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Solar PV fed Super-Lift LUO Converter and modified SEPIC Converter for LED Drivers

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Abstract
Advancements in Photovoltaic (PV) technologies has enabled the harnessing of solar power for energy, even in remote locations such as rural areas which has given rise to the advent of Distributed Generation (DG). PV array is an intermittent source of power due to its dependence on solar irradiance. DC-DC converters along with MPPT control algorithm form an integral part of a PV system enabling a regulated output with maximum gain and high conversion efficiency. This paper undertakes two popular converters, a Modified SEPIC converter and Super-Lift LUO converter, for powering LED driver. Some of the advantages of a Super-Lift LUO converter are reduced ripple current, high voltage transfer gain, high efficiency and a high power density while Modified SEPIC converter has low output voltage ripple, non-inverting output and less switching voltage stress. MATLAB/Simulink environment is used to simulate the converters. A prototype hardware implementation of the converters is also undertaken. The experimentation results obtained are shown. This paper proves that Modified SEPIC is more efficient than Super-Lift LUO converter for LED Drivers.

Keywords*: LED; Maximum Power Point Tracking; Modified Sepic Converter; Solar PV; Super-Lift Luo Converter.*

1. Introduction

Non- renewable energy sources are major contributors of greenhouse gases, noxious chemicals, toxic emissions that cause global warming, irregular climates, habitat destruction and even irreversible health problems [1, 13]. For a better future, the world is gradually adopting green energy sources. Technological improvements have made accessing renewable energy easier, feasible and affordable. Ever increasing oil prices is another important factor to switch to green energies like solar (PhotoVoltaic/PV) energy. Sunlight is the most abundant and inexhaustible source of energy available on earth. Photovoltaic-based renewable energy is also pollution-free, noiseless, does not generate emissions and hence is carbon neutral. In addition to these factors, photovoltaic modules are known to have a 20 year lifespan thus reducing huge maintenance cost. Before integrating a photovoltaic system based power generation into the electric grid there are several issues need to be addressed such as intermittent supply, low voltages and grid disconnections. To reduce the PV array size and thereby the space utilized, grid integration incorporates either a boost converter or

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step-up transformer [7, 11, 12]. A survey of the available literature for DC-DC converters [3] based on isolated [10, 14, 15, 16] and non-isolated topologies [11, 12], single-ended primary-inductor converters (SEPIC) [8, 9] and LUO converters [17, 2] have gained popularity because they offer many advantages such as high efficiency, low EMI and high reliability. This paper deals with the implementation of Super-Lift LUO converter and Modified SEPIC Converter, and their results obtained from the simulations and hardware prototype.

2. System Description

The block diagram of a basic system consisting of a PV array module, controller, converter and load is shown in Fig. 1. These modules are explained in detail in the upcoming subsections.

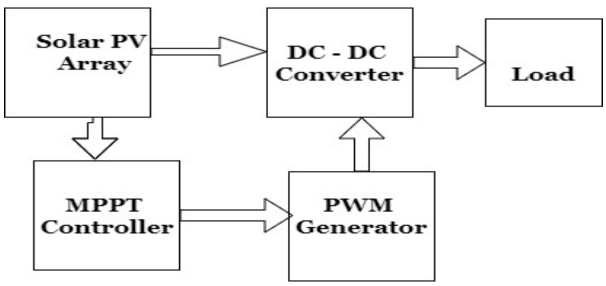

Fig 1: Block Diagram

2.1. Solar PV Array

Solar energy is a green energy source which is being widely adopted worldwide because it is an inexhaustible source of renewable energy. The proposed system uses solar PV array as the source. The specification of a single PV unit is listed in Table 1.

Table 1: Array Specifications

Parameters	Specifications
Standard Conditions	1.5 AM, 1000 W/sq.m,
Cell Temperature	25°C
Maximum Power, Pmax	100W
Irradiance	1000W/m
MPP Voltage, Vmpp	19.6 V
MPP Current, Impp	5.1 A

2.2. DC-DC Converter

The output DC voltage from PV array is fed to DC-DC converter. This paper uses types of converters, such as modified SEPIC and Super Lift LUO converter. These two converters are explained in the following sub sections.

