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Comparative Study of The Performance for Some Power DC-DC Converters; Design and Implementation

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A B S T R A C T

The present study focuses on the performance analysis of the basic (boost) and advanced (SEPIC) power DC-DC converters operating in the discontinuous conduction mode (DCM). Parameters such as switching signal frequency (fs), duty cycle (D), and DC input voltage (Vin) are investigated to study their influence on the output voltage (Vo) of the converters. Results show that the SEPIC converter is more efficient than the Boost converter with higher output voltage values obtained at different Vin levels. Where, the obtained output voltage values were 5.5 V and 5.6 V at Vin of 1.5 V, which mean that the increasing ratio of the output voltage of SPEIC over Boost converter was about 18.2 %. Similarly, its value was reported to be, 42.2 V and 48.6 V, measured at Vin of 10 V, causing the increasing ratio of SEPIC converter to be about 15.16 % relative to Boost converter. Concerning the dependence of their output voltage on the switching duty cycle, it was noticed that, the increasing ratio of the output voltage of SEPIC over Boost converter ranges from 19.3 % to 30.8 % depending on the duty cycle. The effective operating bandwidth (BW) of the output voltage is wider for the SEPIC converter compared to the Boost converter. The switching frequency has an effect on the output voltage of the converter, with the SEPIC converter showing a wider operating bandwidth compared to the Boost converter (8 kHz).

1. Introduction

The switching mode DC/DC converters can be realized by different circuit topologies. The Boost and SEPIC converters are the mostly used depends on the requirements for power conversion system [1, 11]. It has become popular in recent years that step up or down DC-DC converters are useful in applications where the battery voltage can be above or below the regulator output voltage like powered vehicles, photovoltaic systems, continuous power supplies, and fuel cell systems [7,10,16]. Mobile charging and utilizing the power generated from solar and wind power plants and electrical power systems in vehicles, in which battery power systems often stack cells in series to achieve higher voltage. The converter must be able to operate as step up or down in order to continue supplying the constant load voltage over the entire battery voltage range. In these converters, SEPIC converters which have the advantages of high-voltage transfer

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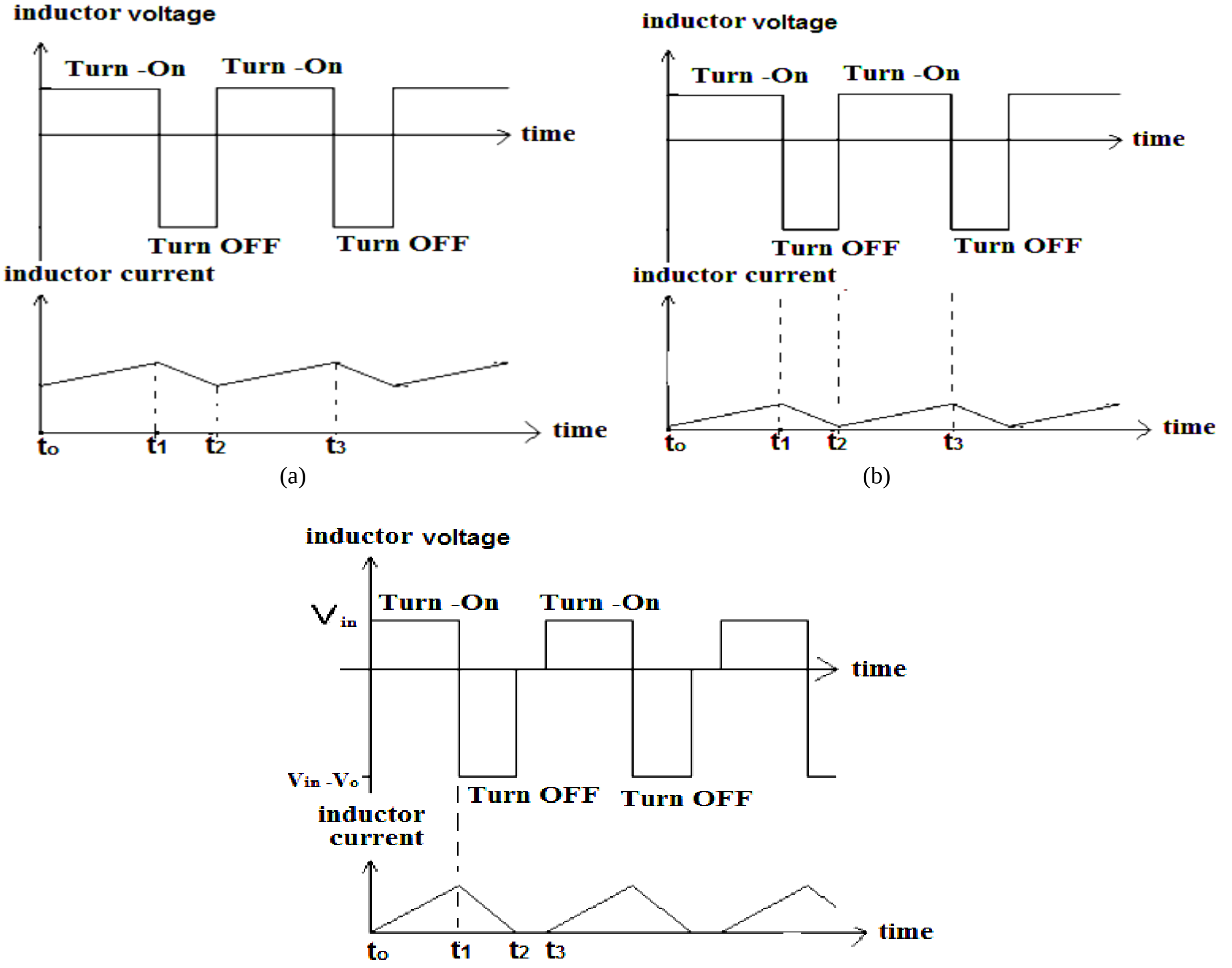
gain, high power density and high efficiency, as well reduced ripple voltage and current. These converters are most widely used in computer peripheral equipment, industrial applications and switched mode power supply [2,4-6]. Generally, the switching mode DC-DC converter circuits are used to convert the unregulated DC input voltage (V_{in}) into a controlled DC output voltage (V_o) at a desired value. They are mainly consisting of power active devices; power diodes and power switch (S), as well power passive components; power inductors (L), capacitors (C) and load resistance (R_L). During the operation of DC-DC converter circuits with a given V_{in}, the DC output voltage is controlled by controlling the switch ON and OFF durations. These types of circuits could be operating in three different modes namely; continuous conduction mode (CCM), discontinues conduction mode (DCM), as well the critical conduction mode (CrCM) depending on the switching duty cycle (D). The theoretical output waveforms of the inductor; voltage (V_L) and current (I_L) of the converter operating in CCM (Fig.1a), CrCM (Fig.1b), as well DCM (Fig.1c) is shown below. When a boost converter operates in CCM, I_L never falls to zero. While in DCM, I_L drops to zero during a part of the periodic cycle, where in some cases, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period [8,13-15,17]. In CrCM operation, sometimes referred to as boundary mode or transition mode operation, the inductor current is allowed to completely go to zero before the next switching cycle of the switch is initiated [3].

