Republic of Iraq
Ministry of Higher Education
And Scientific Research
Babylon University
College of Engineering
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Analysis and Modification of Positive Super Lift Luo Converter Based on Switching Cell for Photovoltaic Application

A Thesis

Submitted to the College of Engineering/ University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master in Engineering /Electrical Engineering /Industrial Electronic

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2022 A.D.   **1443 A.H**

بسم الله الرحمن الرحيم

((لَقَدْ آتَيْنَا دَاوُودَ وَسُلَيْمَانَ عِلْمًا ۖ وَقَالَا الْحَمْدُ لِلَّهِ الَّذِي فَضَّلَنَا عَلَىٰ كَثِيرٍ مِّنْ عِبَادِهِ الْمُؤْمِنِينَ (15) وَوَرِثَ سُلَيْمَانُ دَاوُودَ ۖ وَقَالَ يَا أَيُّهَا النَّاسُ عُلِّمْنَا مَنطِقَ الطَّيْرِ وَأُوتِينَا مِن كُلِّ شَيْءٍ ۖ إِنَّ هَٰذَا لَهُوَ الْفَضْلُ الْمُبِينُ (16) وَحُشِرَ لِسُلَيْمَانَ جُنُودُهُ مِنَ الْجِنِّ وَالْإِنسِ وَالطَّيْرِ فَهُمْ يُوزَعُونَ (17) حَتَّىٰ إِذَا أَتَوْا عَلَىٰ وَادِ النَّمْلِ قَالَتْ نَمْلَةٌ يَا أَيُّهَا النَّمْلُ ادْخُلُوا مَسَاكِنَكُمْ لَا يَحْطِمَنَّكُمْ سُلَيْمَانُ وَجُنُودُهُ وَهُمْ لَا يَشْعُرُونَ(18)))

صدق الله العلي العظيم

Dedication

To the memory of my father

Acknowledgements

Abstract

The DC/DC converters with high efficiency and high gain are the most important parts of photovoltaic systems and other power electronic system applications

This thesis begins with analysis, verification and simulation in continuous conduction mode (CCM) and discontinuous conduction mode (DCM) of the elementary circuit of the positive output super-lift Luo converter (POSLC) checked using simulation in MATLAB / (R2020a) program.

In the next stage of this thesis, a modification was made to the original circuit of (POSLC) in order to raise the gain coefficient, performed by switching inductor cell consisting of three inductors and five diodes. Operating of inductors parallel when the switch is on, discharged in series to the load when the switch is off. This modification was designed, analyzed and checked in the simulation, and the theoretical results matched with the analytical. The gain factor improved to be (5) at duty (0.5)

In the same approach, another modified model was proposed by replacing the main capacitor with two capacitors and three diodes to form a switching capacitor cell that works on the same principle as the cell in the first modification, but it charges in series and discharges power in parallel. This modification was designed, analyzed, modeled, validated and matched with Simulink. The gain factor improved to be (4) at duty (0.5) for modified circuit

To obtain a very high gain at a very low duty cycle, a large expansion of the switching cell was made using a hybrid capacitor-inductor switching cell consisting of four inductors and two capacitors, placed instead of the main inductance in the elementary (POSLC). It was concluded that at a half duty

cycle, the gain reaches (8) times the input voltage and a little ripple about (0.025) and high efficiency.

Finally, the best model was used as a power regulator for the solar cell system, which the voltage gain is (8) at duty cycle (0.5) through the use of the maximum power point tracker to control the work of the converter by controlling the duty cycle of the converter to obtain the greatest power from the solar panel, because the entire solar system connected in series and distribution is restricted to the power of the weakest panel in the group, it is necessary from an economic point of view to get the maximum benefit from the solar panel.The circuit and the proposed circuits were all connected with the maximum power point tracker controller. The results were compared with and without the maximum power tracker to show the effect of this MPPT on extracting the maximum possible power from the solar panel.

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List of abbreviations

CCM	Continuous conduction mode
CO2	Carbon dioxide gas
CP	Charge pump
D	diode
DC	Direct current
DCM	Discontinuous conduction mode
IC	Incremental conductance
MOSFET	Metal oxide semiconductor field effect transistor
MPPT	Maximum power point tracker
NOLC	Negative output Luo converter
NOSLC	Negative output super lift Luo converter
P&O	Perturb and observation
PC	Personal computer
PI	Proportional-integral controller
PM	Permanent magnet
POLC	Positive output Luo converter
POSLC	Positive output super lift Luo converter
PV	Photo voltaic
PWM	Pulse-width modulation
SC	Switching capacitor
SCI	Switching capacitor-inductor
SI	Switching inductor
SL	Super lift

List of symbols

Symbols	Name	Unit
(1-D)	Duration time in state off, at DCM	-
$\in co$	Ripple of the output capacitor	-
C	Capacitor	F
Co	Output capacitor	F
D	Duty cycle	-
Δi_L	Change in inductor current	-

Δi	Change in current	-
Δt	Change in time	-
F	frequency	HZ
G	Gain	-
I_L	Inductor current	A
Io	Output current	A
Ic_0	Current of the output capacitance	A
L	Inductor	H
Pin	Input power	W
Po	Output power	W
R	Resistive load	OHM
S	Switch	-
T	Time period	S
V	Volte	V
Vc	Capacitor voltage	V
V_{in}	Input voltage	V
V_L	Inductor voltage	V
Vo	Output voltage	V
Qc_0	Output capacitor-charge	-
τ	Normalize Resistance	-
ξ_L	Variation of inductor current	-

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Chapter One

Introduction

1.1: Introduction

With technological development in recent decades, increasing environmental pollution and global warming, efforts have been directed towards the use of renewable energy. The most important is solar and wind energy. Researchers are mainly interested in renewable energy systems to make maximum use of the energy produced from the sun, and since solar panels generate continuous voltage, the most important problems that occur are the low level of voltage and the fluctuation of the output voltage [1].

To avoid these problems, a dc-dc converter is used which is simple to configure, easy to control, and operate. One of the main challenges in this type of converter is the amount of profitability, the accuracy of work, and design using minimal elements to reduce wasted energy to a minimum [2].

The main type of step-up dc-dc converters is the Boost converter, the output voltage gain coefficient is the duty cycle, buck-boost, SEPIC, CUK and ZETA don't provide a steep step-up gain voltage [3]. To achieve high dc gain, the basic boost would be operating at a very high duty cycle large than 0.8, but this unrealistic cap for conduction time of recovery diode. Also, operation at a high switching frequency cannot be possible because the diode does not turn on/off instantaneously [4, 5].

The alternative available solution to reach large output voltage, is the use of a greater number of inductors or capacitor elements in a specific way, providing an increase in the output voltage and a certain cycle ranging from 0.4 to 0.8 to avoid stress on the semiconductor switches [5, 6].This structure is called "cell" there is three construction of cells. When it contained diodes and capacitors only it is

called switching capacitor cell (SC), it is called switching inductor cell (SI) when it contains diodes and inductor, and it is called hybrid switching inductor-capacitor cell (SIC) when it contained diodes, capacitor, and inductor.

These cells can provide a high dc gain ratio when charging these elements (capacitor and inductor) in parallel and discharged in series [4], the switching capacitor cell (SC) is small in size because it is composed of diodes and capacitor only and there is no inductor, the output voltage of the SC depend on the number of capacitors only, for ideal components, the output voltage is equal to $V_o = (1+n) V_{in}$ [7]. Where n is the number of capacitors.

