

# Luo Converter For Low-Power Applications Using A Super Capacitor

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## ABSTRACT

*In the recent years, there is increased need to develop alternative energy to harvest renewable energy instead of using the conventional energy supplies. These kind of energies can be used at small energy scale with the objective to supply power to low-power systems. This project presents a different methodology of an advanced dc-dc converter for Non-Conventional sources of energy. It uses a 1-W high efficiency solar mono-crystalline cell and an Enhanced Self-Lift Positive Output Luo Converter (ESLPOLC). A Super-capacitor of 1 Farad is implemented to store the collected energy. This method can be employed in low power devices as wireless sensors and other low-power applications. The circuit is simulated in MATLAB\SIMULINK software with and without Super capacitor and their efficiencies are compared.*

**Keywords:** super capacitor, advanced dc-dc converter, Luo converter, low-power

## INTRODUCTION

Now a days, due to the need of developing systems that contribute to the reduction of both reliance on conventional energy sources and greenhouse effect, new forms to improve, take advantage and power conditioning of alternative and renewable energies have been developed.

For low-power applications the use of energy harvesting circuits has increased in the last years aiming to benefit the environment and reduce the pollution. These structures use renewable energy and alternative energies, instead of usage of batteries, to feed many different devices such as wireless devices, controls, instruments, sensors, etc.,

Batteries employed in devices and systems generates troubles due to their short-life and limited power density, due to such reasons they must be periodically replaced and then discarded which is contributing to pollution and continuous requirement in maintenance. For sealed/insulated wireless systems/portable devices that use batteries, the maintenance is complicated or sometimes impossible, so that represents a problem.

The DC-DC conversion technique was established in 1920s. The circuits developed for harvesting energy were simple and robust with low efficiency, but currently it is usual to implement control techniques and dc-dc converters to improve output power and efficiency in these systems. In order to use energy harvesting systems to feed the low-power devices in a variety of applications such as: wireless sensors, industrial process monitoring, home automation, healthcare and structural health monitoring.

Due to the increase in industry energy demand, it has been increasing the development of the self-powered energy harvesting systems in the recent years. Such systems should obtain their energy directly from the environmental sources without use of batteries or extra energy sources using the collected energy for themselves.

Various energy sources have been proposed for such systems, such as electrostatic effect, mechanical vibrations, RF in environment, solar energy, wind energy and the combinations of two or more sources. Each source had their benefits and drawbacks but solar energy has the most benefits and the least drawbacks compared to other technologies of energy sources. For these reasons solar technology was chosen for the proposed system.

Many kinds of sources of energy are available to be exploited and incoming power depends on category of environmental source. Focusing on the energy transducers, it can be distinguished between - microwatt generators such as piezoelectric or thermal, and milli-watt generators such as air-flow and solar devices. Thus, the topology of the transducers is fundamental to determine the class of the harvester, its design methodology and efficiency.

Through the following sections, it will be appreciated a brief description of the development of proposed structure, starting with solar cell characterization, description of proposed approach and operation of Luo converter. Afterwards, will be shown a short description of design process and breakdown of power losses to obtain its efficiency and finally, it will present the performed experimental results.

**LUO CONVERTER**

The simplest form of DC-DC conversion was using a voltage divider. Now various advanced methods are available for DC-DC conversion. It ranges from voltage lift technique to super-lift and ultra-lift technique. Luo converters are one of the simplest form of DC-DC converters which operates on voltage lift technique. Many series of luo converters are available now, ranging from elementary 2 lift to 192 lift luo converter. These luo converters operates in push-pull state and can be of mainly two types, either switched capacitor type or switched inductor type. The switched capacitor type luo converter has no inductors and transformers. It allows controlled energy transfer from unregulated source to regulated output voltage. This converter performs positive to positive DC-DC increasing voltage conversion with higher density of power, high efficiency and topology is cheaper with simpler structure.

**ENHANCED SELF-LIFT POSITIVE OUTPUT LUO CONVERTER**

*B. Configuration of Enhanced Self-Lift Positive Output Luo Converter*

A DC to DC converter takes the voltage from a DC source and converts the DC voltage from supply into another DC voltage level. The conversion is necessary in order to decrease or increase the voltage level for a desirable voltage. This is used in portable chargers, automobiles, and portable devices which require constant or variable DC voltage. If higher amount of power developed then it destroys the device or else if lower amount of power is developed then device does not operate. So, in order to achieve this converter with good performance and with good power quality is required.