For the high-power applications such as hybrid electric vehicles and fuel cell power conversion systems, CCM is needed because it offers the lowest peak to average current ratio for the converter than CrCM and DCM, and it operates at a fixed switching frequency. While, CrCM and DCM are needed for lower power applications, because of the low cost and simplicity of the circuitry. Also, it turns out that the CrCM approach offers the same simplicity and low cost for power factor correctors in the kilowatt range and can additionally offer several performance advantages over the more conventional CCM typically used in this power range [12].



(c)

Fig. 1. Waveforms of the inductor voltage and current for the boost converter systems

The present study focuses on the performance analysis of 5/20 VDC boost (Fig.2) and advanced (SEPIC) power DC-DC converter (Fig.3) (V_{in}: 5 V, V_o: 20V) operating in the discontinuous conduction mode (DCM). Where, the practical life applications such as low voltage photovoltaic systems require highly efficient converters to deliver as much as possible energy to the load with high gain DC voltage conversion [16]. During the study, parameters such as switching signal frequency (f_s), duty cycle (D), and DC input voltage (V_{in}) are investigated to study their influence on the output voltage (V_o) of the converters.

1.1 DC-DC Boost Converter Circuit

During the study, the proposed DC-DC boost converter (Fig. 2) is constructed from the following: n-channel MOSFET type; IRF44N, fast recovery diode type; FR101, power inductor type; ELC18B331L with inductance (L) and an input / output capacitors electrolytic capacitor (Cin, Co), as well the load resistor (R_L). The theoretical output voltage [17] of the circuit in DCM could be determined applying Eq. (1).

$$V_o = 0.5\left[1 + \sqrt{1 + \frac{2\, R_L D^2}{f_s L}}\right] V_{in} \tag{1}$$

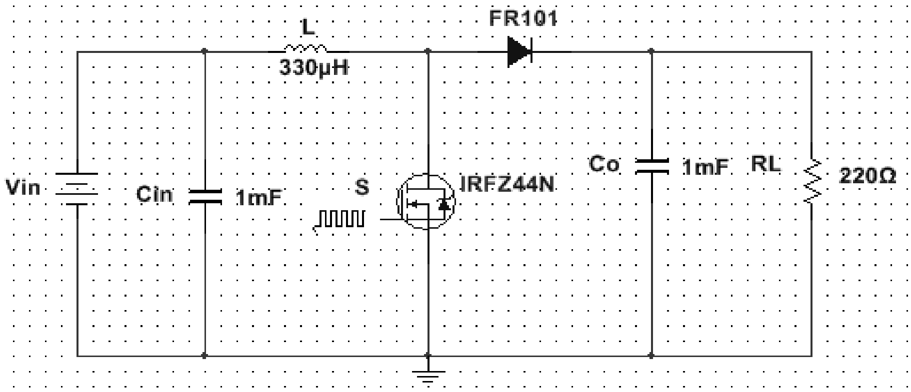


Fig. 2. Experimental set up of the boost converter circuit

1.2 DC-DC SEPIC Converter Circuit

Referring to the studied SEPIC circuit (Fig.3), it constructed from n-channel MOSFET switch type; IRF44N, fast recovery diode type; FR101, two power inductor (L_1 and L_2) type; ELC18B331L and three similar electrolytic capacitors; transfer, input, and output (C_s, C_{in}, C_o), as well the load resistor [1,9]. The theoretical output voltage of the circuit in DCM could be determined applying Eq. (2).

$$V_o = \frac{D\, V_{in}}{\sqrt{\frac{2\, L_1 L_2}{R_L (L_1 + L_2) \cdot T}}} \tag{2}$$

Where, T is the periodic time of the switching signal.