The main drawback of SC is low efficiency since not able to use the full capacity of the capacitor to transfer the regulated voltage to the load, increasing the number of capacitors needed more switching devices which means more losses [4,7]

The (SI) cell can provide high dc a gain ratio when charged in parallel and discharged in series. However, the main issues of the (SI) cell are cost and sizing. Due to the significant advancement of DC-DC converters to achieving high output voltage gain with high efficiency and high-power density, the voltage lift (VL) has been proposed [5, 8]. These converters are combined from the (SC) cell and SL cell. The key problem of the (VL) converter is using more inductors and capacitors as inner storage elements.

In the last years, the family of Luo converter is more widely used because of its simple operations and control. Positive and negative super lift Luo converter is the most commonly used in the family of Luo converters with renewable energy and electric vehicle applications [6]. Due to having a high gain ratio and can extend to get the required output voltage. The types of this family include elementary, re-

lift, and triple circuits. The expanded analysis of positive and negative super lift Luo converter in the different conditions of operation is presented in [8].

In this thesis, the positive super-lift Luo converter and also proposed three modification of positive Luo converter with MPPT controller for each model has been presented. The mathematical model and steady-state analysis for these converters have been presented.

1.2: Problem statement

The main issues of DC-DC converter

1- Several traditional DC-DC converters cannot be getting a high gain ratio by lower duty cycle as well as it cannot be using large duty cycle due the problem of reverse recovery diodes.

2- The semiconductors devices like diodes and active switching (MOSFET, IGBT, etc.) are suffering from high voltage stress across them.

3- When extended the DC- DC converter to get a high gain, the number of components are significantly increased which implies higher sizing and cost.

4- Due to the DC-DC converters have at least one electronics switching, the operation of these switch cause inherently nonlinear characteristics. So, the DC-DC converters are needed control strategy with high switching frequency to avoid overshoot, high output ripple and decrease the settling time

5- In the normal working of the DC-DC converter in PV system, the PV cell doesn't deliver its full power generated from the sun. It's required to use the DC-DC converter to get maximum power from the panel.

1.3: Thesis objective

1. Get high output voltage at low duty cycle.

2. Reduce duty cycle to reduce the stress on the switch and reduce the losses.

3. Reduce the effect of input pulsating current to save the power source.

4. Use small size inductor to reduce the overall size and save cost.

5. Verify applicability of the proposed converters in MPPT application.

1.4: Thesis contribution

1- Modification by using two capacitors only (SC) cell, make a switching cell and smoother output voltage , increase the gain and reduce the input pulsating current.

2- Proposed another modified for (POSLC) using (SI) cell to get a high gain ratio more than the first modification for high power applications,

3- Proposed modified (POSLC) using a hybrid capacitor-inductor switching cell to get a high gain ratio more than the first and second new modification for high power applications.

1.5: Literature survey

B. Axelrod 2008 [9] Proposed six structure of cells three of it are used for step-down and other structure are used for step-up, which are applied to classical buck, boost ,buck-boost, cuk, sepic, and zeta converter. The features of these structures are lower energy in magnetic elements, safe size, weight, cost, less conduction losses and increase efficiency.

P. Sanjeevikumar1 2008 [10] Proposed a converter by using 5 inductor and 6 capacitor and 8 diode to obtains $G = 4/1\text{-}D$

Yu tong 2015 [11] Proposed three structure are proposed one of them is active switch network ANC and other two are SC and SL cell, which are applied in boost converter for getting higher gain about 20 time and low voltage and current stress, the stress is flexible and the o/p voltage can be adjusted.

Manxin chen 2016 [12] Proposed simple graph with four nodes and seven elements these elements are either a capacitor or diode or inductor or short circuits he get five types of cell and twelve structure of converter. With different value of efficiencies the best one is 92.43% using 5 capacitors, one inductors and five diodes, one transistor the voltage stress was 1/3Vo on diode or switch.

Archana Nath in 2016 [13] Proposed new modification for POSLLC used in PV, in elementary POSLLC the output is increased three times the input. But in Improved Positive Output Super-Lift Luo converter, the output is increased six times of the input which is specified by adding an inductor and diode.

M.Pradeep Chand in 2016 [14] Modify (POSLC) to increase the gain and compare with other converter such as, buck-boost, POLLC and POSLC.

Chaitanya Pansare and et al, 2017 [15] Proposed a modify structure of converter from inductor, capacitor and diodes to made cell to the original converter to lift the voltage so the gain formula is   G = 2/1-D

Nilanjan 2018 [16] Proposed new converter from SI and two active switches to obtain bidirectional converter, G = 3-D/1-3D   when D = 0.3 the gain is 27 times.

Manxin chen 2018[17] Proposed a modification on traditional boost converter by inserting two switching capacitor cells in input side and on output side and inserted split-inductor; all that to boost o/p voltage from 11v to 400v and avoiding spikes induced by the leakage inductance at the switch turn-off

Sama Salehi and et al 2019 [18] Proposed new converter used hybrid SC-SI cell and 5 active switch the main feature of this converter is flexible in voltage gain because we can achieve different high voltage gain.

Gagan deep 2019 [19] Proposed new non-isolated DC-DC converter with high gain by using hybrid switch inductor cell (diode & MOSFET) G= 7 η=95%   is similar to work of nilanjan 2020.

Ahmed T. mohammed 2020 [20] Proposed new modification of positive o/p Luo converter, the modification is adding hybrid cell instead of inductor and so the gain become   G = 3+D/1-D.

S.S. Dheeban and et al 2021 [21] Used Luo converter with MPPT controller to improve the performance of PV system as compared to the traditional boost converter. It has been observed that the use of Luo converter extracts more voltage from PV panel and the performance is more efficient

2008	B. Axelrod	Proposed six structure of cells three of it are used for step-down and other structure step-up
2008	P. Sanjeevikumar1	Proposed a converter by using 5 inductor and 6 capacitor and 8 diode to obtains G = 4/1-D
2015	Yu tong	Proposed one of them is active switch network ANC and other two SC and SI
2016	Manxin chen	Proposed simple graph with four nodes and seven elements these elements are either a capacitor or diode or inductor or short circuits he get five types of cell and twelve structure of converter

2016	Archana Nath	New modification for POSLC used in PV, by adding inductor and diode.
2016	M.Pradeep Chand	Modify POSLLC to increase the gain and compare with other converter such as, buck-boost and POLLC and POSLC
2017	Chaitanya Pansare, et al	proposed a modify for (POSLC) from inductor, capacitor and diodes to made cell to lift the voltage to the formula G=2/1-D
2018	Nilanjan	Proposed new converter from SI and two active switches to obtain bidirectional converter
2018	Manxin chen	proposed a modification on traditional boost converter by inserting two switching capacitor cells in input side and on output side
2019	Sama Salehi	proposed new converter used hybrid SC-SI cell and 5 active switch
2019	Gagan deep	proposed new non-isolated DC-DC converter with high gain by using hybrid switch inductor cell
2020	Ahmed T. mohammed	proposed new modification of positive super-lift Luo converter, adding hybrid cell instead of inductor and so the gain become G =3+D/1-D.
2021	S.S. Dheeban and et al	Luo converter was used with MPPT controller to improve the performance of PV system as compared to the traditional boost converter.

1.6: Thesis outlines

This thesis has five chapters as follows:

In Chapter 1, this chapter presents an introduction to the photovoltaic cell and why it needs a DC-DC converter, as well as the objective and contribution of this work are presented.

In Chapter 2, this chapter shows the theoretical and background for the main types of the DC-DC converter especially high gain converter, the types of switching cell, and its operation. Finally, the main methods of extracting maximum power from the PV cell are discussed and focus on one method to use.

