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Dual Output S-Hybrid Step Down DC-DC Converter

Beena M Varghese[1], Anu George[2], Neena Mani[3], Elsa Susan Jacob[4]

Professor, Dept. of EEE, Mar Athanasius College of Engineering, Kothamangalam,Kerala, India[123]

PG Student(PE), Dept. of EEE, Mar Athanasius College of Engineering, Kothamangalam,Kerala, India[4]

ABSTRACT: Smartphones have become widely accepted, and so their system complexity has also steadily increased to meet more functionalities within the limited space. In this situation, a DC-DC step-down converter architecture that allows a power cable, such as USB cable, to deliver both power transmission and power conversion functions. In this architecture, a Dual Output S-Hybrid converter topology is proposed to better utilize the parasitic inductance of the USB cable and thus avoid an additional need of an inductor for power conversion and transmission. Here the cable is used instead of an inductor. The circuit structure is very simple with many advantages such as reduced output voltage ripple, reduced inductor current ripple, high efficiency with two outputs and reduced switching stress. The major application of dual output converter topology is battery charging as well as in low power applications. The performance study of the converter is carried out with MATLAB/SIMULINK R2017a. From the simulation it is observed the efficiency is 84.86%from the simple circuit structure with less inductance.

KEYWORDS: Step-down DC-DC Converter, Inductor-less power converter, S-Hybrid converter, Smart power cable.

I.INTRODUCTION

Nowadays mobile devices such as smartphonesand tablet computers have been worldwide and so their system complexityis increasing progressivelyto get more functionalities within limitedspace and structure.There is a great need for more efficient integrated regulatorsthat charge the mobile battery and supply power to a variety of processorswith high efficiency[1]. Low dropout (LDO) regulator had beenconventionally used in mobilebattery chargercircuits, but it is notacceptable for long dueto theirpoor efficiency and there emerges thermal issue when the desirablepower/current capacity for battery chargers increases[2]. For efficient power conversion, switched mode power supplies including Switched Inductor(SI) and Switched Capacitor (SC) converters have been effectively put together inorder to replace LDOs. The inductor-based converter features fine regulation and high efficiency across a wide range of input and load variations since chargetransfer is in the form of current. But the dependency on the inductor in this converter results in comparatively massive structure, which is undesirable for miniaturization and integration in a compact device, because of high implementation cost and performance degradation[1]. Most of the power electronic components such as power switches and capacitors can be easily merged than inductors. As an alternative to the SI converters, SC converters utilizing capacitors for power conversion show better integration because no bulky inductor is involved and on-chip capacitors are readily available.

A USB cable commonly used for connecting a mobile device to an adapter or to a computer may have significant value of inductance ranging from hundreds of nano Henries to severalmicro Henries, depending on its length, material and manufacturer. This parasitic inductance of the cable is usually ignored by adding decoupling capacitors at its ends. Since inductance is needed for power conversion in the converter, this parasitic inductance can be utilized. A hybrid structures combining inductor (parasitic inductance) and capacitor is proposed to overcome the drawbacks and to exploit advantages from both SI and SC converters.This paper presents a new dual output hybrid converter architecture that eliminates dedicated inductor in the circuit by utilizing parasitic inductance available in the system[1],[3]. It can be applied to power delivery in a wide range of systems.A new converter named Dual Output Smart-Hybrid (S-Hybrid) and power delivery architecture are proposed to allow utilization of parasitic inductance on input USB cable for power conversion and transmission.

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II.DUAL OUTPUT S-HYBRID CONVERTER

A Dual Output S-Hybrid Converter consists of three switches S_1,$S_2$and S_3, three capacitors C_1, C_2, and C_3, two inductors $L_1$and L_2, and two load resistors $R_1$and R_2.In series with the inductors, the network of switches S_{1-3} and capacitors $C_{1,2,3}$ is operated to switch the input voltage to control the output, similar to inductor-based converter and to transfer and balance the charge from C_1 toC_2andC_3, similar to an SC converter. Fig 1 shows the circuit arrangement of dual output S-Hybrid converter.

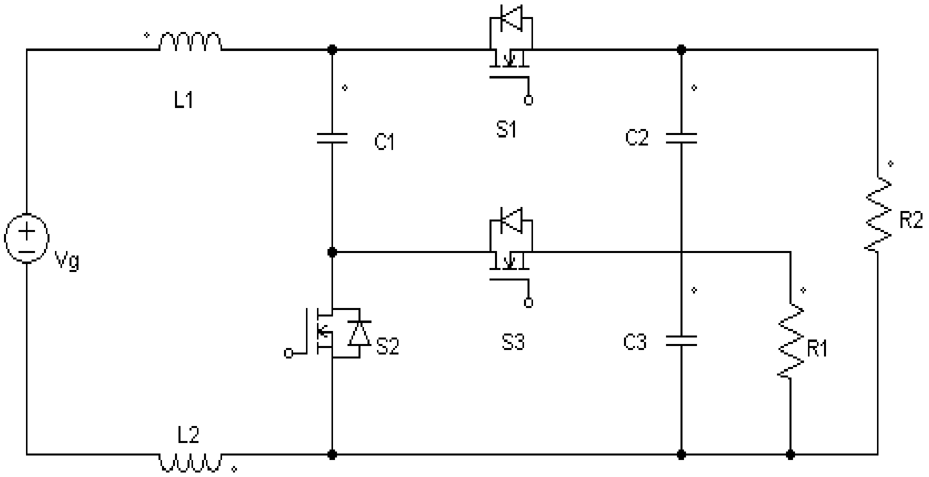

Fig 1. Dual Output S-Hybrid Step-Down DC-DC Converter

III.MODES OF OPERATION

For simplicity in the following analysis, we assume ideal switches S_{1-3} and small ripple approximation for the inductor current and capacitor voltages.

