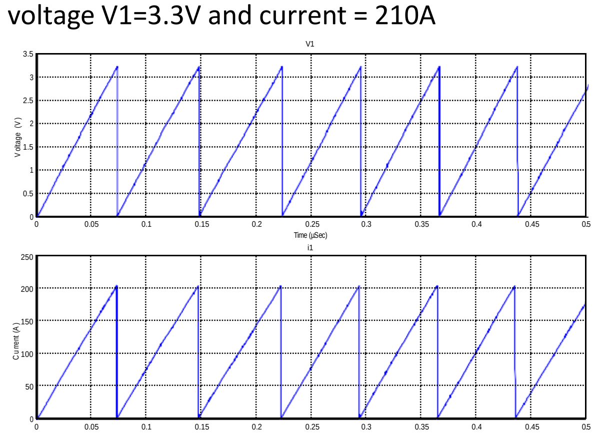


Fig. 4 Voltage and current of output 1

The duty cycle of output two is compared with the reference value and D_2 is obtained. The Fig. 6 shows the voltage V1=5V and current = 285A.

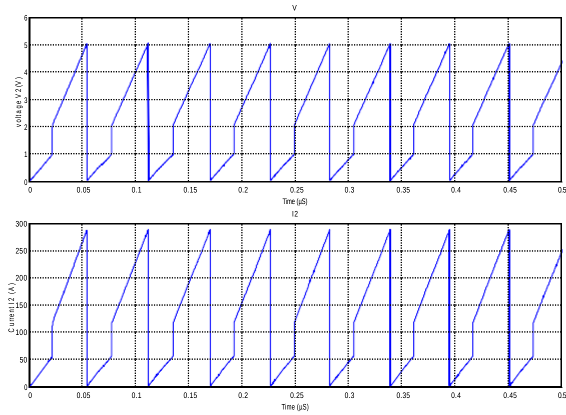


Fig. 5 Voltage and current of output 2

The duty cycle of output two is compared with the reference value and D_3 is obtained. The fig. 7 shows the voltage V1=28V and current = 8.93A. The graph shows the outputs are less cross regulated.

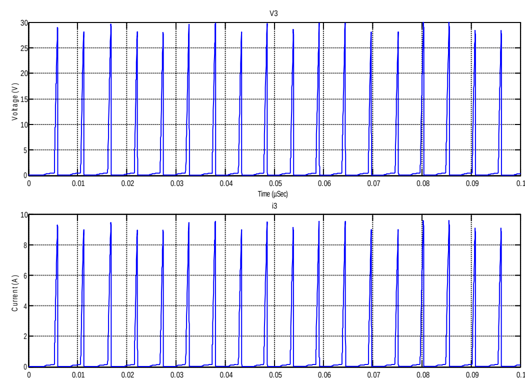


Fig. 6 Voltage and current of output 3

The graph is drawn between efficiency and duty cycle. The fig. 8 shows the efficiency of the SIMO converter using recycled multiplexed control is 95% for wide range of loads.

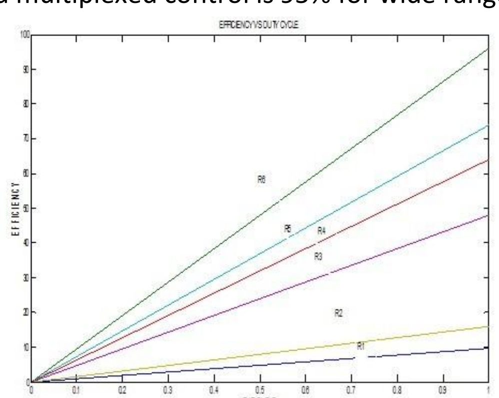


Fig. 7 Efficiency VS Duty cycle for wide range of loads

Conclusions

We have presented a SITO buck DC-DC switching converter that uses recycled power multiplexed control in DCM operation. This converter using RPMC operates in both CCM and DCM. This control scheme efficiently shares the inductor energy between the outputs and also the excess inductor energy is recycled back to input so that the input battery gets charged which is used in military applications. The cross regulation is reduced and the efficiency is 95%. The converter can be used for wider range of loads. The measurement results validate the SITO converter's recycled power multiplexed control scheme.

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