In Chapter 3, analysis and design of (POSLC) and also explain a three-modification structure using three types of switching cells. in terms of CCM and DCM to derived the boundary conditions.

In Chapter 4, the simulation results of proposed converters, simulation of proposed converters using MATLAB software, the discussion of the results and compare with past result and show the advantages and drawbacks of each one.

In Chapter 5, this chapter shows the thesis conclusions and findings and the recommendation for future work.

CHAPTER TWO

Theoretical background

2.1. Introduction

DC-DC converters technique is power electronic systems that convert one level of electrical voltage into another level. It's also called the switching technique, due to the effect of the duty-cycle on the converter behavior. They are generally called according to their function. For instance, converters are Buck, Boost and Buck-Boost used in a large number of power conversion applications. Such as parts of computers, renewable energy systems, and digital systems [8, 22].
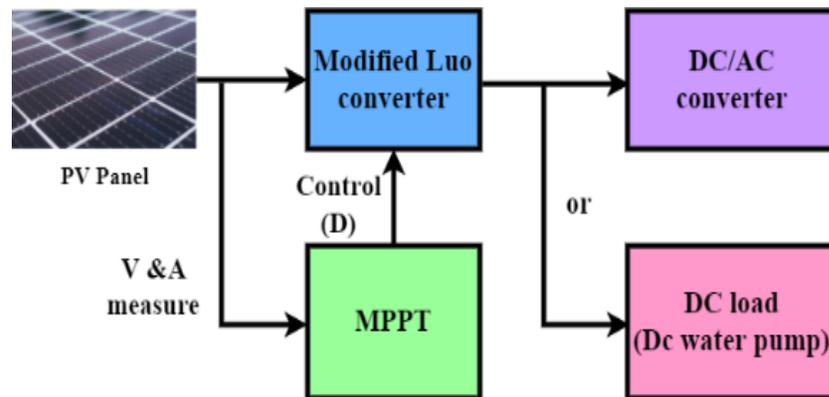
Fig 2.1: DC-DC converter in PV system

Cuk converter and Luo converters are updating to previous types, especially positive Output Super Lift Luo Converter (POSLC) in this research. The principle of operation of the converter is the storage of energy in its main components (inductors and capacitors) where the magnetic field that produce current is stored in the inductance and the voltage is stored in the capacitance through the ON and

OFF of the switch (charge pump). The diode work is to control the current path for the state of ON and OFF to ensure charging and discharging in the circuit [22]. Based on this principle, many of the DC/DC converter circuits are designed to be a stepping voltage or a degenerative voltage, as well as a positive or negative output because each has advantages and disadvantages associated with efficiency and reliability. Such as the number of components, the complexity of the number of switches, the state of closing and opening each one and save cost, etc., that included in [23]. Moreover, the core of the converter's work came through the urgent need to improve raise the DC-DC voltage to high levels for storage and energy transfer because storing in batteries requires high currents and transportation requires high voltage [24]. Therefore, some modern converters increase in geometric to quickly reach the required limit [25].

Obtaining high lift ratios comes through increasing the duty cycle. It must reach 80% of the time of the dominant wave. The switch here is taken seriously by the increased stress on the switches as well as limiting the lifting voltage. In order to use renewable energy such as the sunlight and the wind, therefore need circuits in the DC/DC field in order to achieve energy tracking and maintain a stable level because the energy of light and wind is changing, so the concern of researchers has become the most appropriate tracking of the energy source [26].

There are two modes of operation where the design of the converter can be based on, continuous conduction mode (CCM) and discontinuous conduction mode (DCM). These two cases are taken into consideration by design. The value of the inductor and the load state where the converter is able to work with a constant current (CCM) where the current does not reach zero, and it is the most used and the current ripple less, and the low efficiency. In the case of (DCM), the inductance current reaches zero and for each one a certain use. [8,22]. One of the

characteristics of the DCM state is the implementation of a small inductance to obtain a higher voltage lift as preferred when raising the voltage of the solar cell. [27]. briefly, can describe the operation of the two cases by looking at the effect of the Dynamic of the inductor at work, as the inductor pumping the capacitor before it's Charge is discharged, and this is a CCM case, after which the current signal is, complete and does not pass in the zero states. The capacitor was not injected by the inductor with a current and the capacitor discharge in the load. Both cases are CCM and DCM, the effect of which is the size of the inductance and the efficiency of the control because the responsible for charging and discharging is the switch and thus the duty cycle frequency [27, 28].

The Converters are classified into two basic types: i) The Isolated DC-DC converter contains of a transformer and ii) non-isolated dc/dc converter without a transformer. Figure (2.2) shows the scheme basic converters of Isolated and non-isolated converter.
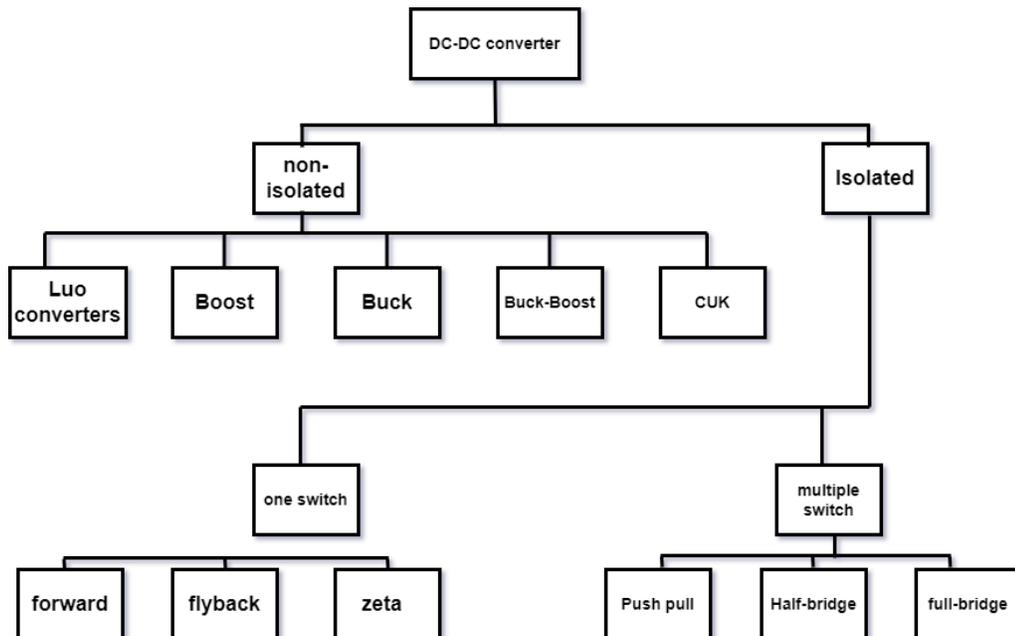
Fig 2.2: The basic classification scheme of DC-DC converters

Also, each of these types is divided into two types, which are synchronous and non-synchronous. The synchronous converter contains a transistor that can be controlled while the non-synchronous contains diodes which are switch that cannot be controlled and have their operational limits.