For novelty devices and calculators, PV cells are used since decades. Improvements in low power LCD displays and integrated circuits made it possible to power such devices for several years. Recently the increase in the solar powered remote or wireless devices have seen increased usage in locations where significant connection cost from grid power makes prohibitively expensive. For example parking meters, water pumps, temporary traffic signs, emergency telephones, trash compactors, and remote signals & guard posts are some of the applications.

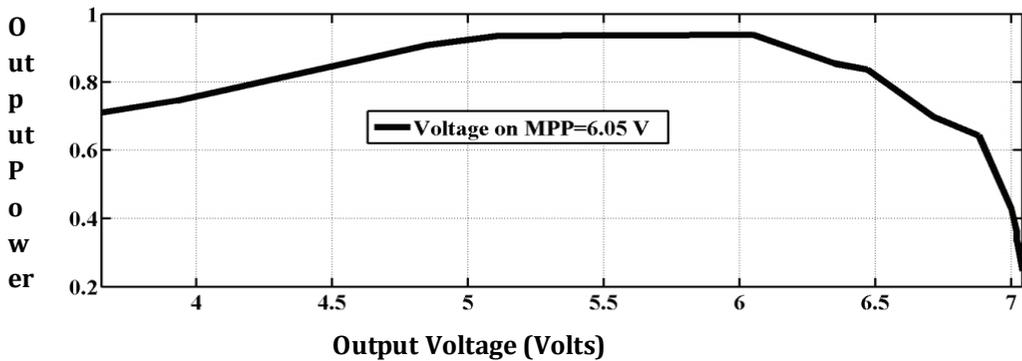


Fig.1. Variation of output power,  $P_o$ , vs. solar cell's output voltage,  $V_{sc}$

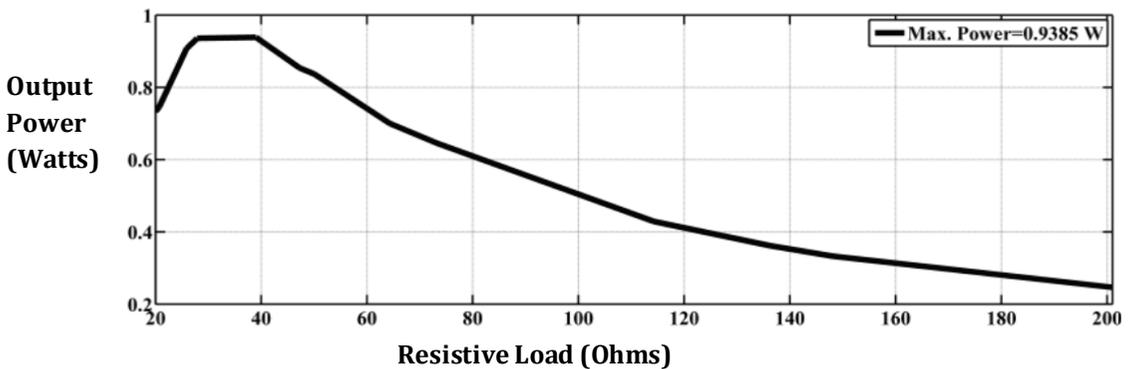


Fig.2. Variation of output power,  $P_o$ , vs. resistive load,  $R$

Commonly used structures for energy harvesting developed in recent years use traditional dc-dc converters, these power conditioning structures show acceptable efficiencies but after reviewing different literary sources, it was found that in harvesting structure the use of advanced dc-dc converters was limited.

Therefore, it was determined to develop a power structure using an advanced dc-dc converter in order to determine whether this could be functional and efficient.

After the review of both traditional and advanced dc-dc converters, an enhanced self-lift positive output Luo converter (ESLPOLC) was selected due to its capabilities to convert a small voltage to a higher voltage level with high efficiency and high power density by a simple dc-dc power structure. Also, additional advantages of Luo converter are that the switching power element is referenced to ground, making the switch easy to drive and turn it ON and OFF. Moreover directly connected input inductor to the dc source is helping to filter the input current, as it is illustrated in ESLPOLC circuit.

The Enhanced Self-Lift Positive Output Luo Converter (ESLPOLC) uses voltage lift (VL) technique to lift level voltage and to overcome the parasitic elements effects. To apply the voltage lift (VL) technique in this converter, the capacitors in Enhanced Self-Lift Positive Output Luo Converter are charged to a determined voltage level. By means of the control of some parameters this voltage is fixed to certain level, in order to the output voltage,  $V_o$ , be lifted to a higher level to provide the property of self-lifting.