2.2(a) Modified SEPIC Converter

A SEPIC converter incorporates the working principle and advantages of both, a boost and a buck-boost topology as shown in Fig. 2. The output is either greater or lesser or equal to that at its input and non-inverting. Due to the presence of capacitors in the input and output, ripples in the voltages are minimized. In order to increase the gain, this circuit is further refined into a Modified SEPIC DC-DC power converter with an additional diode and capacitor as depicted in Fig 3. It has two modes of operation

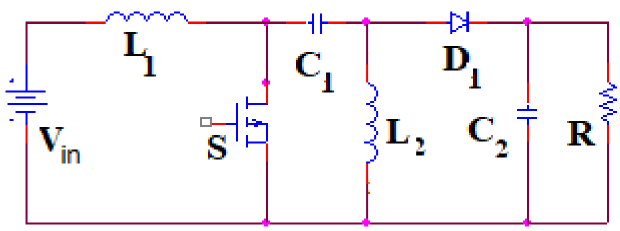

Fig 2: SEPIC Converter

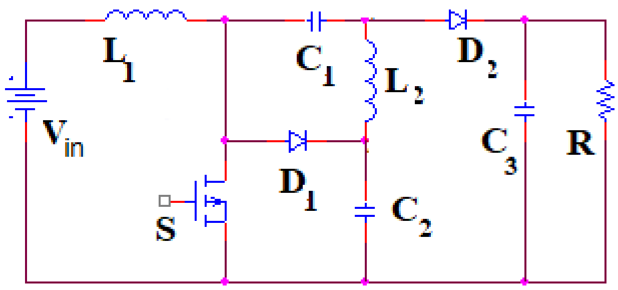

Fig 3: Modified SEPIC converter

(i) Mode 1

During this mode switch S is turned ON, which reverse bias the diodes D_1 and D_2 Supply voltage (V_{in}) charges the Inductor L_1 upto V_{in}. Initially charged Capacitor C_1 transfers its energy to the tank circuit L_2 & C_2 . Fig. 4 shows the direction of flow of current.

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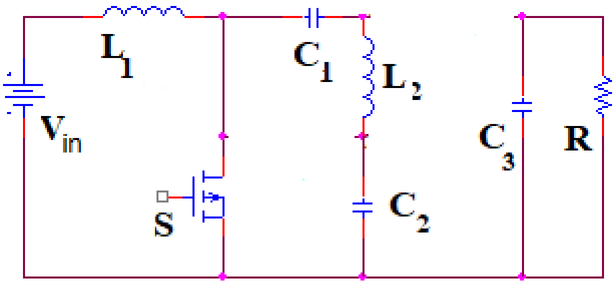

Fig 4: Mode1

Using Kirchoffs Voltage Law (KVL)

$V_{in} = V_{L1} = L_1 * dI_{L1}/dt = L_1 * \Delta I_{L1}/T_{on}$

$V_{in} * T_{on} = L_1 * \Delta I_{L1}$ (1)

$V_{c1} = V_{L2} + V_{c2} = L_2 * dI_{L2}/dt + V_{c2} = L_2 * \Delta I_{L2}/T_{on} + V_{c2}$ (2)

Where T_{on} is the ON period of the switch, V_{in} is the input voltage, V_{c1} and V_{c2} are the voltage across the capacitors C_1 and C_2 respectively. ΔI_{L1} and ΔI_{L2} are the ripple currents in L_1 and L_2.

(ii) Mode 2

During this mode, switch is turned OFF. When switch S is opened (Fig.5), the charged inductor L_1 forward biases diode D_1 & D_2. Two closed paths are formed in this mode, they are: (1) Supply, Inductor L_1, diode D_1 and capacitor C_2 (2) Supply, Inductor L_1, L_2 and diode D_1, D_2 and load R.

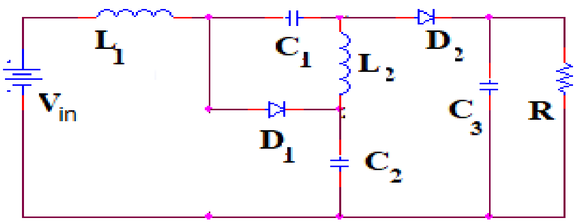

Fig 5: Mode 2

Using KVL,

$V_{c2} = V_{in} + V_{L1} = V_{in} + L_1 * dI_{L1}/dt = V_{in} + L_1 * \Delta I_{L1}/T_{off}$ (3)

$V_{C1} = V_{L2} = L_2 * dI_{L2}/dt = L_2 * \Delta I_{L2}/T_{off}$ (4)

$V_{C1} * T_{off} = L_2 * \Delta I_{L2}$

Also, the output voltage V_0 is as expressed in equation (5):

$V_0 = V_{C2} + V_{L2} = V_{C2} + V_{C1}$ (5)

Using equations (1)-(5) V_0 for the modified SEPIC is obtained as:

$V_0 / V_{in} = (1 + D) / (1 - D)$

T_{off} is the OFF period of the switch S. The value of V_0 lies between 0 and 1 based on the duty cycle (D). A larger duty cycle will yield a higher value of V_0.