2.2. The DC-DC Converters without a Transformer (non-Isolated)

2.2.1. Buck Converter

Recently the development in the digital field, and as a result, many different digital devices have begun to appear to facilitate our daily life, as new undesirable obstacles have emerged accompanying digital development, such as running out of batteries and replacing them with new ones, and this has affected additional costs and obstacles. Therefore, the demand for battery charging technology has increased, and the tendency has become for the small size of devices that increasingly carry batteries. Here, the solution has become attractive in developing low-power DC/DC converters like Buck, although there are some flaws like high ripple and medium efficiency. However, this was not the case with continuous development, as work also began to develop and increase its efficiency [29, 30, and 31]. Just as we mentioned earlier in mentioning the cases that the transformer goes through are two CCM and DCM cases, preferably it is designed to work in the CCM case. In this case, buck converter work.at the switch-on current path through inductor and capacitor energy storage in the inductor. At switch close, an energy pump from inductor and capacitor to load mathematical of gain shows the behavior of this circuit in figure (2.3). The work it as step-down voltage [32, 33, 34].
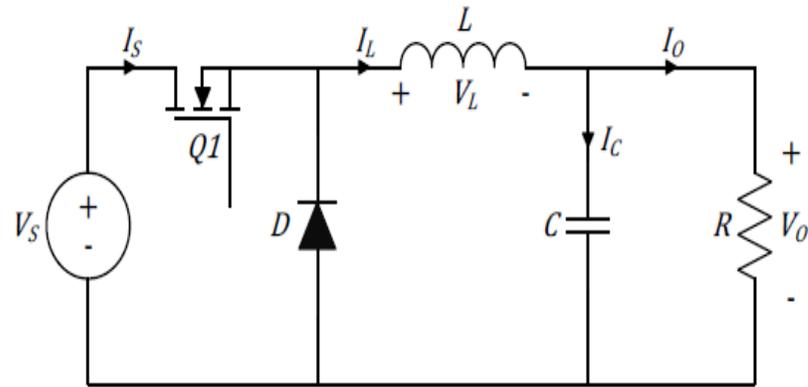
Fig 2.3: Buck converter [29]

2.2.2. Boost Converter

When using converter, usually need to raise voltages more than the previous ones for many uses such as the need for the load of a higher voltage from the source or for energy transfer as is the case in renewable energies such as wind energy, photovoltaic panels also need to maintain the voltage despite the change in the load because the voltage is always affected This is through a control circuit. Here, the boost circuit as shown in the figure (2.4) is the first department that has been used in this field [32].

And with reference to the effects on the rate of the lifting of the voltage always comes from the speed of the switch (frequency and work cycle) and some losses in the diode also decrease the efficiency due to increasing the voltage [35]. However, losses in the new technologies have become few by reducing switching, to become mostly up to 65%, and to allow a percentage change in effort of designing [25, 36]. It usually operates in continuous conduction mode (CCM) and notes the location of the switch-ON condition to be the current path from the

source to the inductor. It is to be a magnetic field that turns into a current and then
and when the switch is placed in a state of OFF [37].
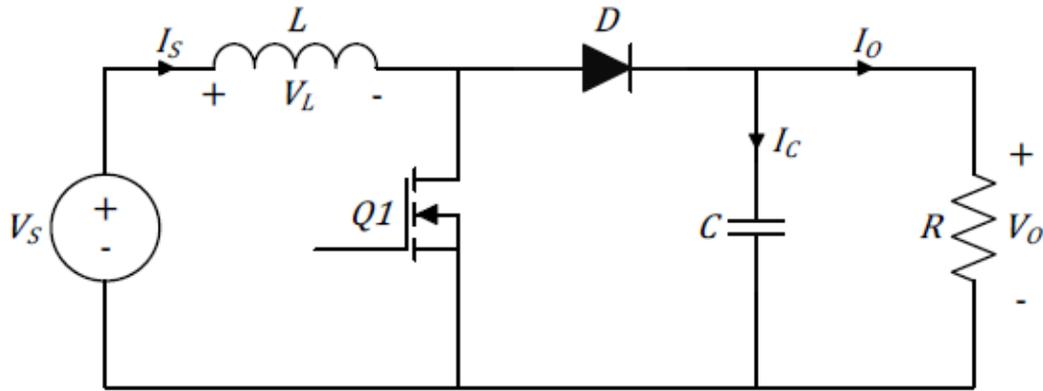
Fig 2.4: Boost converter [35]

2.2.3. Buck-Boost Converter

The buck-boost converter DC/DC converter. It works in third-quadrant operation.
Buck-boost combination of the buck step-down converter and boost step-up
converter. The output of them depends on the switch-duty [38]. The principle of
working of a buck-boost is somewhat similar to the previous techniques in terms
of the inductor and the switching process, but it differs in its structure. Certainly,
the advantages that make it combine the previous techniques in terms of lifting
and lowering. The gain equation describing its work, and since the renewable
energy sources need to be regulated because there are changes in the source makes
this type desirable There are similar converters in earning for buck-boost such as
CUK, SEPIC, and ZETA [22, 23]. As shown in the following figure (2.5) the basic
buck-boost circuit, which consists of a power switch, an inductance, diode,
capacitance, and load [32, 39]. The work of the buck-boost circuit is when the

switch ON state, the inductor is charged and the diode in the reverse bias (open circuit), where the load is isolated from the source and the current flow through the inductor is only. The second case of buck-boost circuit operation in which the switch OFF state, then the inductor becomes as a source where the power is supplied to the capacitor, the diode works forward biased to complete the current flow in the circuit. In the second cycle of the switch (2nd ON), the inductor is connected to it again with the source and the diode is also become in the case of an opposite bias to isolate the rest of the circuit, and the capacitor works as the source to discharge in the load. The current flows into the load Notice that the output voltage is resulting from the circuit becoming the opposite polarity, due to the polarity of the capacitor, the work continues in the second OFF state in which the inductor works as a source to pumped the capacitor by the energy, as well as the work of the diode in the case of a forward-biased to complete the current path [38]. The details of buck-boost convert and mathematical model with whole equations are presented in [39].
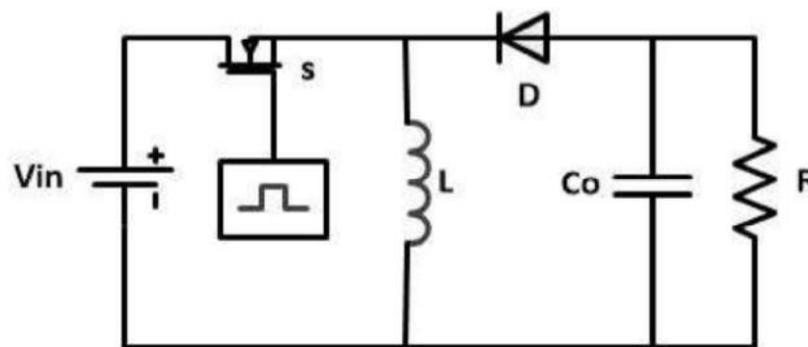
Fig 2.5: Buck-boost converter [39]

2.3. Positive Output Super Lift Luo Converter (POSLC)

In order to boost the voltage to several levels in the DC/DC converters, there are many techniques for this purpose. The positive super lift Luo converters are one of the best DC/DC converters due to the many advantages. The super lift Luo converter has a high voltage lift ratio and a geometric progression and the MOSFET switch connected in low side mode. It's used in a wide range of applications such as renewable energy, for example, Solar cells, wind energy.