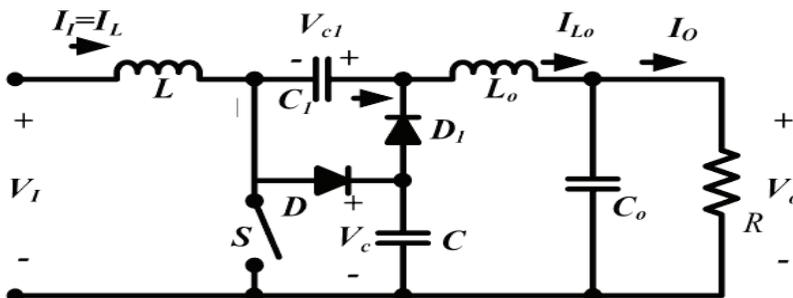


Fig.3 . Schematic diagram of the dc-dc power circuit of ESLPOLC.

**B. Operation of Enhanced Self-Lift Positive Output Luo Converter:**

As shown in above Fig3, the converter is comprised of a relatively simple topology, where two inductors are included, an input inductor L, which functions as an input current filter, and an output inductor  $L_o$ , which is part of a  $L_o$ - $C_o$  filter along with the output capacitor  $C_o$ . Also, the converter has two capacitors, C and  $C_1$ , two diodes, D and  $D_1$ , and a switching device.

During the switch on time, see Fig3,a diode  $D_1$  and the switch S are turned on, while diode D is turned off; at the same time the inductor L is taking energy from the source and the capacitors C and  $C_1$  deliver energy to inductor  $L_o$  and this inductor delivers energy to output capacitor,  $C_o$ , and external load. During the switch off time, see Fig3.b, diode  $D_1$  and the switch S are turned off, whereas diode D is turned on. Inductor L delivers energy to capacitor C and inductor  $L_o$  as well as to the external load. Also the output capacitor delivers energy to the external load.

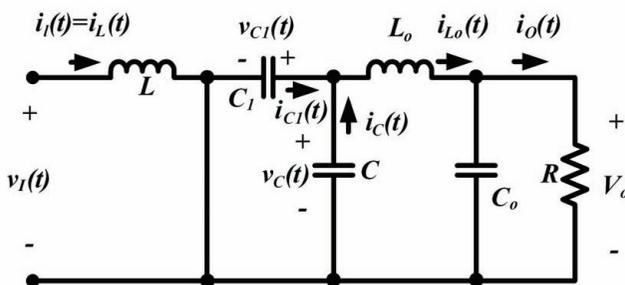


Fig. 3.a. Equivalent circuit of ESLPOLC during switch on time,  $t_{on}$

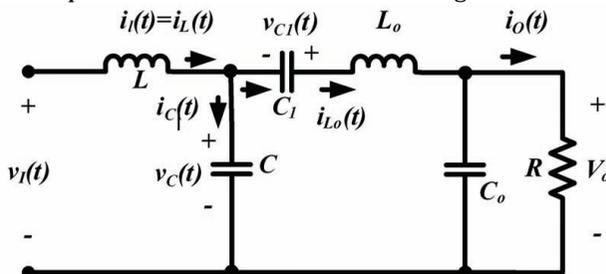


Fig. 3.b. Equivalent circuit of ESLPOLC during switch off time,  $t_{off}$

The following relations, presented in and by others, were determined by mathematical analysis, and describe some of the Enhanced Self-Lift Positive Output Luo Converter's parameters used in the design of our general structure.

The relation between input voltage,  $V_i$ , and output voltage,  $V_o$ , is given by,

$$M = \frac{V_o}{V_i} = \frac{2-k}{1-k} \quad (1)$$

Where  $k$  is the duty cycle.

If the input power and output power of the converter are equal, the relationship between input current,  $I_i$ , and output current,  $I_o$ , can be given as,

$$I_o = \frac{1-k}{2-k} I_i \quad (2)$$

The value of the output inductor,  $L_o$ , and input inductor,  $L$ , can be calculated as,

$$L_o = \frac{(V_o - V_c) kTR}{2\xi_1 V_o} \quad (3)$$

$$L = \frac{V_i kTR}{2\xi_2 V_o} \left( \frac{1-k}{2-k} \right) \quad (4)$$

Where  $T$  is the switching period,  $R$  is the output load,  $\xi_1$  is the variation of range of output inductor current,  $\xi_2$  is the variation of range of the input inductor current.