A. MODE 1 OPERATION

Mode 1 Operation starts when $S_1$and $S_2$are turned on, thus shorting C_1 to $C_2$and C_3. L_1 and L_2start to be charged along with the two capacitors $C_2$and C_3.During mode 1, $C_1$is discharging and the capacitor supply the output together with the inductor current. Fig 2 shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

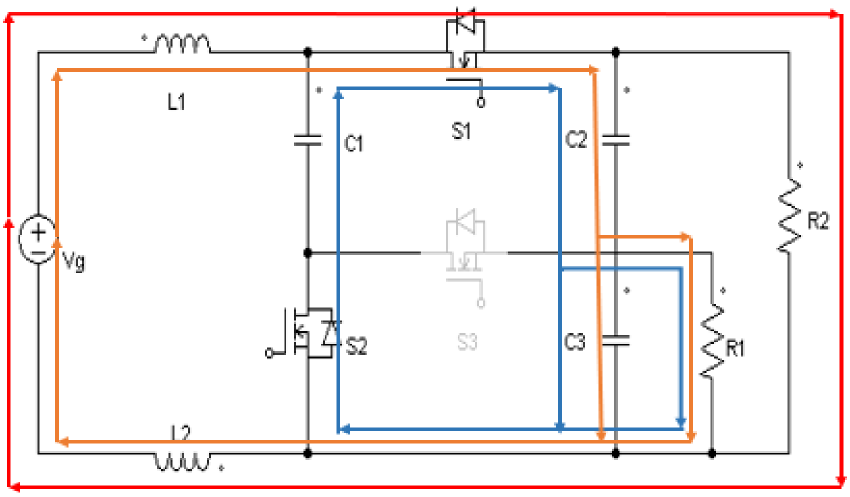

Fig 2. Operating circuit of Mode 1

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B. MODE 2 OPERATION

In mode 2, $S_1$and $S_2$are turned off while $S_3$is turned on, thus making a series connection of capacitor $C_1$with the input supply. Capacitor C_1 charges and the load is supported by the capacitors $C_2$and C_3during this mode and the charge from the inductor current that also charges C_1in series. Fig 3 shows the equivalent circuit diagram of the converter andcurrent paths for this mode.

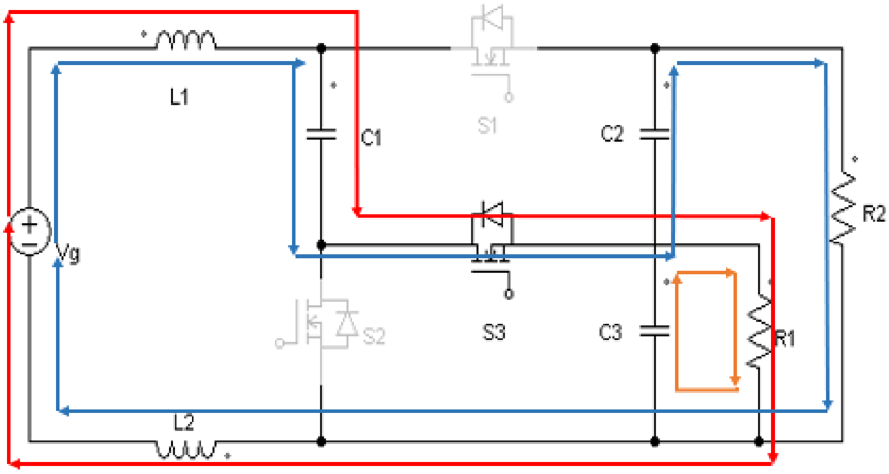

Fig 2. Operating circuit of Mode 2

Fig 4 shows the theoretical waveforms of the converter.