2.2(b). Super-Lift Luo Converter

Fig. 6 depicts the Super Lift Luo converter is shown in Fig. 6. This is a DC-DC boost converter with a non- inverted output voltage.

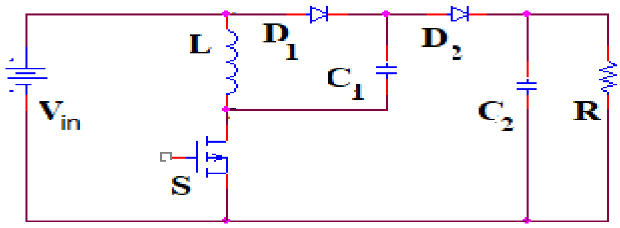

Fig 6: Super-Lift Luo

LUO Converter is characterized by a simple circuit structure, high efficiency and negligible current ripples. The converter operates in two modes, which are explained in the following sub sections.

Mode 1

During this mode S is turned ON as shown in Fig.7, the supply charges the tank circuit formed by L and C_1 to V_{in} since D1 is forward biased. The current through the load is fed by the initially charged filter capacitor C_2.

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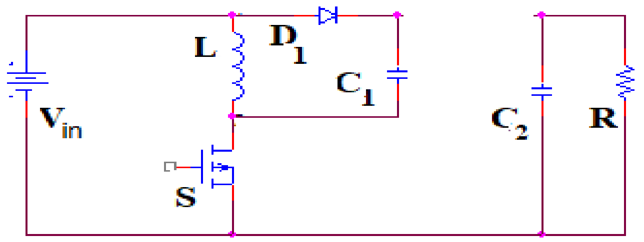

Fig 7: Mode 1

Using KVL, the voltage across L is given by

$V_L = V_{in} = V_{c1} = L * dI_L/dt = L* \Delta I_L/T_{on}$

$V_{in} * T_{on} = L* \Delta I_L = V_{c1}$ (6)

$V_{C2} = V_0$ (7)

Where T_{on} is the ON period of the switch, V_{in} is the input voltage, V_{c1} and V_{c2} are the voltage across the capacitors C_1 and C_2 respectively. ΔI_L is the ripple current.

(ii)Mode 2

Switching OFF S forces the current i_{L1} to pass through $D_{2,}$ thus creating a freewheeling path to charge filter capacitor C_2 through inductor L and Capacitor C_1 as shown in Fig. 8.

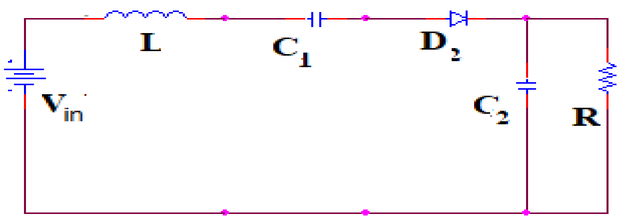

Fig 8: Mode 2

Using KVL,

$V_{c2} = V_0 = V_{in} + V_L – V_{c1} = V_{in} + L * dI_L/dt - V_{c1} = V_{in} + L* \Delta I_L/T_{off} – V_{c1}$

$(V_{C2} – V_{in} + V_{c1}) * T_{off} = L * \Delta I_L = V_0$ (8)

Using equations (6) - (8) V_0 is :

$$V_0 = \{ (2 – D) / (1 – D)\} V_{in}$$

T_{off} is the OFF period of the switch S. The value of V_0 lies between 0 and 1 based on the duty cycle. A larger duty cycle will yield a higher value of V_0.

2.3. MPPT Controller

Due to PV array's inherent dependence on the solar irradiance its output is intermittent and fluctuating. A controller circuit is incorporated into the system to obtain maximum efficiency by maintaining a constant voltage to the load. Many controller techniques are presented in the literature to handle this issue [4-6]. Among these the P&O (Perturb and observe) type of MPPT technique is found to be most suitable to optimize the solar PV array power in all kinds of dynamic weather conditions.

The P&O MPPT algorithm implemented in PV controllers ensures peak power point operations in the PV array by adjusting the impedance based on key parameters like irradiance, load and temperature. Its function is to derive maximum power irrespective of the operating conditions.