The value of the capacitors  $C$  and  $C_1$  can be calculated as,

$$C = \frac{(2-k)V_c}{R\Delta V_c f} \quad (5)$$

$$C_1 = \frac{V_{C1}}{R\Delta V_{C1}} (1-k)(2-k) T \quad (6)$$

Where  $V_c$  is the voltage of capacitor  $C$ ,  $V_{C1}$  is the voltage of capacitor  $C_1$ ,  $T$  is the switching period,  $R$  is the output load  $\Delta V_c$  and  $\Delta V_{C1}$  are the variation of range of  $V_c$  and  $V_{C1}$ , respectively.

#### C. Design of Enhanced Self-Lift Positive Output Luo Converter:

The system is completely self-powered, that is, the dc-dc power structure is independent of any conventional power source by making it a suitable, self-contained and flexible design. Design and a detailed description of every essential component of the structure are:

For the system design, a range of input voltage from 3.6 V to 7.2 V and a current range of 200 mA to 20 mA were considered according to the solar cell characteristics. The values of inductance and capacitance of the converter are calculated based on Continuous Conduction Mode (CMM).

The switching frequency,  $f_s$ , is selected depending on two factors, continuous conduction mode of the converter and the availability of output power. Higher operational frequencies will result in higher switching power losses, and for this project work a switching frequency of 80 kHz was selected.

Pulse generator provides a pulse pattern with a fixed duty cycle at a frequency of 80 kHz. The positive pulse triggers the gate of the power semiconductor device, in this case a MOSFET or an IGBT, allowing switching on and off periodically happen. The pulse will be supplied until the reference voltage feedback senses a voltage output of 9 V, which is the selected output voltage. If reference voltage feedback detects a level below 9 V across the super capacitor output voltage, the positive pulse will be generated again for switching on the power device.

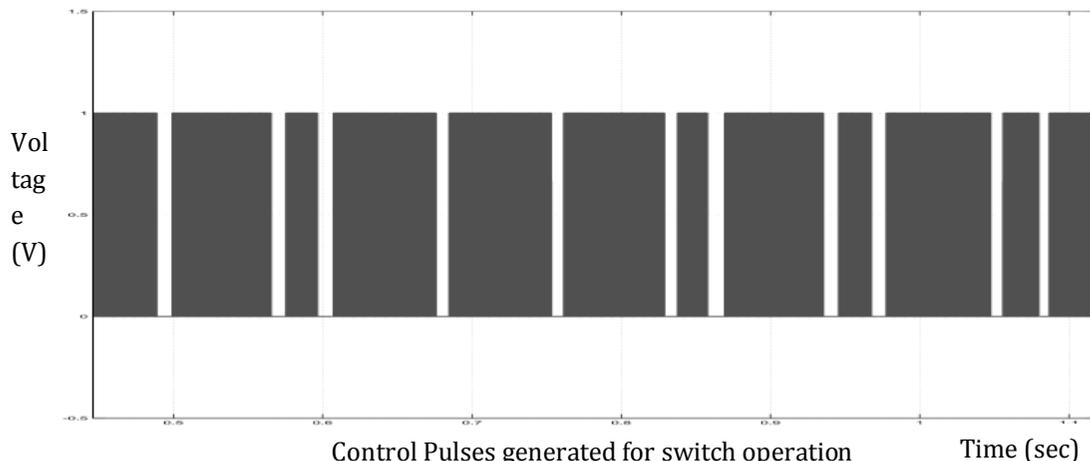
So for the switching frequency of 80 kHz. The circuit element parameters are: Inductance of input inductor  $L = 100\text{mH}$ , Capacitance of capacitor  $C_1 = 100\text{uf}$ , Inductance of output inductor  $L_o = 270\text{mH}$ , Capacitance of capacitor  $C = 68\text{uf}$ , at output a super capacitor of 1F is used in order to eliminate the usage of battery. The super capacitor, also known as ultra-capacitor or double-layer capacitor, differs from a regular capacitor in that it has very high capacitance. A capacitor stores energy by means of a static charge as opposed to an electrochemical reaction. Applying a voltage differential on the positive and negative plates charges the capacitor. Generally, One farad stores one coulomb of electrical charge when applying one volt.