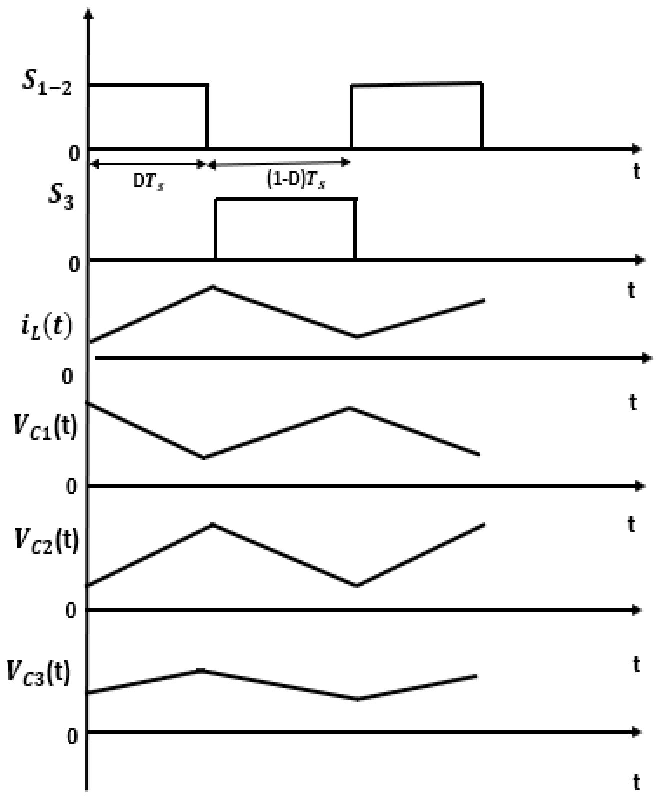

Fig 4. Theoretical waveform of proposed converter

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IV.DESIGN CONSIDERATIONS

The input voltage $V_{in}$is taken as 5V. The pulses are switched at the rate of 2 MHz. The output power is taken as 15W.

$$\text{Conversion ratio,}M=\frac{V_o}{V_{in}} = \frac{1}{2-D} \quad (1)$$

where D is the duty ratio of switch$S_1$and S_2.In this configuration, M ranges from 0.5 to 1.Take D = 48%.

A. LOAD

Taking P_o as 15 W and output voltage as 3.8 V, load resistance is calculated.

$$R_o = \frac{{V_o}^2}{P_o} = \frac{3.8^2}{15} = 0.96\Omega \quad (2)$$

B. INDUCTOR REQUIREMENT

Here, USB cable parasitic inductance is utilised and 1-m input USB cable has 278 nH parasitic inductance. The value of inductor is set as L_1 and L_2 = 278 nH.

C. CAPACITOR DESIGN

Capacitor design are considered inorder to identifythe optimal capacitance ratioC_3/C_1 to minimize the switched capacitor loss and to determine the capacitance values to meet the system requirements such as output voltage ripple and space limit.

$$\text{Capacitance ratio,}K_C = \frac{C_2}{C_1} \text{ or } \frac{C_3}{C_1} \quad (3)$$

Optimum Capacitance ratio, K_{Copt} is always smaller than 1.Therefore,

$$C_2 < C_1 \quad (4)$$

Usually, K_{Copt} = 0.5

$$C_2 = C_3 = 0.5C_1 \quad (5)$$

In this analysis, duty ratio D, switching frequency f_s, maximum output current I_0 to be 0.48, 2MHz and3.94A,respectively, with V_{in} = 5V and V_o = 3.3V. The output voltage ripple is taken as 0.28% of output voltage.The total capacitance C_{total} threshold is defined when,$K_C$becomes K_{Copt},

$$C_{total} = \frac{(I_o - I_L)*T_S}{\Delta v_o} * \left\{ D + \frac{(1-D)*(1+K_{Copt})}{K_{Copt}} \right\} \quad (6)$$
$$= 39.8\mu F$$

C_1 = 26.6 μF, $C_2 = C_3$ = 13.2μF (7)

V.SIMULATION AND RESULTS

The simulation of the converter is done using MATLAB/SIMULINK 2017a and thesimulink model is shown below in Fig 5 and analysis are done.