The figure (2.6) shows the elementary circuit for (POSLC) [40]. As is known, the performance of all DC-DC converters is based on chopper the input voltage through an electronic switch. The switch operates, on and off states [41]. At switch on, the diode D1 is forward bias, and diode D2 Reverse bias, the inductor (L) and capacitor (C1) store energy in parallel, the inductor and capacitor voltage are equal to the input voltage. In a switch-off state, diode D1 is Reverse-bias, and diode D2 forward-bias. The discharge energy path of the inductor (L) and capacitor (C1) with source in series to the load [42].
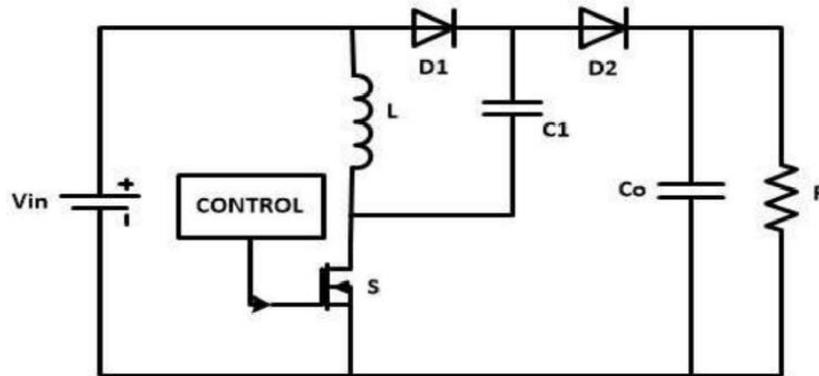
Fig 2.6: Positive Output Super Lift Luo Converters (POSLC) [40].

2.3.1: CCM analysis

Mode 1: (0 ~ DT): Switch ON:

In this mode, the condition of inductor it is the condition in which the inductor does not reach fully discharge (output zero) before the switch becomes (ON) in the long run, i.e., along time have Residual energy in an inductor Until the switch goes from off to on, in this case, the converter will operate at CCM [8], as shown in figure (2.7).
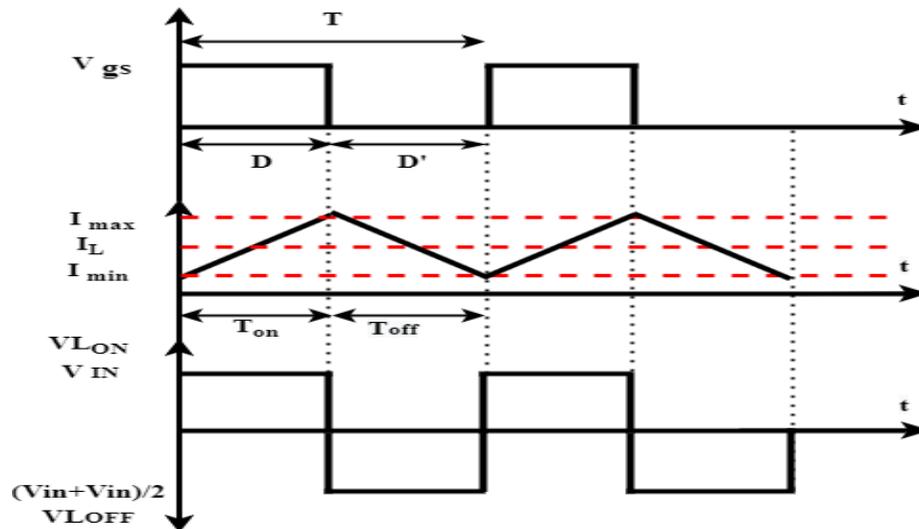
Fig 2.7: the waveform at CCM

When switch on, the inductor (L) and capacitor (C1) are charge in parallel by (V_{in}) and the D2 will be in reverse bias. The voltage across the inductor and capacitor can be indicated as bellow.

$$V_{in} = V_L = V_{C1} \tag{2.1}$$

In a parallel connection, the source voltages become equal on all terminals. Refer to equation (2.1). This causes the inductor (L) to charge in a magnetic field that

leads to a current in the case of discharge at the same time capacitor. In this case, C1 is charging up to the value of the voltage source.

Mode 2 :(DT (1-D) T): switch off

When the switch off, the capacitor and the inductor will be released the storage energy to the output capacitor. In the case, D2 forward-bias, while D1 reverse-bias i.e., cut off state, then the current path becomes composed of the output capacitance (Co), the capacitor (C1) of the source and the inductor (L), in series close loop. This circuit has operational advantages such as when S-ON the passive element are charging in the parallel and gives speed in charging. Another advantage, when S-OFF the passive element are discharging in series which means it gives the sum of the voltages present in the elements such as inductor and capacitor, this causes the speed of reaching the required output voltage (geometric behavior).

Steady-state operation requires that i_L at the end of the switching cycle is the same at the start of the following cycle. That is the change of i_L over one duration is zero. Briefly (no change in the output signal at any period). According to the principle of the Volt-Second balance equation state that the sum of voltage across inductor at on stage and off stage is equal zero [43, 44].

$$V_{L(ON)}DT + V_{L(OFF)}(1 - D)T = 0 \qquad (2.2)$$

DT: Duty cycle at switch-on.

(1 - D)T: Duty cycle at switch-off.

$$V_{in} = V_L = \frac{L\,di}{dt} \qquad\qquad at\ switching-on \qquad (2.3)$$

$$V_O = V_{in} + V_L + V_{C1} = 2V_{in} + V_L \qquad at\ switching-off \qquad (2.4)$$

$$di = \frac{V_L \, dt}{L} = \frac{V_O - 2V_{in}(1-D)T}{L}$$ (2.5)

From above equations and charge time of inductor = discharge time

$$v_0 = \frac{2-D}{1-D} v_i$$ (2.6)

Equation 2.6 is the final equation which represents the gain of the circuit. D is the conduction duty cycle, through the equation; note that the magnification ratio of the voltage is high for the presence of D in the denominator of the equation [44].

In the relationship of output voltage with duty cycle for elementary circuit of (POSLC), it's Clarify raising the value output voltage at increase the duty cycle. It gives great importance to control the value of the duty cycle that leads to controlling the output of the converter [43].

2.3.2. DCM Analysis

During switch off period, when the inductor fully discharged due to load condition or change frequency and the current of the diode will decrease to zero, the converter will operate at DCM as shown in figure (2.11). In this mode, the converter has a special advantage in certain conditions such as its use in renewable energy, for example, wind energy because of the converter in this case is lifting the output voltage more than in the CCM. In mathematical analysis, the off-time is divided into two parts: discharge time and zero time [43, 44].
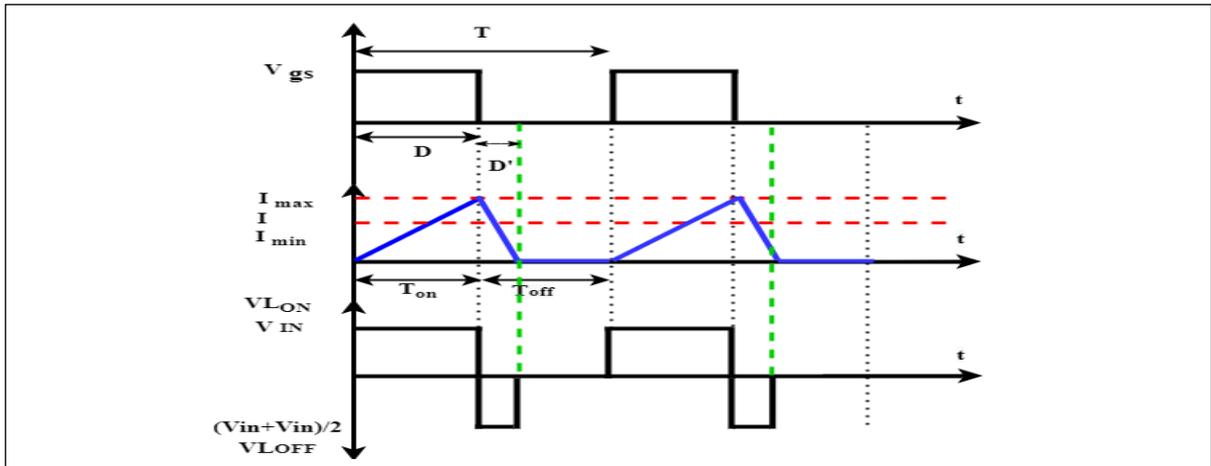
Fig (2.8) voltage and current waveforms of inductor during DCM