The structure eliminates the need of complex control structures with considerable power drawn from the supply so there by losses are reduced. This was done since the low power applications does not require high end calculations which results in more power drawn by control circuit itself and also cost of implementation to hardware increases. By the use of solar cell as an input voltage source there is no need to supply via external cables and using precious energy. By the use of super capacitor at output eliminates need of battery usage and also smoothens the output dc voltage produce there by drastically improving the quality of output voltage.

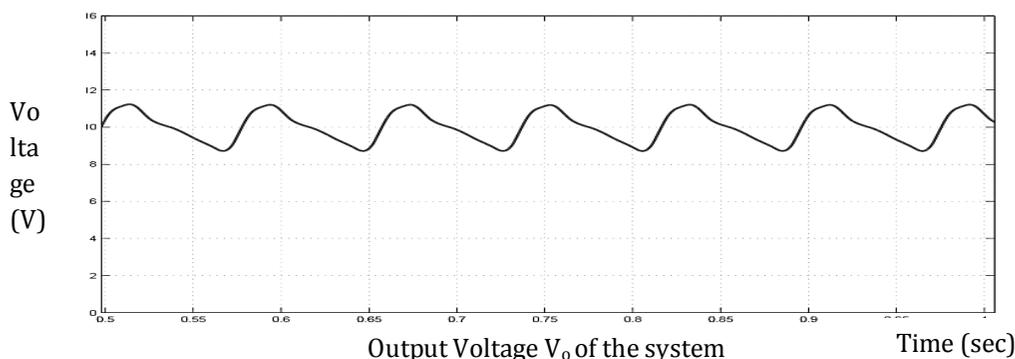
### SIMULATION STUDIES

#### A. Simulation results of Enhanced Self-Lift Positive Output Luo Converter:

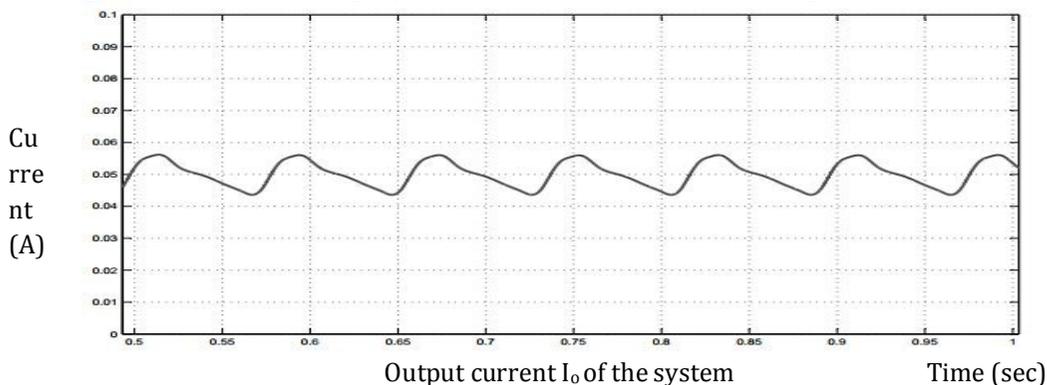
To verify the validity of the proposed Enhanced Self-Lift Positive Output Luo Converter, the system is constructed under MATLAB/SIMULINK environment. The input DC voltage of 7.22 V is provided by a solar panel.



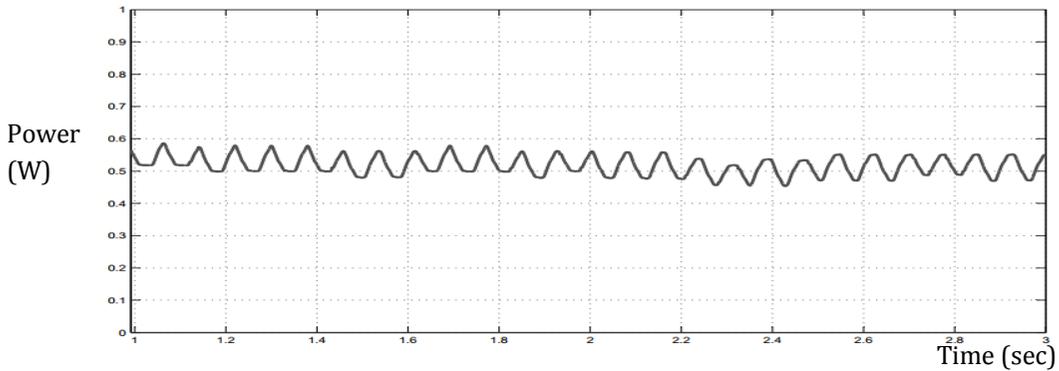
Above Figure shows the control pulses generated after comparison of output voltage to reference voltage.