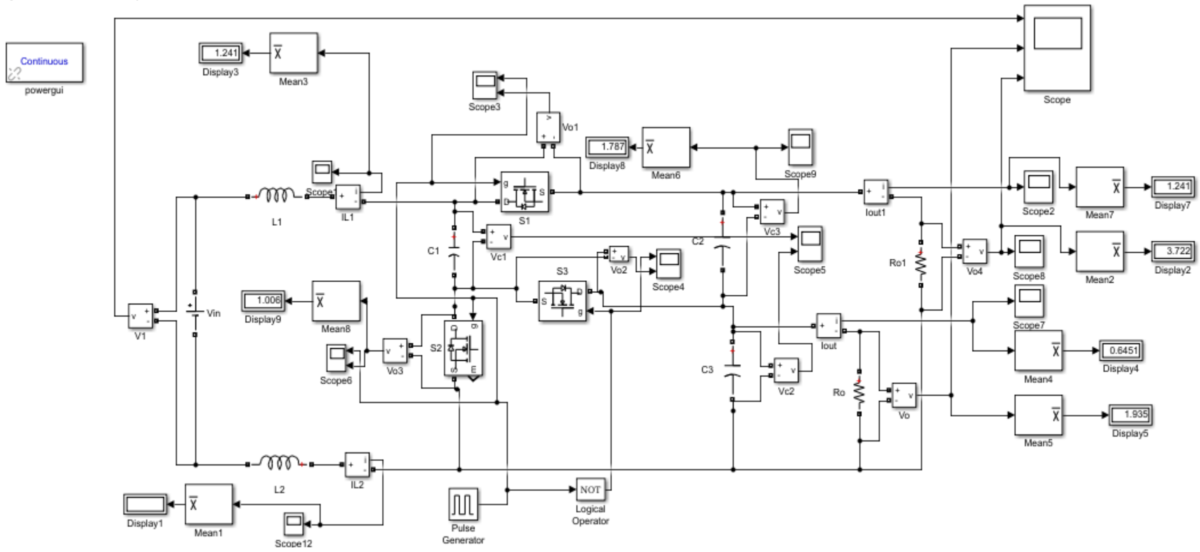

Fig 5. Simulink Model of Dual Output S-Hybrid Converter

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Simulation parameters for the Dual Output S-Hybrid Converter is given in Table 1.An input voltage V_{in} of 5 V gives an output voltage $V_o$of 3.3 V - 3.8 V for an outputpower P_o of 15W.

Table.1Simulation Parameter

Parameters	Specification
Input Voltage (V_{in})	5V
Output Voltage (V_o)	3.3V-3.8V
Switching Frequency (f_s)	2 MHz
Output Load Resistance (R_L)	0.96Ω
Inductors (L_1 , L_2)	278nH
Capacitor C_1	26.6 µF
Capacitors (C_2, C_3)	13.3 µF

A. CONTROL STRATEGY

The switches are MOSFET/ Diode withconstant switching frequency of 2MHz. The duty cycle of switches $S_1$and S_2 is taken as D=0.48.

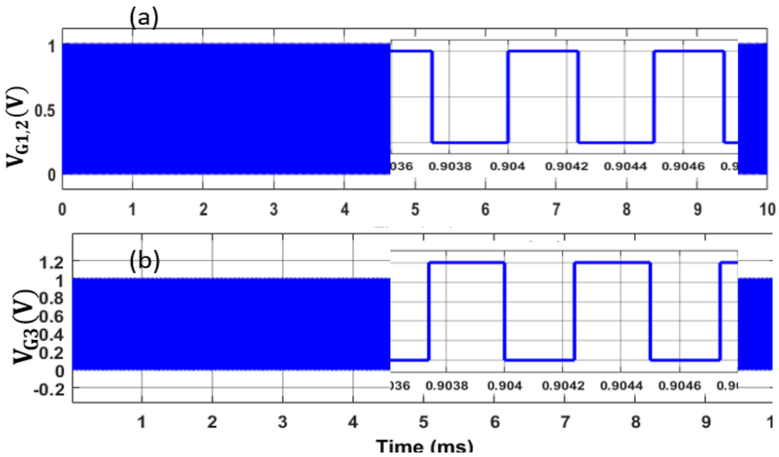

Fig 5. (a) $S_{1,2}$ Gate Pulse (b) S_3Gate Pulse

B. SIMULATION RESULTS

The simulation results of the Dual output S-Hybrid Step-Down DC-DC Converter are shown in the following figures.

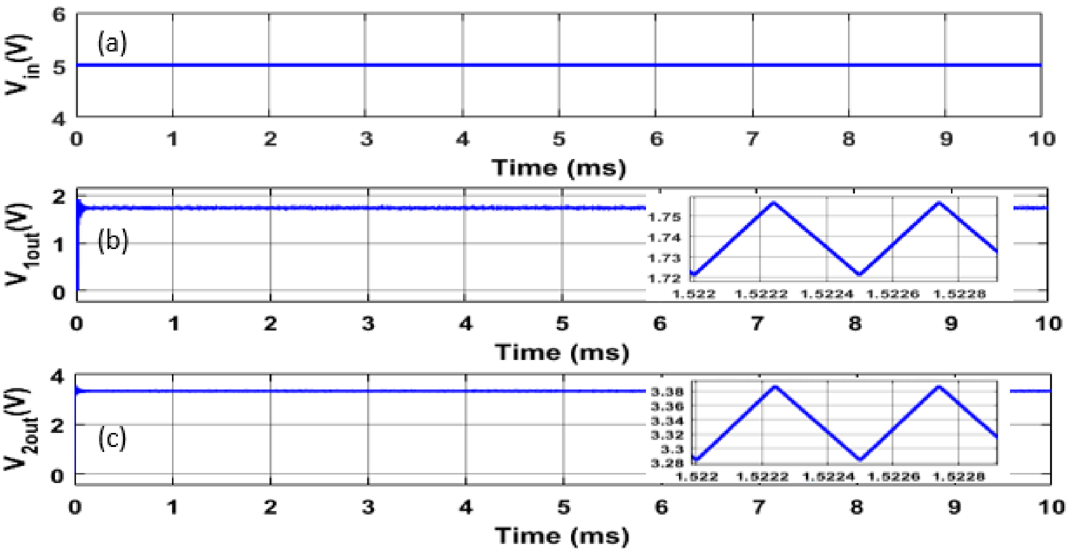

Fig 6. (a) Input Voltage (b)Output Voltages V_1, (c)V_2

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It can be seen that the input voltage $V_{in}$is 5V. The switching frequency is chosen to be 2MHz and the duty ratios of $S_1$and S_2 is equal to 0.48. Fig 6 shows output voltages are 1.74V with a voltage ripple of 0.035V and 3.336V with a voltage ripple of 0.104V.