Mode 1 (0-DT): Switch-on

$$V_L = \frac{L\, di}{dt} \tag{2.7}$$

Equation 2.7 is Faraday's Law (Theory of Inductor), with time t1.

$$V_{in} = \frac{L\, di}{dt1} \tag{2.8}$$

$$di = \frac{V_{in}\, DT}{L} \tag{2.9}$$

For equation (2.9) previously, in (CCM), VL can be easily analyzed as the circuit is stable. In the case of (DCM), it is a sudden and unstable period of time during which the converter operates according to the load conditions, so it is not possible to analyze the VL. Still, it becomes easier to analyze the change in the inductor current (I_L)[44].

Mode 2 (DT~(1-D) T): Switch-off

Where t2 is the time switch-OFF and (1-D) is the period of discharge before the inductor is full discharged.

$$V_L = \frac{L \, di}{dt2} \tag{2.10. a}$$

Equation (2.10a) is Faraday's Law (Theory of Inductor), with time t2.

$$\Delta i = \frac{(v0 - 2v_{in}) \ (1 - D) \ T}{L} \tag{2.10 b}$$

Equal eq. (2.10.a) & (2.10.b), Equation (2.11) can be obtained:

$$V_{in}D = (V_O - 2V_{in})(1 - D) \tag{2.11}$$

$$D_2 = V_{in} \, D/V_O - 2V_{in} \tag{2.12}$$

Equation 2.12 represents duty cycle (D2) at switch-off in a condition (DCM).

$$I_{CO} = I_L - I_O \tag{2.13}$$

Equation 2.13 through which I_O is easily calculated, as I_{CO} becomes zero at steady state condition.

$$I_L = (1 - D)di \, L/2 \tag{2.14}$$

From signal figure (2.11) (to calculate the area of a triangle mathematically).

At steady state $I_{CO}=0$,   sub 2.14 in 2.13

$$I_O = (1 - D)di \, L/2 \tag{2.15}$$

$$I_O = \frac{V_O}{R} \tag{2.16}$$

Sub 2. 9, 12, 16 in 2.15

$$\frac{V_O}{R} = \left(\frac{V_{in}D}{V_O - 2V_{in}}\right) * \left(\frac{V_{in} \, DT}{L}\right) \tag{2.17}$$

T=1/F (2.18)

τ=fL/R (2.19)

$$V_0^2\tau - 2v_0 V_{in}\tau - \frac{1}{2}v_{in}^2 D^2 = 0 \tag{2.20}$$

Then sub 2.17 and 2.19 in 2.20 and solve by law to get (V$_O$):

$$Vo = \frac{2Vin\ \tau \pm \sqrt{(2vin\tau)^2 - 4\tau(-\frac{1}{2}vin^2\ D^2)}}{2\tau} \tag{2.21}$$

$$v_0 = 1 \mp \sqrt{1 + \frac{D^2}{2\tau}} * v_{in} \tag{2.22}$$

$$\frac{Vo}{Vin} = 1 \mp \sqrt{1 + \frac{D^2}{2\tau}} \tag{2.23}$$

Equation (2.23) is equation gain at DCM state. By equal, equation (2.6) (voltage gain at CCM state) and equation (2.23) (voltage gain at DCM state) Boundary condition CCM&DCM.

$$\frac{2-D}{1-D} = 1 \mp \sqrt{1 + \frac{D^2}{2\tau}} \tag{2.24}$$

$$\tau = \frac{D^2}{2\left(\left(\frac{1}{1-D}\right)^2 - 1\right)} \tag{2.25}$$

2.3.3. Design positive output super lift Luo converter (POSLC):

To validate the performance of the elementary of (POSLC) need to do some design calculations to ensure the circuit operates in the CCM case.

$$v_0 = \frac{2-D}{1-D}v_i \tag{2.26}$$

At designing, losses negligible because it's very small

$$P_{in} = P_0 \tag{2.27}$$

$$I_{in} = \frac{I_0 v_0}{v_{in}} \tag{2.28}$$

Sub eq. (2.26) in (2.28) Give an equation 2.29:

$$I_{in} = \frac{2-D}{1-D} I_0 \tag{2.29}$$

At steady state, the charging time for the output capacitor is equal to the discharging time.

Equation (2.30) is the Capacitor-Charge Balance equation:

$$Qc_0^+ = Qc_0^- \tag{2.30}$$

$$i_{in-on} = i_{L-on} + i_{c1-on} \tag{2.31}$$

$$i_{in-off} = i_{L-off} = i_{c1-off} \tag{2.32}$$

If inductance L1 is large enough, iL1 is nearly equal to its average current iL1. Therefore:

$$i_{in-off} = i_{c1-off} = I_L \tag{2.33}$$

$$i_{in-on} = I_L + \frac{1-D}{D} I_L = \frac{I_L}{D} \tag{2.34}$$

Because

$$DT\, i_{c1-on} = (1-D)T i_{c1-off} \tag{2.34a}$$

And average input current:

$$I_{in} = D\, i_{in-on} + (1-D)i_{in-off} = I_L + (1-D)\, I_L = (2-D)I_L \tag{3.34 b}$$

$$\frac{Vin}{Iin} = (\frac{1-D}{2-D})^2 \frac{Vo}{Io} = (\frac{1-D}{2-D})^2 R \tag{2.35}$$

The variation ratio of inductor current i_L is:

$$\xi = \frac{\Delta i L/2}{I_L} = \frac{D(2-D)T\ Vin}{2\ L\ Iin} = \frac{D(1-D)^2}{2(2-D)}\ \frac{R}{fL} \tag{2.36}$$

The variation ratio(ξ) is recommended between these values (0.2 to0.4)[43].

The ripple voltage of output voltage (V_O) is:

$$\Delta v_0 = \frac{\Delta \mathbb{Q}}{C_O} = \frac{Io(1-D)T}{C_O} = \frac{1-D}{f\ C_O}\ \frac{Vo}{R} \tag{2.37}$$

Therefore, the variation ratio of output voltage (V_O) is [8]:

$$\varepsilon = \frac{\Delta v_0/2}{v_0} = \frac{1-D}{2fRC_0} \tag{2.38}$$

The variation ratio of output voltage ε Recommended 5% or less than [45].

$$\Delta v_{C_1} = \frac{\Delta Q}{C_1} \tag{2.39}$$

Note that: the minimum value of the inductor is the lowest value that makes the converter work in CCM. If the value is less than the converter is work in DCM case. From eq. (2.10 b) and eq. (2.34), can get L_{min} and C_{min}

$$L_{min} = \frac{(v0-2v_{in})\ (1-D)}{f\ \Delta i} \tag{2.40}$$

$$C_{min} = \frac{1-D}{2fR\ \varepsilon} \tag{2.41}$$

$$C_1 = \frac{Io(1-D)T}{\Delta v_{C_1}} = \frac{Io(1-D)}{f\ \Delta v_{C_1}} \tag{2.42}$$

The ripple is of two types, voltages ripple (produce from boost capacitor C1) and current ripple and (produce from the inductor L) which is the main elements that make up the converter. To reduce a ripple should be designed filter at the output of the converter. But in proposed converter make inductors values equal and capacitor (C1) in hybrid cell contribute well to reduce ripple [8].