Above Figure shows the output voltage across the load terminals for a resistive load of 200 Ω. The output voltage obtained contains slight pulsation around the desirable voltage.

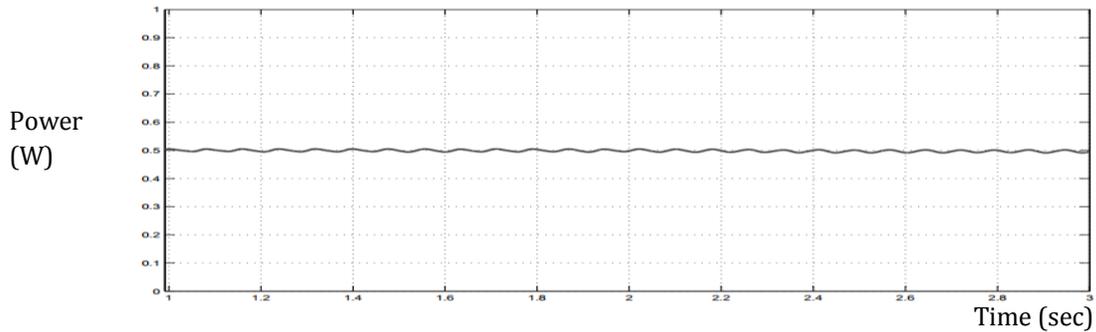


Above Figure shows the output current that is being fed to the load. The output current obtained shows a slight rise and fall of current due to charging and discharging of filter capacitor.



#### Input Power drawn by the Enhanced Self-Lift Positive Output Luo Converter

Above Figure shows the input power drawn by the enhanced self-lift positive output Luo converter. The numerical value obtained after simulation is displayed on the digital display scope in simulation model. From the figure 5.1 the input power after mean value is 0.55 W.

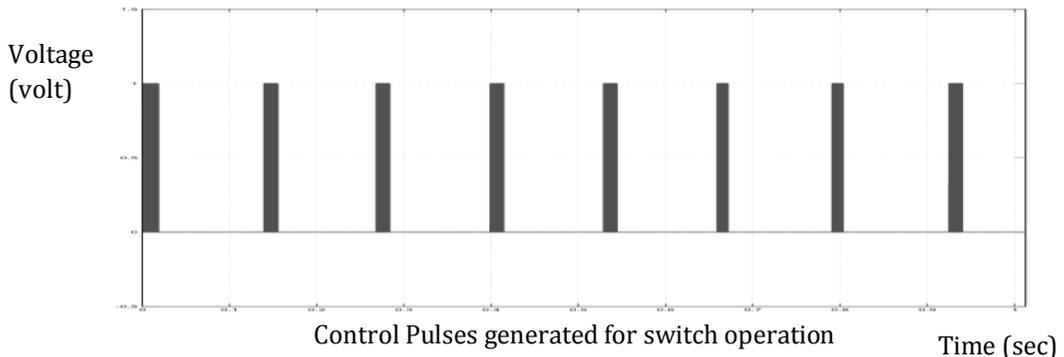


#### Output Power delivered by the Enhanced Self-Lift Positive Output Luo Converter

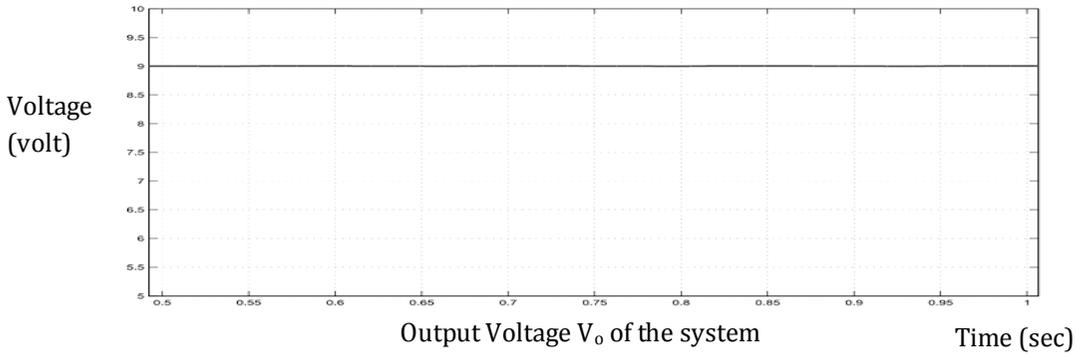
Above Figure shows the output power delivered by the enhanced self-lift positive output Luo converter to load. The numerical value obtained after simulation is displayed on the digital display scope in simulation model. From the figure 5.1 the output power after mean value is 0.49 W.