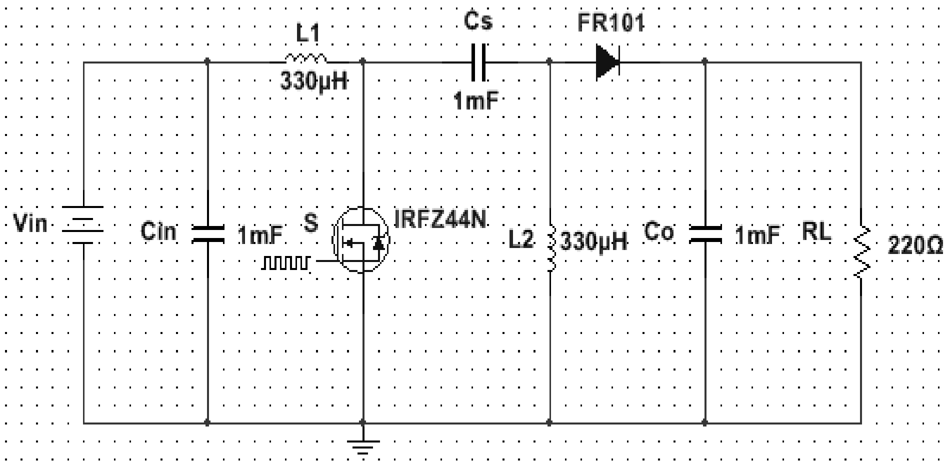


Fig. 3. Experimental setup of SEPIC converter circuit.

For the DC-DC converter circuits, the output voltage gain (G) is determined using Eq. (3) as [9]:

$$G = \frac{V_o}{V_{in}} \quad (3)$$

Moreover, the output power (P_o) and conversion efficiency (η) could be calculated [14] applying Eqs. (4 and 5), respectively.

$$P_o = \frac{V_o^2}{R_L} \quad (4)$$

$$\eta = \frac{P_o}{P_{in}} \quad (5)$$

Where: P_{in} is the input power, and could be calculated as; $P_{in}=I_{in}V_{in}$

2. Methodology and Experimental Setup

The present study aims to investigate the electrical performance of 5/20 VDC (V_{in}: 5 V, V_o: 20V) boost/SEPIC converters depending on the following steps:

Firstly: the converter circuits were designed depending on the initial electrical parameters illustrated in Tables. (1 and 2), applying Eqs. (1 and2)

Secondly: the following experimental procedures were carried out:

- The influence of the switching frequency on the output voltage was studied at fixed switching duty cycle and DC input voltage in order to identify the range of operating frequency that the converter can operate in the DCM
- The switching frequency of 20 kHz is selected at fixed V_{in} value of 5 V, and the influence of D on V_o was studied for selecting D value verifying the higher V_o value and identify the range of D that the converter can operate at.

- The influence of V_{in} on V_o values was investigated at f_s of 20 kHz, D value of 82%, for identify the range of DC input voltage that the converter can operate at.
- The final step is concerned with calculating the generating output power (P_o) and the efficiency (η) of the converter.

For the study to be carried out, the following laboratory instruments were used:

i. Digitizing oscilloscope, model TDS2024C,
ii. HM 8030-5 function generator, and
iii. Regulated DC-power supply, model PW36-1.

Table 1: Initial electrical parameters for the designed boost converter circuit

V_{in} (V)	V_o (V)	P_o (W)	f_s (kHz)	D (%)	C_{in}, C_o (mF)	L (uH)	R_L (Ω)	η (%)
5	20	1.81	10	50	1	330	220	45.67

Table 2: Initial electrical parameters for the designed SEPIC converter circuit

V_{in} (V)	V_o (V)	P_o (W)	f_s (kHz)	D (%)	C_{in}, C_s , C_o (mF)	L_l, L_2 (uH)	R_L (Ω)	η (%)
5	20	1.81	20	65	1	330	220	68.6

Moreover, the electrical characteristics of the used fast recovery diode and MOSFET power switch during the converters design is shown in Tables. (3 and 4).