Fig. 9 shows a basic P&O algorithm implemented for the PV array. It maintains MPP by repeatedly adjusting the operating voltage to derive maximum output from the PV array.

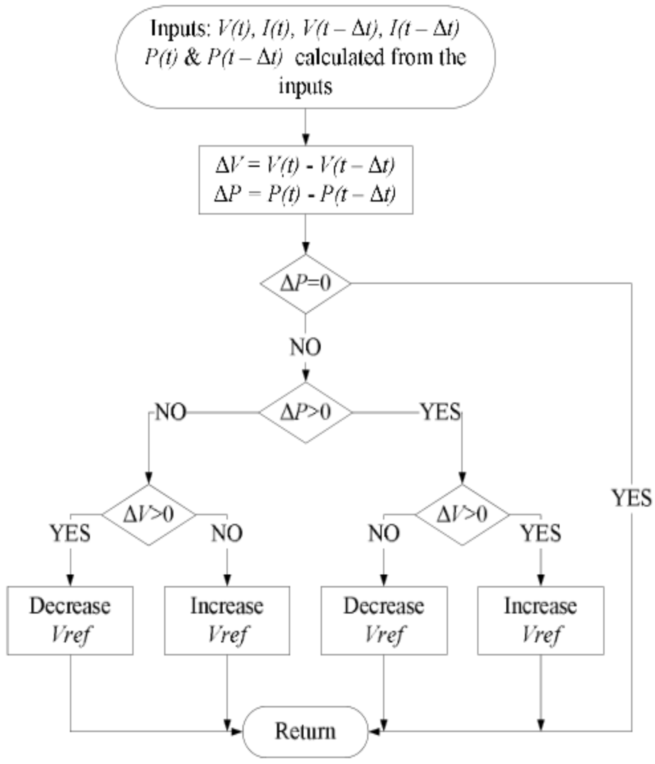

Fig 9: P&O algorithm

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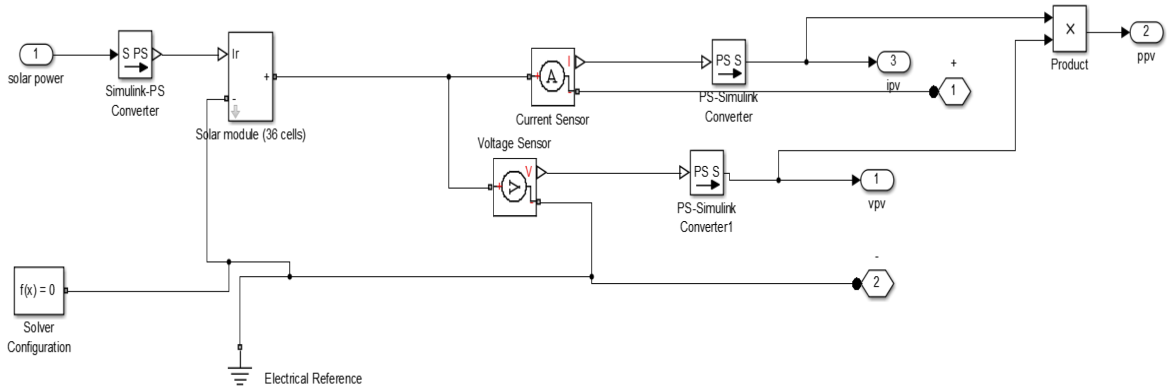
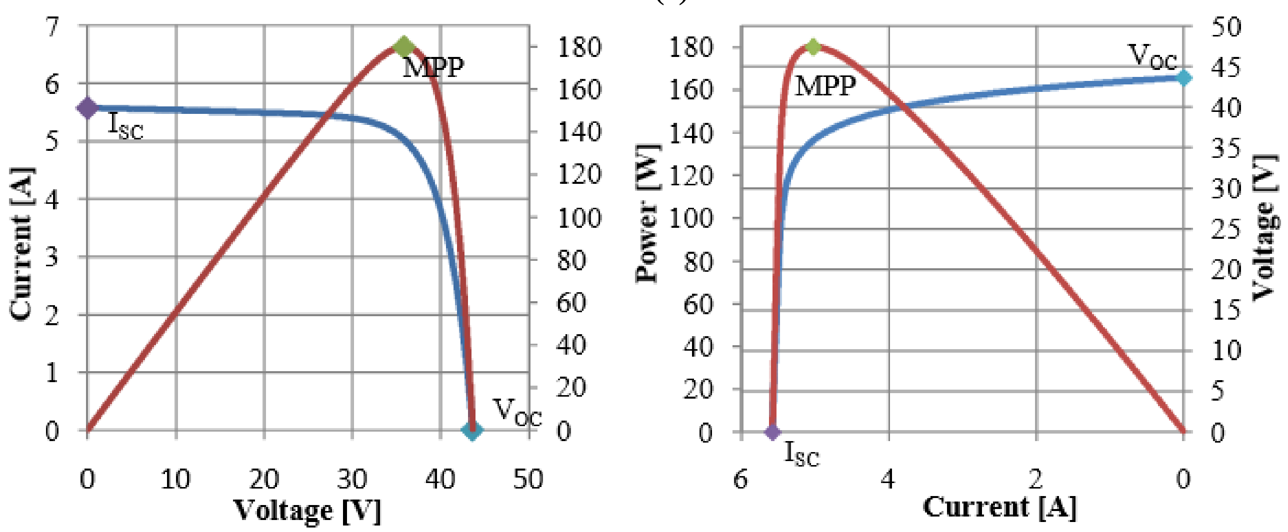
3. Simulation and results