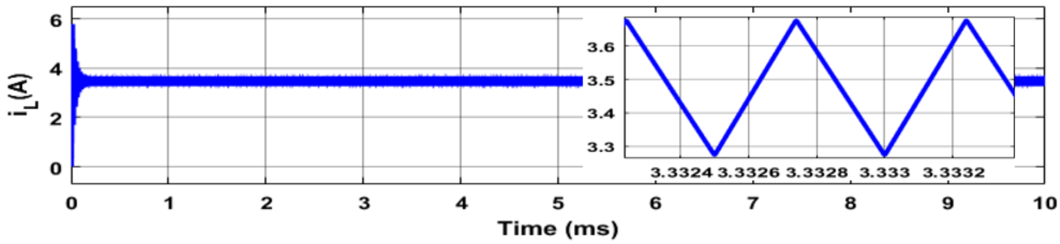

Fig 7. Inductor Current, i_L

An inductor current of 3.475A with a current ripple of 0.405A is obtained as shown in the above Fig 7. Following Fig 8 shows output currents of the converter having a magnitude of 1.812A with a current ripple of 0.037A and 3.475A with a current ripple of 0.108A.

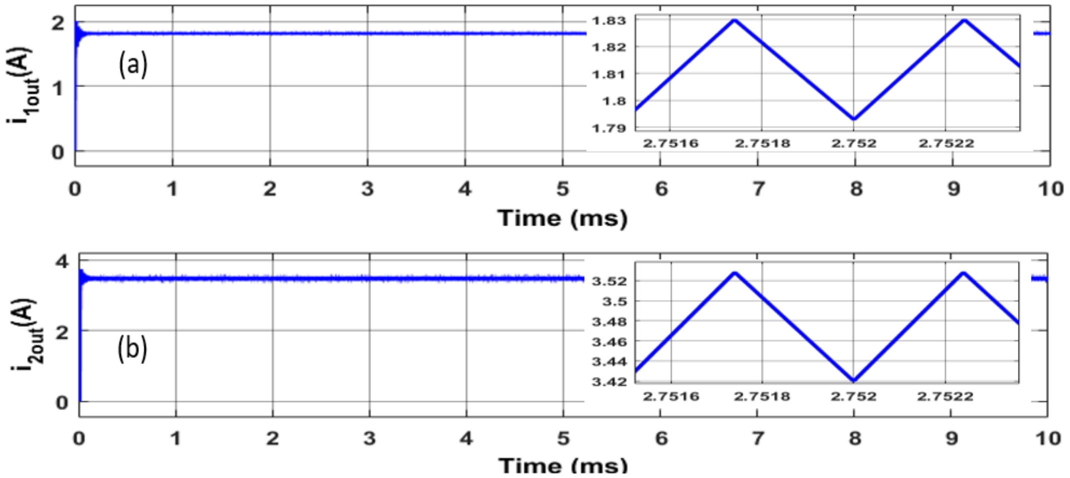

Fig 8. Output Currents (a)i_{1out} (b) i_{2out}

The capacitor voltages V_{C1}, V_{C2}, $V_{C3}$are 4.096V, 1.59V, 1.74V with capacitive voltage ripple of 0.032V, 0.07V, 0.036V respectively are shown below Fig 9.

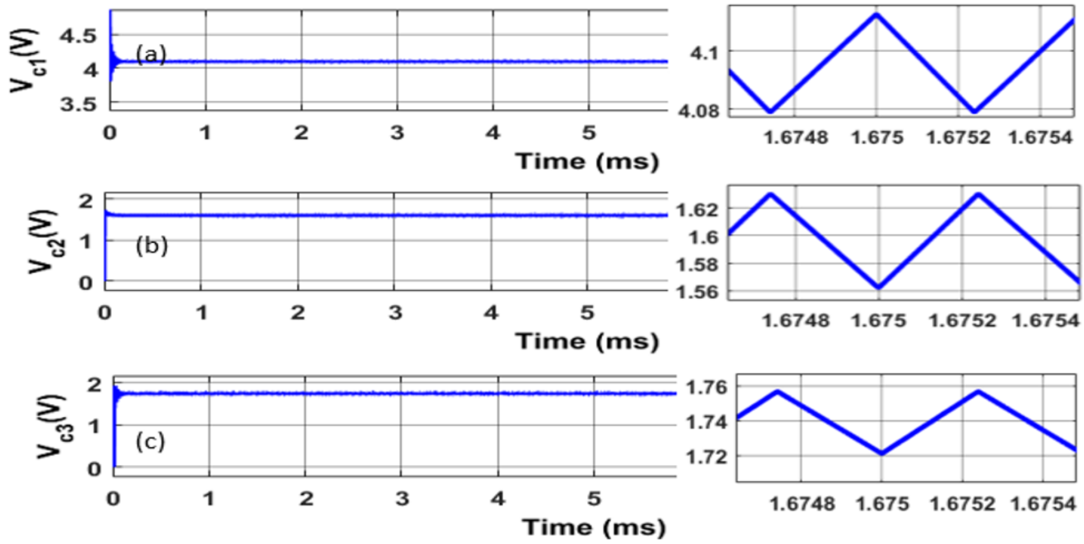

Fig 9. Capacitor voltages V_{C1}, V_{C2}, V_{C3}

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The switching stress has been reduced considerably to 2V and 1.8V for the switches $S_1$and $S_{2,3}$, respectively, from Fig 10.