Table 3: Electrical characteristics of FR101 fast recovery diode

Electrical parameter	Diode forward voltage (V)	Diode forward current (A)	Breakdown voltage (V)
Value	1.3	1	50 V

Table 4: Electrical characteristics of IRF44N MOSFET

Electrical parameters	Breakdown voltage (V)	Drain current (A)	On resistance (Ω)
Value	55	49	0.022

3. Results and Discussions

Concerning the effect of switching frequency variations on V_o of the tested converters, it was noticed that their V_o values were function of the switching frequency and it was found that their effective operating band width was wider for SEPIC converter than boost converter. Where, the operating frequency range for boost converter was varied from 10 up to 20 kHz, leading to the values of V_o to be changed from 20 V to 12.7 V with variation ratio of 36.5 % **Fig. (4a)**. While, the operating frequency range for SEPIC converter was varied from 12 up-to 30 kHz, leading to the values of V_o to be changed from 39.6 V to 15.2 V with variation ratio of about 66.6 % **Fig. (4b**). Besides, the voltage gain of boost converter was varied from 2.54

to 4 during the switching frequency range (Fig.5a), while its value was observed to be changed from 4 to 8 for SEPIC converter (Fig.5b).

A snapshots of DC input voltage, output voltage at the switch node, and DC output voltage for boost and SEPIC – converters are shown in Fig. (6 a and b).

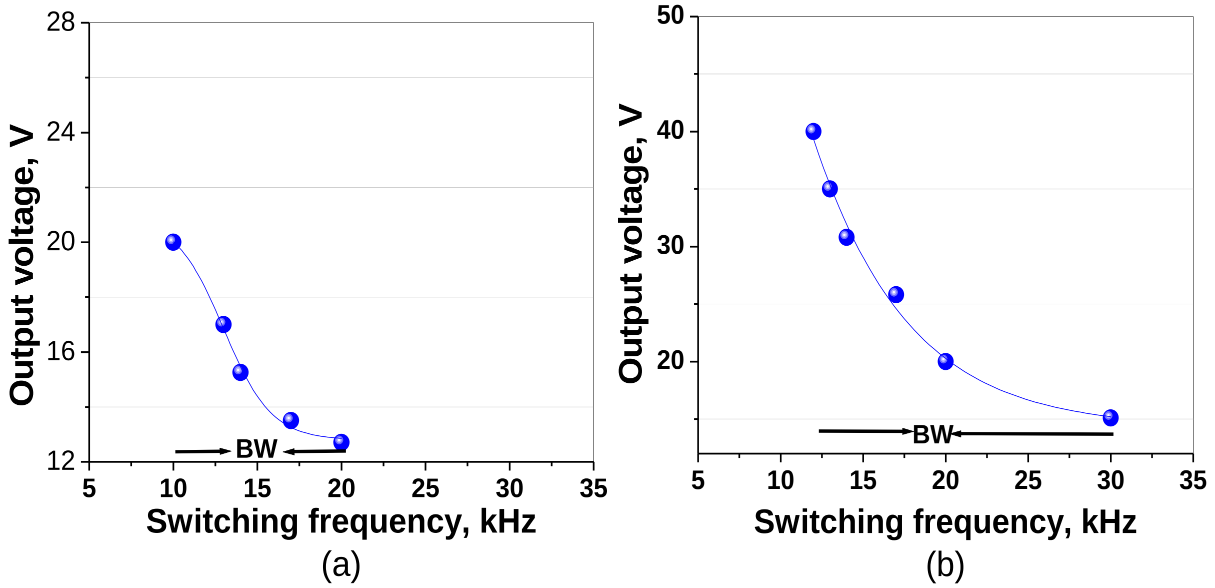


Fig. 4. Dependence of the output voltage of; (a) boost-and (b) SEPIC converter circuits on the switching frequency