A Figure.10(a) shows the block diagram of a solar array designed in Matlab. The panel's peak power capacity i.e., P_{mpp}=100W. The voltage at MPP (V_{mpp}) for a PV array with 100W, 5.1A ratings is estimated as, $V_{mpp} = P_{mpp}/I_{mpp} = 100/5.1 = 19.6V$

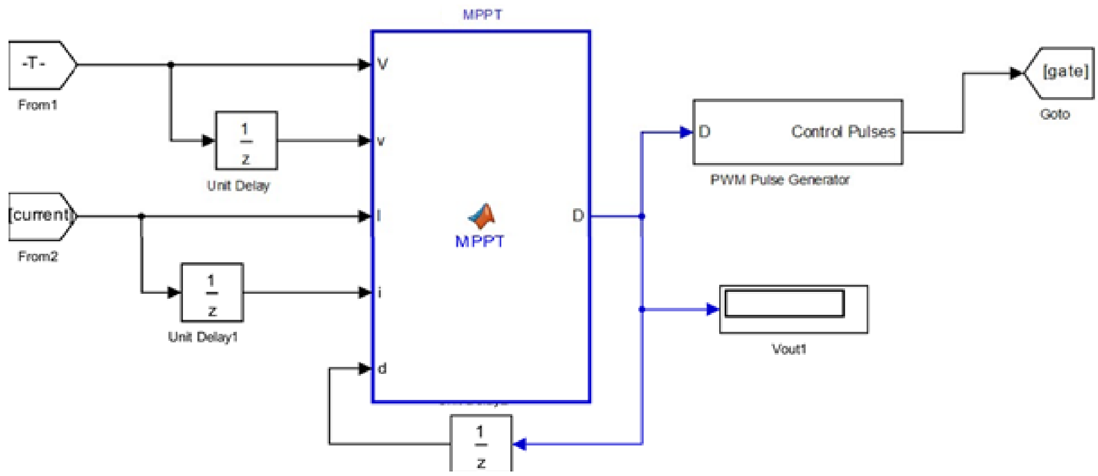
Fig. 10(b) displays the Voltage, Current of solar array chosen. The MPPT controller block diagram is shown in Figure.10(c).



(a)



(b)



(c)

Fig 10: (a) Solar array simulation (b) MPP Curves (c) MPPT

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3.1. System with Modified SEPIC Converter

This converter is operated at switching frequency of 20kHz. The theoretical duty cycle calculated is 0.56. The open loop and closed loop simulations are conducted with these specifications. Fig. 11 shows the system with modified SEPIC converter