Table (2.1): Comparison between the negative output super- lift Luo converter and some basic boost converters [13]

attributes	Conventional boost converter					
	Buck	boost	Buck-boost	Cuk	Positive output Luo	POSLC
Voltage gain expression	D	$\dfrac{1}{1-D}$	$\dfrac{D}{1-D}$	$\dfrac{-1}{1-D}$	$\dfrac{1}{1-D}$	$\dfrac{2-D}{1-D}$
Gain at D=0.5	0.5	2	1	1	2	3
No. switches	1	1	1	1	1	1
No. components	3	3	3	5	6	5
No. diodes	1	1	1	1	2	2
High/low side gate driver	high	low	high	low	low	high
Common ground	yes	yes	yes	yes	yes	yes

According to the table (2.1) in comparison of (POSLC) with other traditional converter, can see that the (POSLC) is produce large output voltage gain than other converter that used one active switch only. The CUK converter is the same of Luo converter in gain equation but CUK is negative and used less number of elements.

Table (2.2): Comparison between (POSLC) and (NOSLC) DC-DC converters.

attributes	POSLC	NOSLC
Voltage gain formula	$\dfrac{2-D}{1-D}$	$\dfrac{-1}{1-D}$
Gain at D=0.5	3	2
No. switches	1	1
Component count	5	5
No. of diodes	2	2
High/low side gate driver	low	High
Common ground	yes	yes

The table (2.2) shows comparison (in numbers) between (POSLC) and (NOSLC) in term of elements count and diodes, the (POSLC) is positive output and more voltage gain than (NOSLC).

2.4. Component Losses of DC/DC Converter

The voltage on both ends of the switch is formed as a result of the speed of switching the switch (ON and OFF). When the switch is ON, the voltage is not reached to zero and the current is rapidly increasing at the same time, resulting in losses because voltage and current are changed at maximum ranges. This will result in a loss of power. The most significant losses are caused by the large number of components. During quick switching operations, the number of diodes produces some losses, and the number of switches causes some losses. Losses can also be reduced by reducing the number of components and using the appropriate diode. For switching situations, the frequency can be reduced and MOSFET can be used instead of the regular transistor. The losses resulting from the switching process are reduced by taking advantage of the resonance process or the resonant

frequency [38]. Leakage inductances, high voltage stress, and electromagnetic interference are some of the other switching losses. In isolated converters, losses are exacerbated by the use of a transformer and passive components. Isolating the converter from the source voltage, which leads to the isolation of the load current from the source current by employing a transformer, is one condition that reduces converter losses. To reduce losses, it's best to run the converter in CCM mode. It also lowers the frequency of the switch's operation noise [25, 37].

2.5: Cells Technique (Voltage Multiplier Cell)

There are many ways to raise voltages, but each one has limitations, advantages, and disadvantages. One of them is the increased duty cycle by the control circuit of the switch; the primary Lifting converters must operate with a certain value for the duty cycle, from 0.1 to 0.9 the higher the voltage will increase, also for buck converters [45]. But there are limitations. Where the increase in the duty cycle leads to the switch working more often to losses due to temperature as a result of continuous work and less efficient. Also, the voltage can be raised by increasing the frequency but there are limits to the operation of the switch at very high frequencies and consequently lead to other losses as a result of the failure to reach the switch to zero when state OFF. There is also a third way to raise the voltages, which is through the multiple stages (cascade-connect) of the same converter and also has limits to raise the voltage because it will decay if the stages increase more than that, the cost increase is also due to the increase in components of the circuit in this way. There is another way around raising voltages, and the last is based on adding an inductance or capacitance individually in designated places where it works to raise the voltages, the capacitance technique is the switched capacitor (SC) method is voltage-boosting primarily based on a charge pump (CP) circuit that is used in often converters. Voltage-level improvement in (CP) circuit comes

entirely from the capacitive power switch. A lot of many techniques to (CP) circuit, (SC) topologies are widely used due to their structuralism it and Lift voltage integration method. Figure (2.9), practically there are two switches that are turned ON & OFF in sequence. When the switch (A) becomes ON, capacitor (C1) charges until equals the input voltage level, and when the switch (B) is growing to become ON, the stored, electricity in (C1) transfers to the capacitor (C2) and the switches are change alternately. This technique is known as feed the energy from one capacitor to another and after many of cycles the output voltage reaches voltage level design. Now it does not give high values of lifting voltages, but it is better than its predecessors as it is characterized by lifting as a geometric sequence of voltages and higher values. Here comes the most important talk about the use of the cell, which is the best among the aforementioned methods, because it provides many advantages for raising voltages, as it is considered a progressive revolution in the history of DC/DC converters.

Among these features are very high lifting values, the small size of the converter, and speed to obtain the required voltages because the transition period has very few compared to other cases where it works in the geometric sequence method. Also, the fewest number of components[46].

 Therefore, discuss the types and shapes of the cell, as well as methods of connecting it in the converter and its work as shown in the figure (2.10) (A) switching capacitor cell, (B) switching inductor cell and (C) hybrid switching inductor-capacitor cell for later.
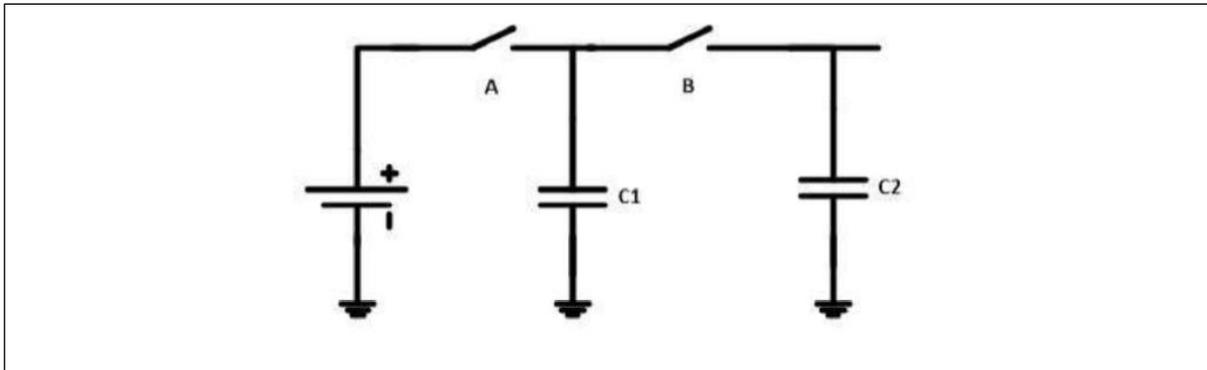
Fig 2.9: Basic charge pump
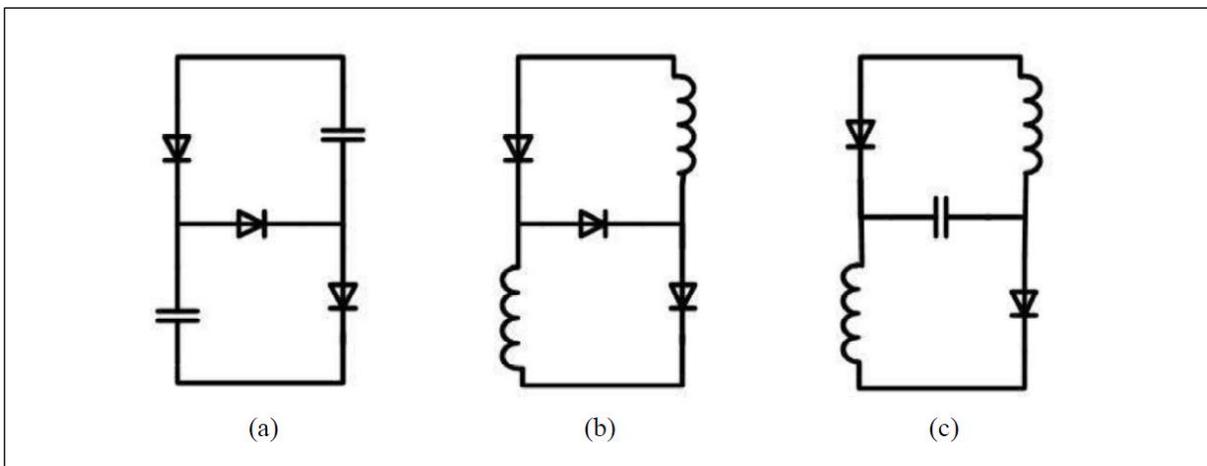
Fig 2.10: voltage multiplier cell a) switching capacitor cell b) switching