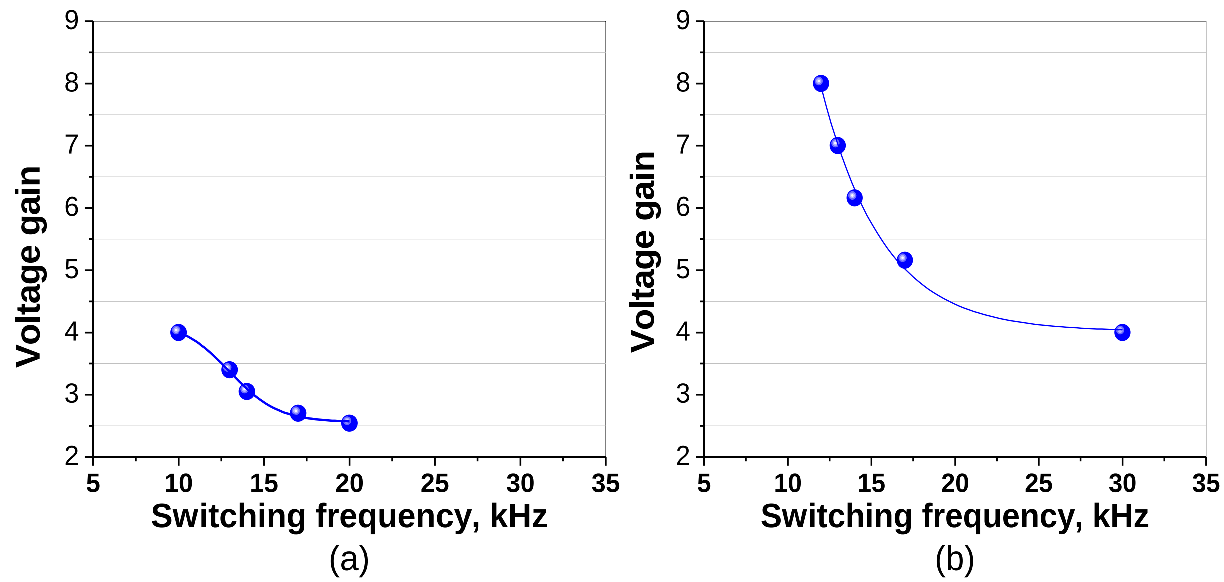
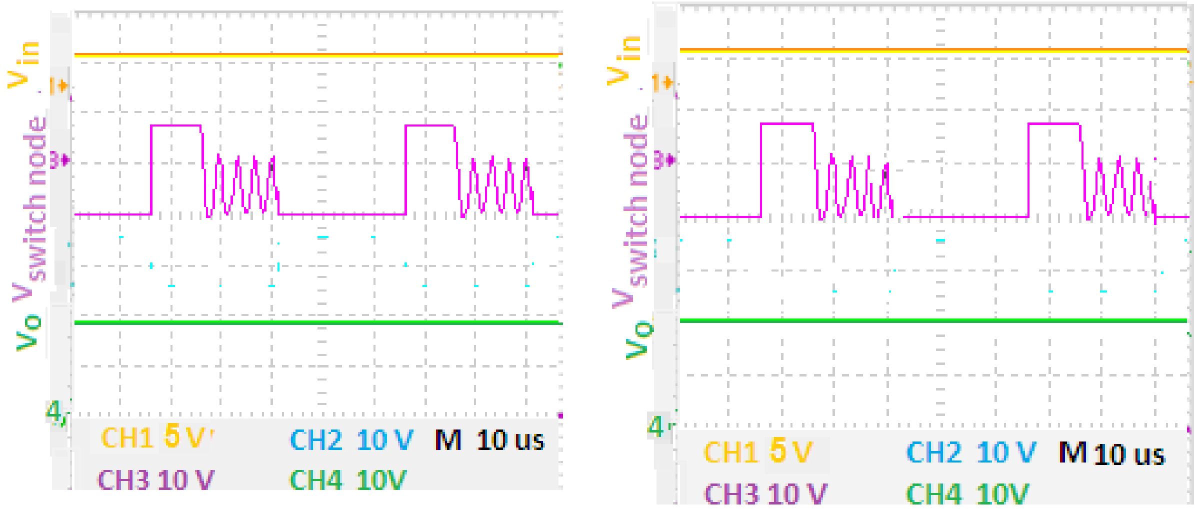


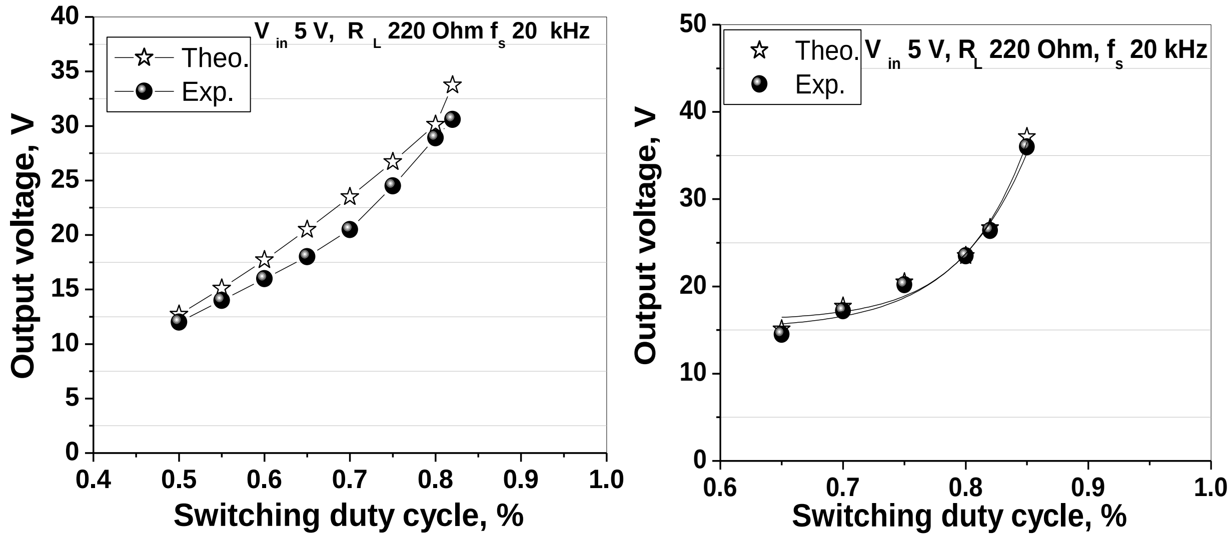
Fig. 5. Dependence of the voltage gain of; (a) boost-and (b) SEPIC converter circuits on the switching frequency



(a) (b)

Fig.6. DC input voltage, output voltage at the switch node, and DC output voltage for; (a) DC-DC boost and (b) SEPIC-converter circuits at DCM

The effect of the switching duty cycle on V_o of both converters is shown in Fig. (7a and b). It was observed for both converters that, V_o is increasing function with D and there is good agreement between the experimental results and theoretical calculations. It was noticed that at D of 65 % their V_o values were measured to be 12 V and 15.7 V, i.e the increasing ratio of SEPIC over the boost was 30.8%. While, at D of 82 % their reported V_o were shown to be 30.6 V and 36.5 V, respectively with increasing ratio of 19.3 % for SEPIC relative to boost converter.