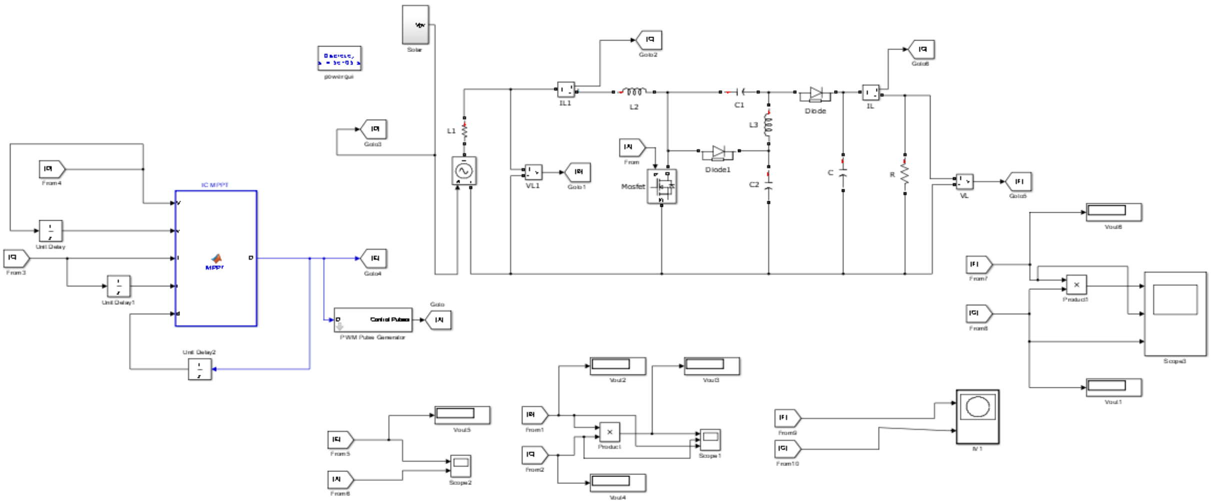

Fig 11: Simulation diagram with Modified SEPIC Converter.

3.2. System with Super-Lift LUO Converter

Super-Lift LUO converter parameters are estimated for Continuous Conduction mode (CCM) operation. Converter switching frequency is chosen as 20 kHz to allow reduction in storage elements size. The duty cycle of operation is 0.56 for the same input voltage and power rating as that of the modified SEPIC. Fig. 12 represents the closed loop Matlab simulation for the Solar Fed Converter.