#### B. Simulation results of Enhanced Self-Lift Positive Output Luo Converter with super capacitor:

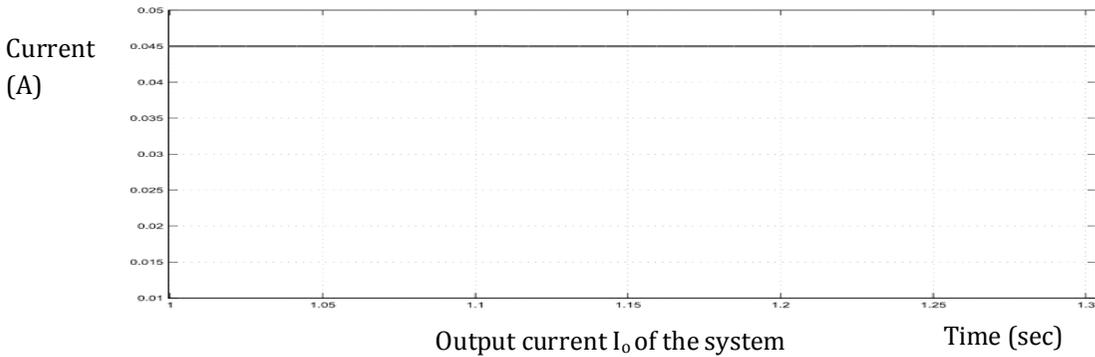
To verify the validity of the proposed Enhanced Self-Lift Positive Output Luo Converter with super-capacitor, the system is constructed under MATLAB/SIMULINK environment. The input DC voltage of 7.22 V is provided by a solar panel.



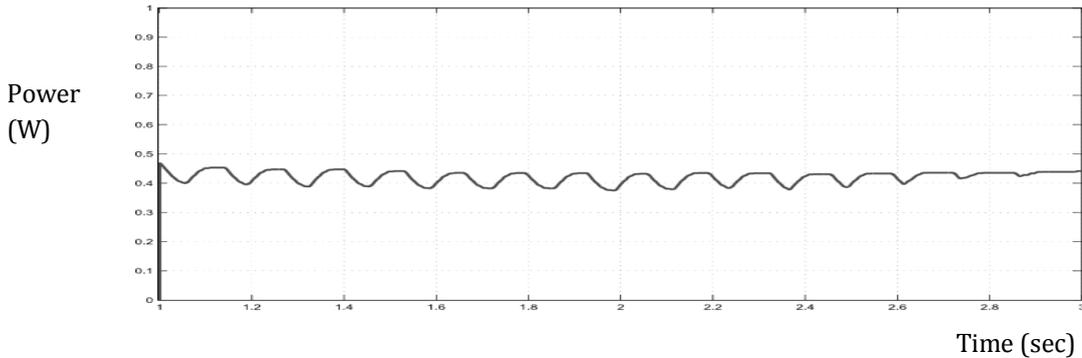
Above Figure shows the control pulses generated after comparison of output voltage to reference voltage.



Above Figure shows the output voltage across the load terminals for a resistive load of  $200 \Omega$ . The output voltage obtained is smooth with higher accuracy in desired voltage.

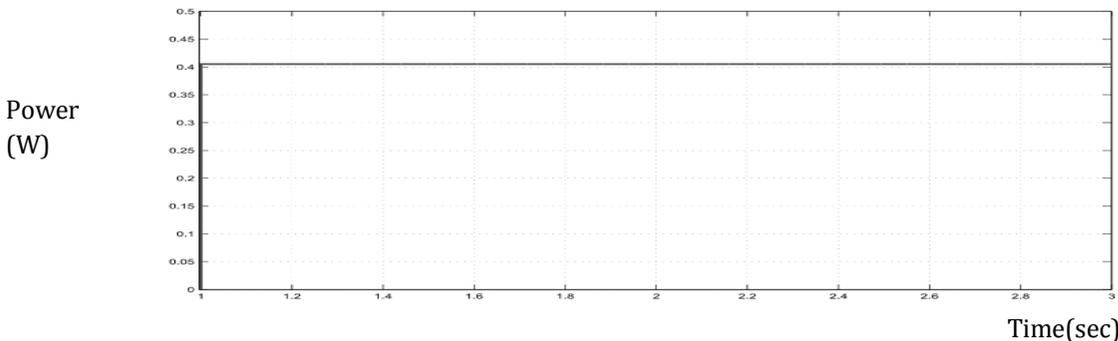


Above Figure shows the output current that is being fed to the load. The output current obtained is also smooth as perfect desired voltage is obtained.