(a) **(b)**

Fig.7. Impact of switching duty cycle on the output voltage for; (a) DC-DC boost and (b) SEPIC- converter circuits

In addition, the voltage gain of the boost converter was varied from 2.4 to 6.12 during the range of switching duty cycle (Fig.8a), while its value was observed to be changed from 2.9 to 7.2 for SEPIC converter (Fig.8b).

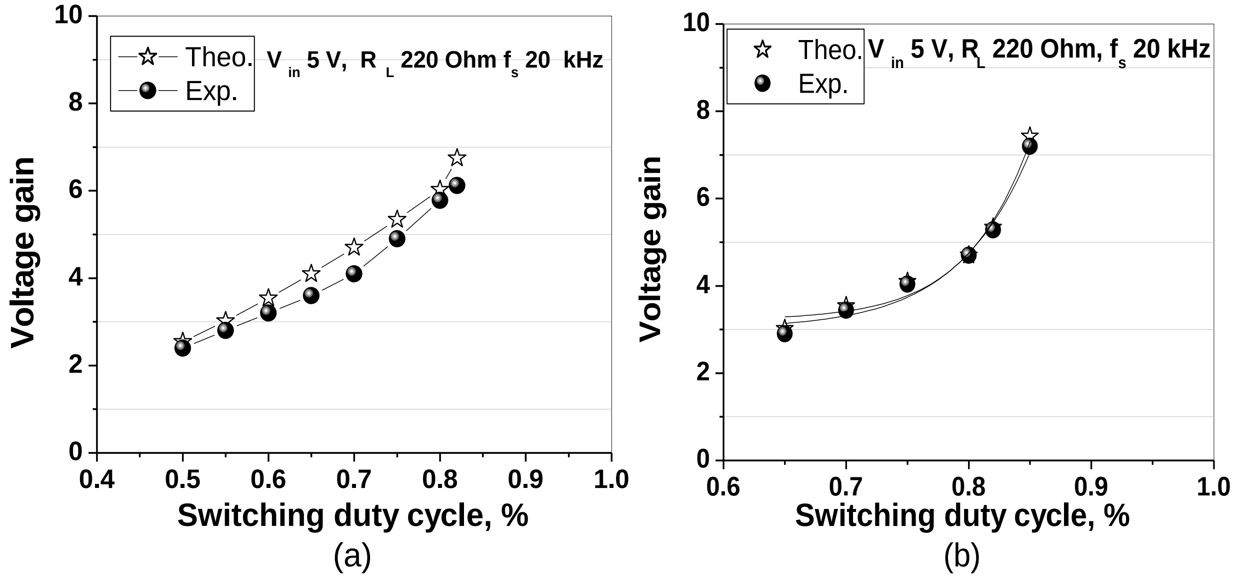


Fig.8. Impact of switching duty cycle on the output voltage gain for; (a) DC-DC boost and (b) SEPIC- converter circuits.

The effect of the DC input voltage on V_o of both converters is shown in Fig. (9 a and b). It was observed for both converters that, V_o is increasing function with V_{in} and there is good agreement between the experimental results and theoretical calculations. Also, the results show that the SEPIC converter is more efficient than the boost converter with higher output voltage values obtained at different V_{in} levels. Where, the obtained output voltage values were 5.5 V and 5.6 V at V_{in} of 1.5 V, which mean that the increasing ratio of SPEIC over boost converter was 18.2 %. Similarly, its values were reported to be, 42.2 V and 48.6 V, measured at V_{in} of 10 V, causing the increasing ratio of SEPIC converter to be about 15.16 % relative to boost converter.