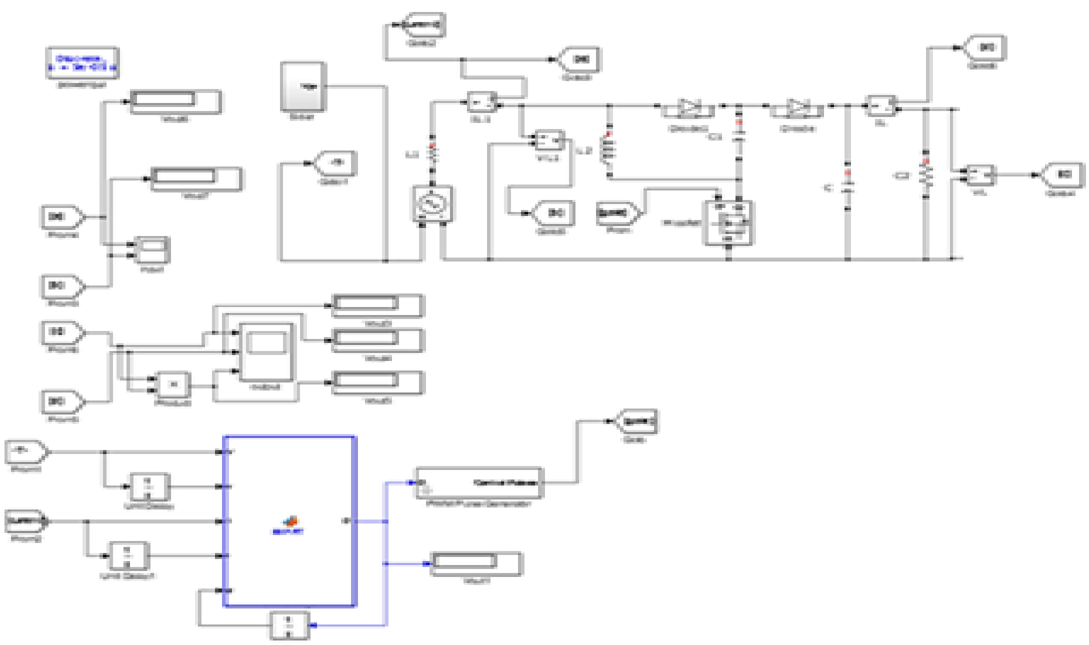

Fig 12: Simulation diagram with Super lift LUO Converter

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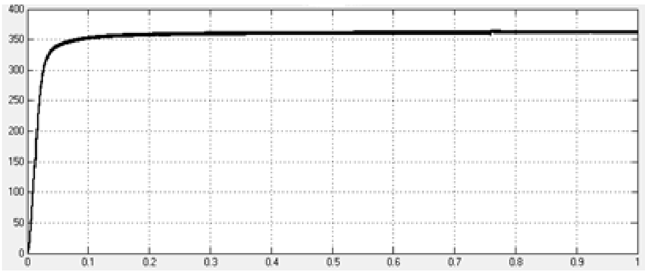
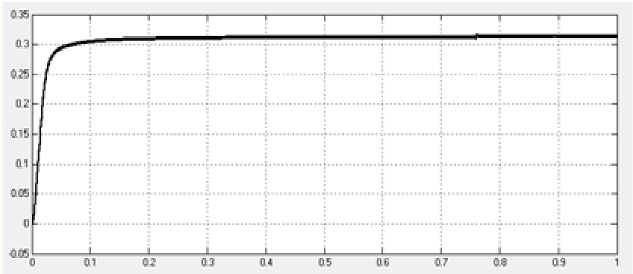
Both the converters are simulated and their output voltages and currents are obtained which are shown in Fig. 13 (a) and (b) respectively.



(a)

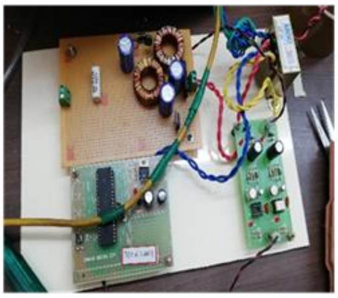


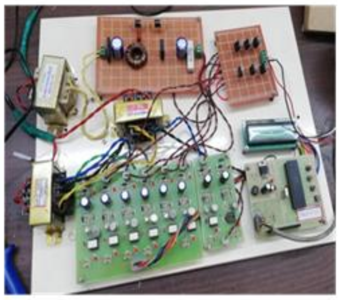
(b)

Fig 13: Simulated waveforms of (a) Output voltage (b) Load current

4. Hardware and result analysis

A prototype of low power rating (4.2 W) was developed for both the converters. Fig 14. (a) & (b). Shows the hardware implementation of the system with Modified SEPIC converter and Super-Lift LUO converter. The Modified SEPIC converter and LUO converter are designed for CCM operation to decrease the stress on power electronic devices. The outputs obtained for the two converters are shown in Fig. 15. The voltage output is 14V and current output is 0.3A. The LED driver circuit is used to power the LED. The output is same for both the converters except for the ripple voltage.





(a) (b)

Fig 14: Hardware implementation with (a) Modified SEPIC (b) Super-Lift LUO

Fig. 15: Output voltage and current

The voltage ripples for modified SEPIC at the output is 40mV and is 88mV for the LUO converter as shown in Fig. 16 (a) and (b) respectively.

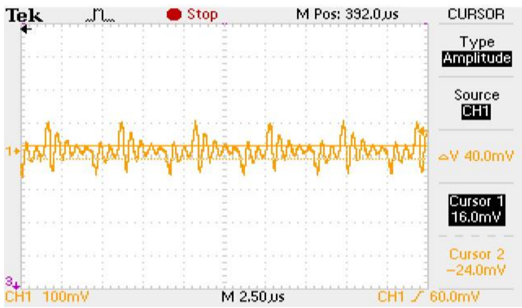


Fig 16: Output ripple voltage for both the Converter

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Table 2: Output ripple and Efficiency

Parameters	Super-Lift LUO	Modified SEPIC
Output Ripple (mV)	88mV	40mV
Efficiency (%)	88%	91%

Based on the results obtained from the prototype, the efficiencies calculated are listed in Table 2. The Modified SEPIC exhibits an increased efficiency of 3% compared to that of Super-Lift LUO converter. Also, the output voltage ripple of the Modified SEPIC converter is lesser by 48mV. These observations prove that Modified SEPIC converters are more suitable than Super-Lift LUO converters for LED drive applications.

5. Conclusion

Low power applications require converters with negligible voltage ripple. The Super-Lift LUO and Modified SEPIC converters are simulated with PV system. Both the converters have simple circuits, use Renewable energy as source, and are operated in continuous mode of operation. Simulation and hardware experimentation of both the converters are carried out for the same power rating and application in similar operating conditions. In simulations, both the converters are able to boost the voltage from 110V to 340V under full load conditions. In hardware implementation, the modified SEPIC converter showed an increase of 3% efficiency over the Super-Lift LUO converter. The output voltage ripple of the same was also found to be lower by 48mV than the super lift LUO converter. The Modified SEPIC has an improved efficiency of 91%. Due to these favourable factors it is concluded that the modified SEPIC is more suited for a LED driver applications.