Input Power drawn by the Enhanced Self-Lift Positive Output Luo Converter with super-capacitor

Above Figure shows the input power drawn by the enhanced self-lift positive output luo converter with super-capacitor. The numerical value obtained after simulation is displayed on the digital display scope in simulation model. From the figure the input power after mean value is 0.44 W.



Output Power delivered by the Enhanced Self-Lift Positive Output Luo Converter with super-capacitor

Above Figure shows the output power delivered by the enhanced self-lift positive output Luo converter with super-capacitor to load. The numerical value obtained after simulation is displayed on the digital display scope in simulation model. From the above figure the output power after mean value is 0.41 W. So, finally by observing all the above results we can observe the following:

*For Enhanced Self-Lift Positive Output Luo converter without super capacitor:*

1. In output voltage and current wave forms, some ripple Content is still present
2. At pulse signals, as the voltage is dropping quickly with respect to reference voltage thereby resulting in the frequent switching of switch i.e. switch controller not powering OFF for longer duration leading to switching losses is observed.
3. The efficiency can be calculated by the input power  $P_i$  and output power  $P_o$  values, the calculated mean values displayed on scope as:

Input power,  $P_i = 0.55$  W

Output power,  $P_o = 0.49$  W

Efficiency =  $(P_o / P_i) \times 100\% = (0.49/0.55) \times 100 = 89.09\%$

*For Enhanced Self-Lift Positive Output Luo converter with super capacitor:*

1. In output voltage and current waveforms, ripple Content is drastically reduced producing a better power quality.
2. At pulse signals, the voltage is not dropping quickly with respect to reference voltage thereby resulting in the less frequent switching of switch i.e. switch controller is powering OFF for longer duration leading to minimized switching losses can be observed.
3. The efficiency can be calculated by the input power  $P_i$  and output power  $P_o$  values ,the calculated mean values displayed on scope as:

Input power,  $P_i = 0.44$  W

Output power,  $P_o = 0.41$  W

Efficiency =  $(P_o / P_i) \times 100\% = (0.41/0.44) \times 100 = 93.18\%$

Table: Enhanced Self-Lift Positive Output Luo converter with and without the super capacitor

S.no	Enhanced Self-Lift Positive Output Luo converter	Input Power (W)	Output Power (W)	Efficiency (%)
1	Without the super capacitor	0.55	0.49	89.09
2	With the super capacitor	0.44	0.41	93.18

By noticing the above data. The efficiency is higher for the Enhanced Self-Lift Positive Output Luo converter with super capacitor i.e. 93.18%. So, Enhanced Self-Lift Positive Output Luo converter with super capacitor is considered here.

## CONCLUSION AND FUTURE SCOPE

This project handles Enhanced Self-Lift Positive Output Luo Converter where the efficiency enhancement is done at a lighter load. Here Enhanced Self-Lift Positive Output Luo Converter without super capacitor and Enhanced Self-Lift Positive Output Luo Converter with Super Capacitor have been considered. These diverse Enhanced Self-Lift Positive Output Luo Converter without super capacitor and Enhanced Self-Lift Positive Output Luo Converter with Super Capacitor have been simulated in MATLAB/SIMULINK environment. The efficiency is compared at constant resistive load with same input parameters. By comparing efficiency values the Enhanced Self-Lift Positive Output Luo Converter with Super Capacitor gives 93.18% and Enhanced Self-Lift Positive Output Luo Converter with external DC source and without super capacitor gives 89.09%. So, at a constant resistive load the Enhanced Self-Lift Positive Output Luo Converter with Super Capacitor gives 4% higher efficiency than Enhanced Self-Lift Positive Output Luo Converter without super capacitor.

The scope of the project lies in auxiliary enhancement of the circuit for high power applications. Diverse topologies of switching operation and designs can be fabricated with identical efficiencies for high power applications.

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