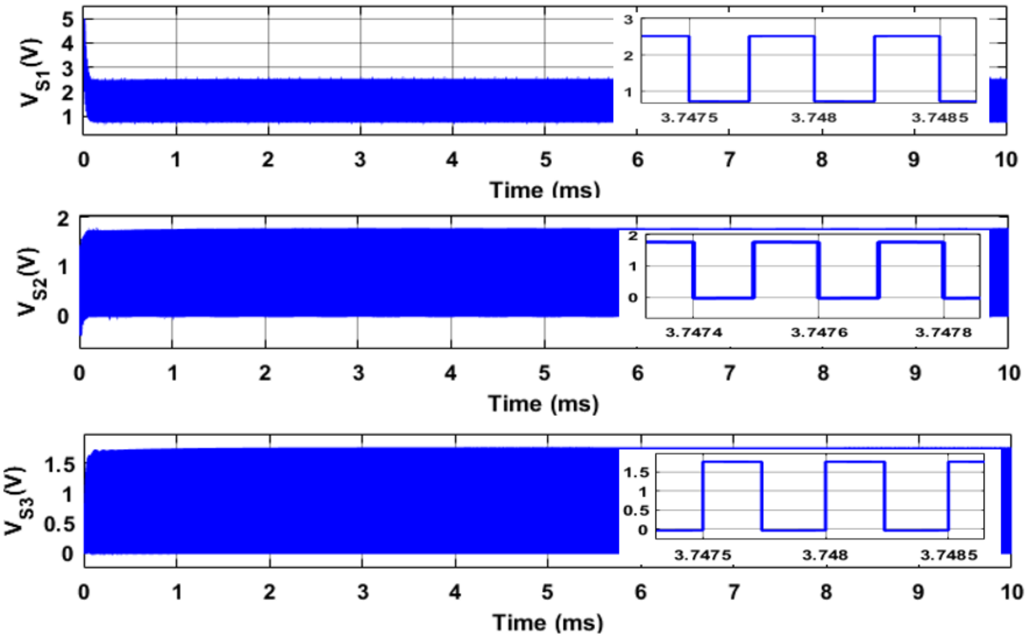

Fig 10. Voltage Stress across switches

VI. ANALYSIS

The analysis of Dual output S-Hybrid Step Down DC-DC converter is carried out by considering parameters like efficiency,duty ratio, output voltage ripple and switching frequency.

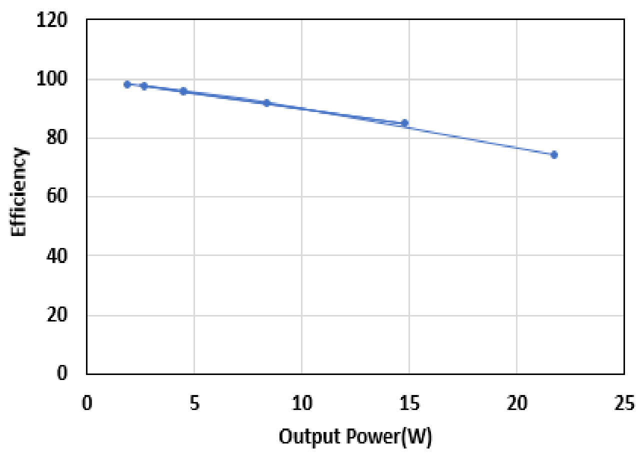

Fig 11.Efficiency Vs Output Power

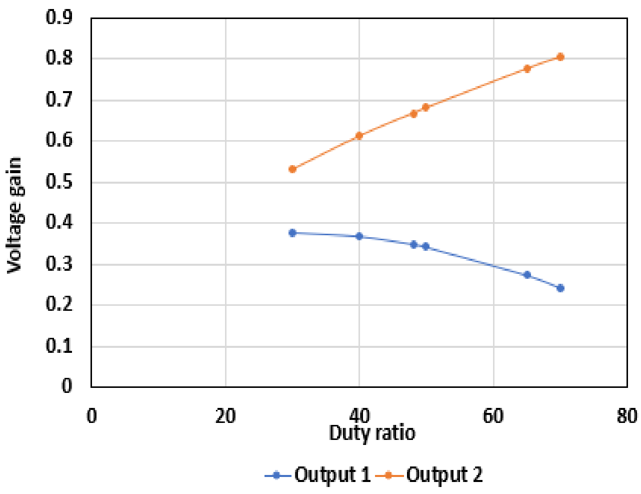

Fig 12. Conversion ratio Vs Duty ratio

From the analysis of efficiency Vs output power in Fig 11, it is seen that the converter is well applicable in low voltage, low power applications. Fig 12 shows the variation of conversion ratio with duty ratio. Conversion ratio is improved better for output 1 since it is a buck converter. With increasing duty ratio, input current also increases, so choosing a duty ratio of 40-50%.