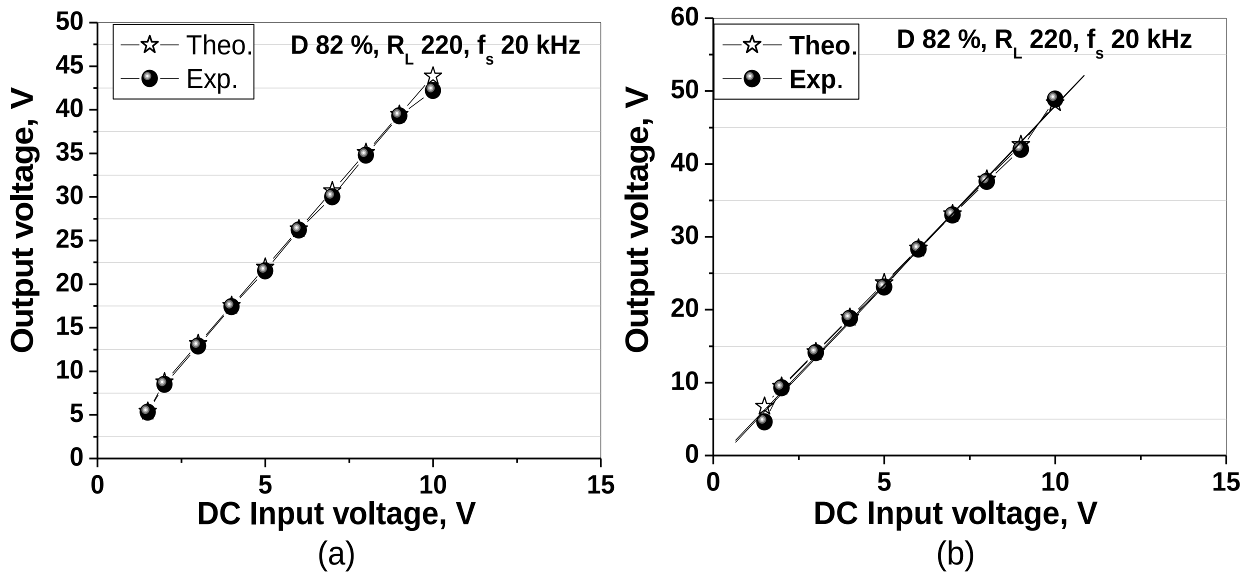


Fig.9. Dependence of the output voltage on the DC input voltage for; (a) DC-DC boost and (b) SEPIC - converter circuits

For the studied range of the DC input voltage at the switching duty cycle of 82%, the generated output power of both converters was calculated and plotted as a function of converter efficiency (Fig.10a and b). It was observed that, the boost converter efficiency was observed to be varied from 45.6 % to 70.4 %, while varying P_o values from 0.13 W up to 8.09 W (Fig.10a). Referring to Fig. (10b), the SEPIC converter efficiency was observed to be varied from 68.9 % to 82.4 %, while varying P_o values from 0.196 W up to 10.86 W.

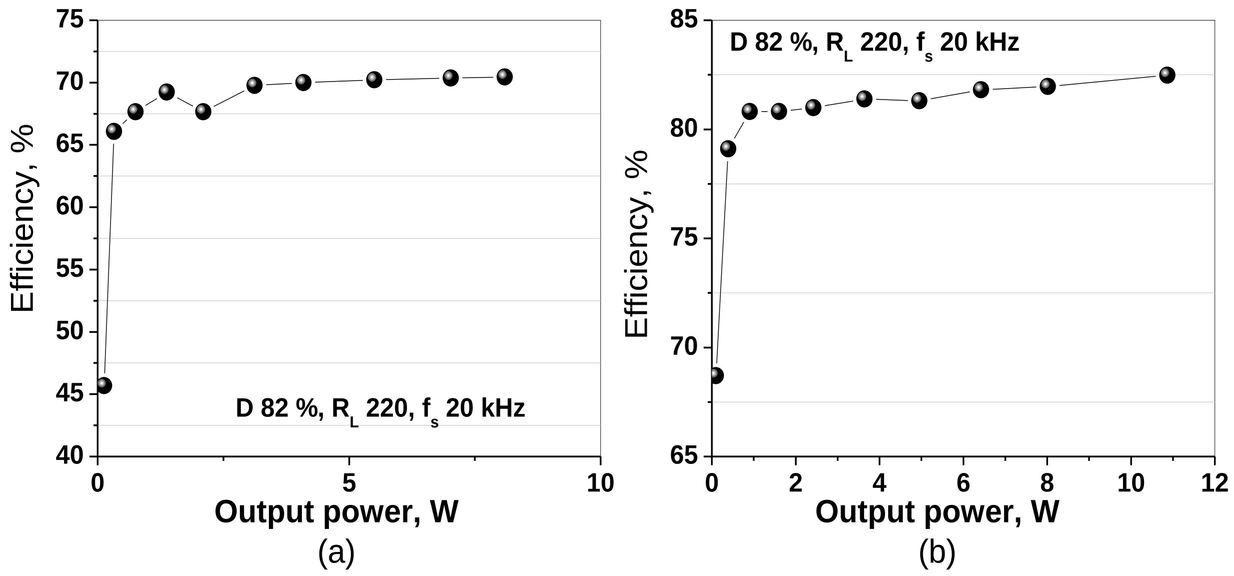


Fig.10. Dependence of the converter efficiency on the output power for; (a) DC-DC boost and (b) SEPIC – converter circuits

4. Conclusions

The present study was concerned with a comparative analysis of the performance for the boost and SEPIC systems, whenever operating in DCM. During the work, the dependence of the output voltage on; switching signal frequency, switching duty cycle and DC input voltage was studied and the results were analyzed. Due to the achieved results, it was proved that;

- SEPIC converter was more efficient than boost converter.
- The output voltage of SEPIC converter is increased by increasing ratio of 18.2 V over boost converter, whenever V_{in} value was 1.5 V, while it was 15.16 % at V_{in} value of 10 V.
- For the dependence of V_o on the switching duty cycle, it was noticed that at D of 65 % V_o values were measured to be 12 V and 15.7 V, i.e the increasing ratio of SEPIC over the boost was 30.8%. While, at D of 82 % their reported V_o were shown to be 30.6 V and 36.5 V, respectively with increasing ratio of 19.3 % for SEPIC relative to boost converter.
- It was noticed that their V_o values were a function of the switching frequency and their effective operating bandwidth was wider for SEPIC converter than boost converter.
- From the experimental work, it could be concluded that: A DC-DC converter based on voltage lift techniques introduces high efficiency than the conventional types. Where, they have the advantages of high-voltage transfer gain, high power density and high efficiency, as well reduced ripple voltage and current