References

[1] J.Moreno, M.E.Ortuzar, "Energy-management systems for a hybrid electrical vehicles, victimization ultra-capacitors and neural networks", *IEEE Transactions on Industrial Electronics*, vol. 53, no. 2, 2006, pp.614 – pp.623.

[2] Deepa. K, Md. Fayaz Baig, P. Mohith, A.V. Abhinav, "Dynamic analysis of LUO converter with all parasitics", *International Conference on Trends in Electronics and Informatics (ICOEI)*, 2017, pp 1024-1028.

[3] Muhammad H. Rashid, Power Electronics Handbook, 3rd Ed. Burlington, MA: Butterworth-Heinemann, 2011.

[4] Zhou Xuesong, Song Daichun, Ma Youjie and Cheng Deshu , "The simulation and design for MPPT of PV System Based on Incremental Conductance Method," *WASE Int. Conf. Information Eng. (ICIE*), vol.2, 2010, pp.314-317.

[5] Fei Ding, Peng Li, Bibin Huang, Fei Gao, Chengdi Ding and Chengshan Wang, "Modeling and simulation of grid-connected hybrid photovoltaic /battery distributed generation system," *China Int. Conf. Electricity Distribution (CICED),* 2010, pp.1-10.

[6] B. Gu, J. Dominic, J. S. Lai, Z. Zhao, C. Liu, "High Boost Ratio Hybrid Transformer DC–DC Converter for Photovoltaic Module Applications," *IEEE Transactions on Power Electronics*, vol. 28, no. 4, 2013, pp. 2048 -2058.

[7] D. Y. Jung, Y.H. Ji, S. H. Park, Y. C. Jung, and C.Y. Won, "Interleaved Soft-Switching Boost Converter for Photovoltaic Power-Generation System", *IEEE Transactions on Power Electronics*, 26(4), pp.1137-1145, 2011.

[8] R. Gules, W. M. Santos, F. A. Reis, E. F. R. Romaneli, and A. A. Badin, ‘‘A Modified SEPIC Converter with High Static Gain for Renewable Applications," *IEEE Transactions on Power Electronics*, vol. 29, no.11, 2014, pp. 5860–5871.

[9] B. Ebrahim, "Calculation of Output Voltage Ripple and Design Consideration of SEPIC Converter", IEEE Transactions on Industrial Electronics, Vol. 61, No. 3, 2014 pp.1213-1222.

[10] K.Deepa, Sanju.H.M, Vijaya Kumar, "Soft Switched Multi-Output Flyback Converter with Voltage Doubler", *International Journal of Power Electronics and Drive Systems (IJPEDS),* Vol 6, No 2, 2015, pp. 396 - 403.

[11] D. Zhou, A. Pietkiewicz and S. Cuk, "A Three-Switch High-Voltage Converter", *IEEE Transac-*

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ISSN: 0193-4120 Page No. 2627 - 2635

tions on Power Electronics, vol. 14, no. 1, pp. 177-183, 1999.

[12] M. Prudente, L. L. Pfitscher, G. Emmendoerfer, E. F. Romaneli and R. Gules, "Voltage Multiplier Cells Applied to Non-Isolated DC–DC Converters*", IEEE Transactions on Power Electronics*, vol. 23, no 2, pp. 871-887, 2008.

[13] K Deepa, R Jeyanthi, Dr. M Vijayakumar, "Efficient and Compact Power Supply for Robotic Application", *4th International Conference, ARTCom*, 2012, pp.1-6.

[14] B. Axelrod, Y. Berkovich and A. Ioinovici, "Switched- Capacitor/Switched-Inductor Structures for Getting Transformerless Hybrid DC–DC PWM Converters", *IEEE Transactions on Circuits and Systems - I: Regular Papers*, vol. 55, no. 2, pp. 687-696, 2008.

[15] L. S. Yang, T.-J. Liang and J.-F. Chen, "Transformerless DC–DC Converters With High Step-Up Voltage Gain", *IEEE Transaction on Industrial Electronics,* vol. 56, no.8, pp. 3144-3152, August 2009.

[16] K. Deepa, Kurian, Vijaya Kumar, "Active clamp zero voltage switching multi output flyback converter with voltage doubler", *International Review on modelling and simulation,* Vol.6, No.2, 2013, pp.351 – 359.

[17] Fang Lin Luo , Hong Ye, M.H. Rashid, "Super-lift Luo-converters", *IEEE 33rd Annual Power Electronics Specialists Conference,* Vol 02, 2002, pp 1-6.