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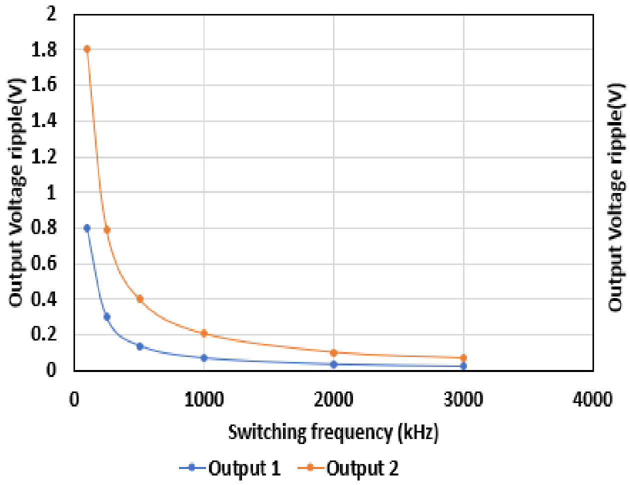


Fig .13 Output Voltage Ripple Vs Switching Frequency

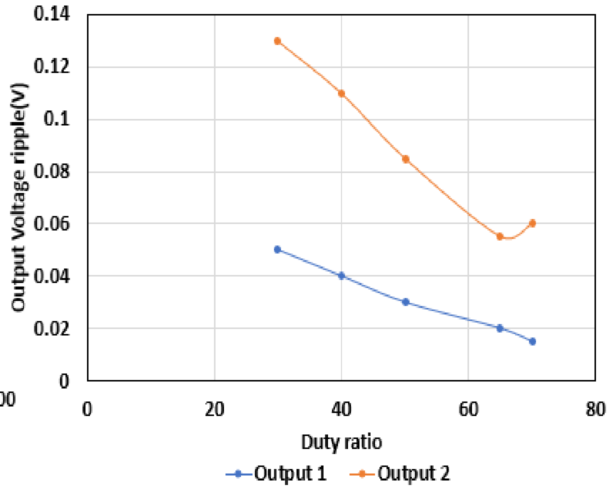


Fig .14 Output Voltage Ripple Vs Duty ratio

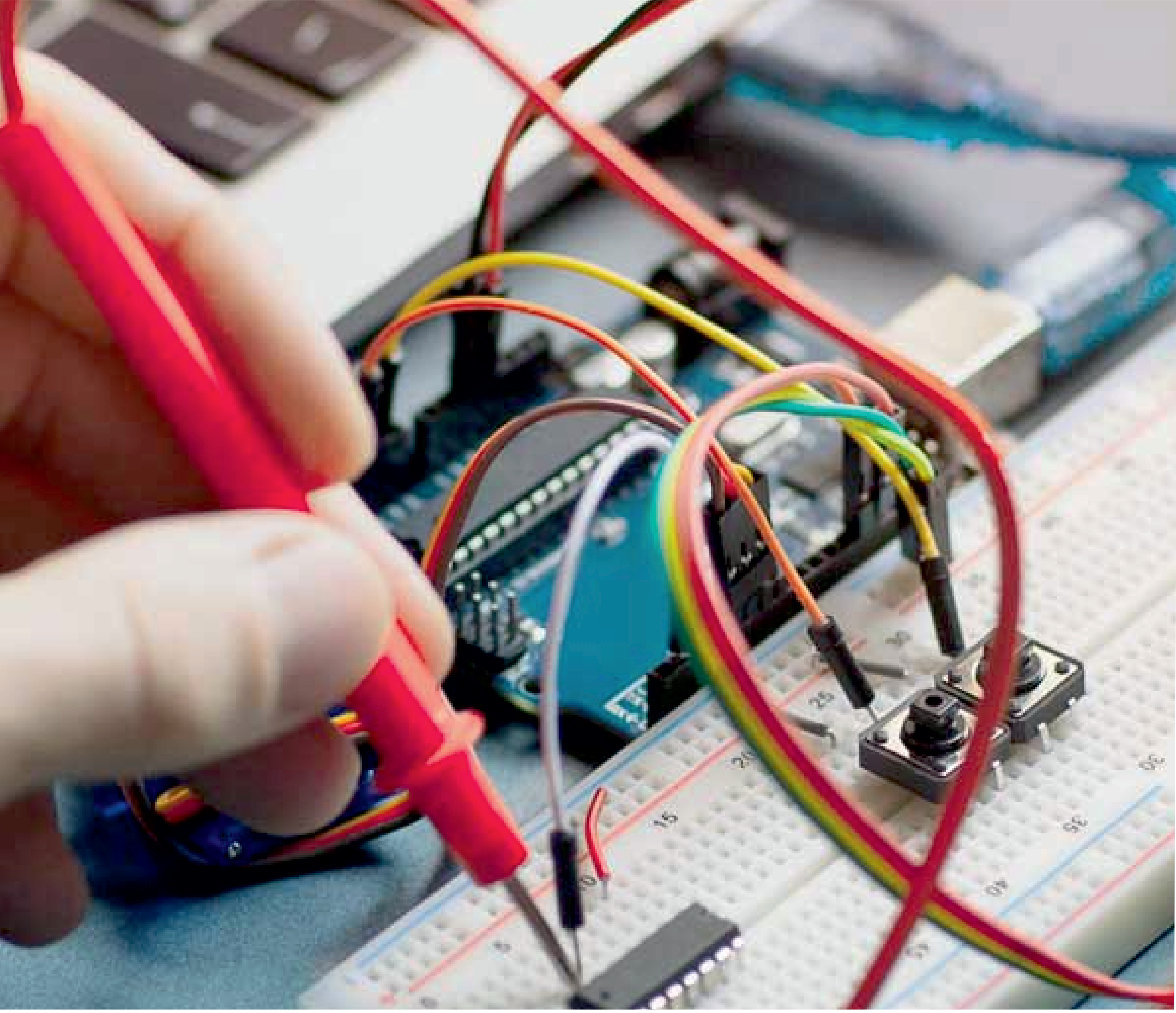
The output voltage ripple decreases with increase in switching frequency. Lower voltage ripple is obtained at 2MHz or 3MHz as shown in Fig 13. Output voltage ripple decreases for higher values of duty ratio but input current increases for higher D, so choosing high values of duty ratio is inappropriate depicted from Fig.14.