References

[1] AlMohaisin, I. A., Mahfouz, A. A., & Akhila, V. T., A Review on SEPIC Converter Topology, *International Journal of Research in Engineering, Science and Management*, 2(12) (2019) 441 - 443. https://www.ijresm.com/Vol.2_2019/Vol2_Iss12_December19/IJRESM_V2_I12_109.pdf

[2] Basanth, A. J., Natarajan, S. P., & Sivakumaran, T. S., Performance Analysis of Positive Output Super-Lift Re-Lift Luo Converter with PI and Neuro Controllers, *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, 6(3) (2013) 21–27. https://www.iosrjournals.org/iosr-jeee/Papers/Vol6-issue3/E0632127.pdf

[3] Cathell, F., Using Critical Conduction Mode for High Power Factor Correction, *ON Semiconductor (AND8179/D)*, (2004). https://www.onsemi.com/pub/Collateral/AND8179-D.PDF

[4] Chand, M. P., & Ramesh, G., Design of New Positive Output Super-Lift LUO Converter for Solar Input in Comparison with Different DC-DC Converters, *International Research Journal of Engineering and Technology*, 3 (9) (2016) 1588–1594. https://www.irjet.net/archives/V3/i9/IRJET-V3I9295.pdf

[5] Jayachandran, D. N., Krishnaswamy, V., Anbazhagan, L. & Dhandapani, K., Modelling and Analysis of Voltage Mode Controlled LUO Converter, *American Journal of Applied Sciences*, 12(10) (2015) 766-774. https://doi.org/10.3844/ajassp.2015.766.774

[6] El-Ghanam, S. M., Design, implementation and performance analysis of positive super-lift Luo-converter based on different MOSFET types, *Indian Journal of Physics*, 94(6) (2020) 833–839. https://doi.org/10.1007/s12648-019-01528-1

[7] Faraj, K. S., & Hussein, J. F., Analysis and Comparison of DC-DC Boost Converter and Interleaved DC-DC Boost Converter, *Engineering and Technology Journal*, 38(5A) (2020) 622–635. https://doi.org/10.30684/etj.v38i5A.291

[8] Kazimierczuk, M. K., Pulse-Width Modulated DC-DC Power Converters, 1st Ed., *John Wiley & Sons*, Ch. 3, UK, London. (2008). https://www.wiley.com/ensg/Pulse+Width+Modulated+DC+DC+Power+Converters%2C+ 2nd+Edition-p-9781119009542

[9] Luo, F. L., & Ye, H., Advanced DC-DC Converter. crc Press., 2 Ed, *Taylor & Francis Group*. (2016). https://doi.org/10.1201/9780203492925

[10] Masri, S., Mohamad, N., & Hariri, M. H. M., Design and development of DC-DC buck converter for photovoltaic Application, *In 2012 International Conference on Power Engineering and Renewable Energy (ICPERE)*, 3-5 July (2012) https://doi.org/10.1109/ICPERE.2012.6287236

[11] Murat.O.K. and ÇAMUR.S., Modeling and Analysis of DC-DC SEPIC Converter with Coupled Inductors, *In 2016 International Symposium on Industrial Electronics (INDEL)* (2016) https://doi.org/10.1109/INDEL.2016.7797807

[12] Park, S., & Choi, S., Soft-Switched CCM Boost Converters with High Voltage Gain for High-Power Applications, *IEEE Transactions ON Power Electronics*, 25(5) (2010). https://doi.org/10.1109/TPEL.2010.2040090

[13] Rashid, M. H., Power Electronics Handbook: Devices, Circuits, and Applications, 3rd Ed., Elsevier Inc., Ch. 13, USA. (2010). https://books.google.com.eg/books?id=41-7BMFjnnsC&pg=PA27&source=gbs_toc_r&cad=3#v=onepage&q&f=false

[14] Rashid, M., Power Electronics: Devices, Circuits, and Application, 4th Ed., Courier Westford, Inc., Ch.16, (2014) 865- 927, London.

[15] Tekade, A., Juneja, R., Kurwale, M., Debre, P., Analysis of a Positive Output Super-Lift Luo Boost Converter, *Int. J. Eng. Res. Appl*, 6(2) (2016) 74-78. https://www.ijera.com/papers/Vol6_issue2/Part%20-%205/M62057478.pdf

[16] Tomaszuk, A., & Krupa, A, Step-up DC/DC converters for photovoltaic applications – theory and Performance, *Electrical Review*, 89 (2013) 51–57. http://pe.org.pl/articles/2013/9/12.pdf

[17] Wens, M., & Steyaert, M., Design and Implementation of Fully-Integrated Inductive DC- DC Converters in Standard CMOS, Analog Circuits and Signal Processing, Spriger, Ch. 2,pp.27- 63, UK, London, (2011). https://doi.org/10.1007/978-94-007-1436-6