VII.CONCLUSION

The Dual Output S-Hybrid Step-Down DC-DC converter offers an improved voltage conversion ratio, low inductor current ripple and output voltage ripple. The input voltage is 5 V and output voltages are 1.74V and 3.336V. The converter has an efficiency of 84.86% and voltage gain of 0.348 and 0.6672. The dual output S-Hybrid step-down architecture that employs parasitic inductance of a power delivery USB cable features no additional inductor in the circuit which is a significant advantage for better future integration. S-Hybrid architecture is indeed a promising candidate to realize future smart power cables that can provide both power transmission and power conversion in a wide range of applications.

REFERENCES

[1] G. Seo and H. Le, "S-Hybrid Step-Down DC–DC Converter—Analysis of Operation and Design Considerations," in IEEE Transactions on Industrial Electronics, vol. 67, no. 1, pp. 265-275, Jan. 2020.
[2] G. S. Seo and H. P. Le, "Small-signal analysis of S-hybrid step-downDC-DC converter," in Proc. IEEE Workshop on Control and Modelingfor Power Electronics (COMPEL), 2017, pp. 1-6.
[3] G. S. Seo and H.-P. Le, "An inductor-less hybrid step-down DC-DCconverter architecture for future smart power cable," in Proc. IEEEAppl. Power Electron. Conf. Expo., 2017, pp. 247-253. “Route and spectrum selection in dynamic spectrum networks,” in Proc. IEEE CCNC 2006, pp. 625-629, Feb. 2006.
[4] X. Ruan, B. Li, Q. Chen, S.-C. Tan, and C. K. Tse, "Fundamental considerations of three-level dc–dc converters: Topologies, analyses,and control," IEEE Trans. Circuits Syst. I, vol. 55, no. 11, pp. 3733-3743, Dec. 2008.
[5] R. Beiranvand, "Regulating the output voltage of the resonant switchedcapacitorconverters below their resonant frequencies," IEEE Trans. Ind.Electron., vol. 64, no. 7, pp. 5236-5249, Jul. 2017.
[6] P. S. Shenoy, M. Amaro, J. Morroni, and D. Freeman, "Comparison of abuck converter and a series capacitor Buck converter for high-frequency,high-conversion-ratio voltage regulators," IEEE Trans. Power Electron.,vol. 31, no. 10, pp. 7006-7015, Oct. 2016.
[7] G.-S. Seo, R. Das, and H.-P. Le, "A 95\%\-Efficient 48V-to-1V/10AVRM Hybrid Converter Using Interleaved Dual Inductors," in Proc.IEEE Energy Conversion Congress and Expo., 2018, pp. 3825-3830:IEEE.
[8] G. S. Seo and H.-P. Le, "An inductor-less hybrid step-down DC-DCconverter architecture for future smart power cable," in Proc. IEEEAppl. Power Electron. Conf. Expo., 2017, pp. 247-253.
[9] H.-P. Le, S. R. Sanders, and E. Alon, "Design techniques for fullyintegrated switched-capacitor DC-DC converters," IEEE J. Solid-StateCircuits, vol. 46, no. 9, pp. 2120-2131, Sep. 2011.
[10] R. W. Erickson and D. Maksimovic, Fundamentals of power electronics.Norwell, MA: Kluwer Academic Publishers, 2001, pp. 331-347. P. K. Visscher, “How Self-Organization Evolves,” Nature, vol. 421, pp. 799–800 Feb.2003.



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