Inductor cell c) hybrid switching inductor-capacitor cell [47]

Many types of cells multiply the voltage. From them, it can be controlled through switches and another in the form of a star and delta and it has many shapes (see Resource No. [22], which shows many different types.

What concerns us from the cell-connected technology is that consisting of diodes, capacitors, and inductors to multiply the voltage as shown in Figure (2.19.a) switching capacitor cell, (B) switching inductor cell and(C) hybrid switching inductor-capacitor cell. Methods of connected the cell. Where it can be connected

in dc/dc converters voltage can it placed them in the location of the inductor (changing the inductor with a cell).

2.6: Photovoltaic System

Photovoltaic system provides customers with the capacitive and efficient electricity. Photovoltaic systems consist of photovoltaic cells, equipment which converts light energy directly into electricity. Because the sun is usually the source of light, they are often referred to as solar cells. The photovoltaic process is to "produce electricity directly from sunlight." Photovoltaic is often referred to as PV. Photovoltaic cells directly convert sunlight into energy without causing emissions. PV cells are made of semi-conductor material in at least two layers. One surface is positively charged, the other negative. The semiconductor atoms absorb some of the photons from the beam as light enters the cell and release electrons from the negative layer of the cell to flow back into the positive layer through an internal circuit. This electrons flow produces electrical current [48].

2.6.1: solar panel:

Solar energy is the most important type of renewable energy generation systems since it is clean, pollution-free sustainable energy as well as the increasing cost-of-electricity which causes high-growth demands amongst utility customers [48].

Growing concerns for the depletion of the world's natural resources and our future energy supply has increased the development and adoption of solar power. The most critical advancement in the development of solar technology has been Photovoltaic, a solar energy system that uses semi-conductors to directly convert solar radiation into electricity [49]. The 'photovoltaic effect' – the ability to create an electrical current using solar rays – was initially discovered in 1839 by Alexandre Becquerel. The technology has developed substantially, with modules

becoming more and more efficient and cost-effective. Much of this research was done leading up to the 1970s and was commemorated by Jimmy Carter putting solar panels on the White House. They were taken down by Richard Nixon shortly thereafter, but the pioneering solar spirit lives on as people across the world continued to adopt solar panel systems [50].

Due to the continued adoption, companies have continued investing in the technology, which has caused the efficiency of most solar panels to increase to between 15-20% – the rest is lost as heat (in comparison, creating electricity from fossil fuels has an efficiency rate of ~40%). This has also resulted in a significant drop in price for solar panels. In the last decade, priced have decreased by over 80% [51].

The process of converting light (photons) to electricity (voltage) is called the solar photovoltaic (PV) effect. Photovoltaic solar cells convert sunlight directly into solar power (electricity). They use thin layers of semi-conducting material that is charged differently between the top and bottom layers. The semi-conducting material can be encased between a sheet of glass and/or a polymer resin. When exposed to daylight, electrons in the semi-conducting material absorb the photons, causing them to become highly energized. These move between the top and bottom surfaces of the semi-conducting material. This movement of electrons generates a current known as a Direct Current (DC). This is then fed through an inverter, which converts the power to Alternating Current (AC) for use in your home.

Different types of solar PV installations require slightly different components. However, in the next two sections explained in detail all the main components that will make up the solar PV array. The solar cell model is shown in fig (2.11).
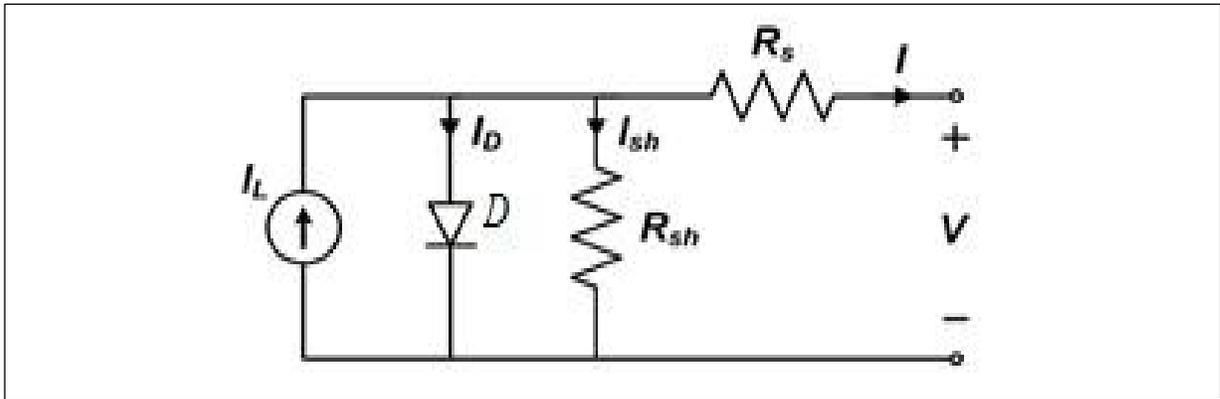
Fig 2.11: PV model circuit [52]

2.6.2: Maximum Power Point Tracking (MPPT)

Full monitoring of power points is an electronic system that maximizes solar panel energy. The efficiency of solar cells is little of about 12% [53]. The operation of the PV module at the maximum power point is therefore necessary to ensure maximum generated power with continuous change of weather conditions [54]. The MPP is not at a certain point but it moves around the curve (P-V) with temperature change and light intensity, so the MPP will change with environmental conditions [55]. MPPT's main objective is to improve the efficiency of solar panels by extracting maximum energy from photovoltaic cells. MPPT can extract more than 97% of the PV power when properly optimized [56, 57]. There are many algorithms used in Maximum power point tracking to perform calculations by reading the voltages and current of the solar panel and then extracting the maximum power point.

Here are some techniques used to track the maximum power point, such as:

1- Perturb and observe (P&O)

2- Incremental conductance

3-Current sweep

4- Constant voltage

5- Temperature Method

6- Fuzzy logic control

7- Neural network

8- Particle swarm optimization (PSO)

The perturb and observe method is widely used in control the MPPT, which is one of the most widely used methods for easy implementation and simple structure. P & O technology monitors the photovoltaic array output power and perturbation (increase or decrease) [58]. The perturb and observe method is a hill climbing

Technique that works to find the maximum position in the power curve in the case of the operation of the electric array as shown in Figure (2.12).
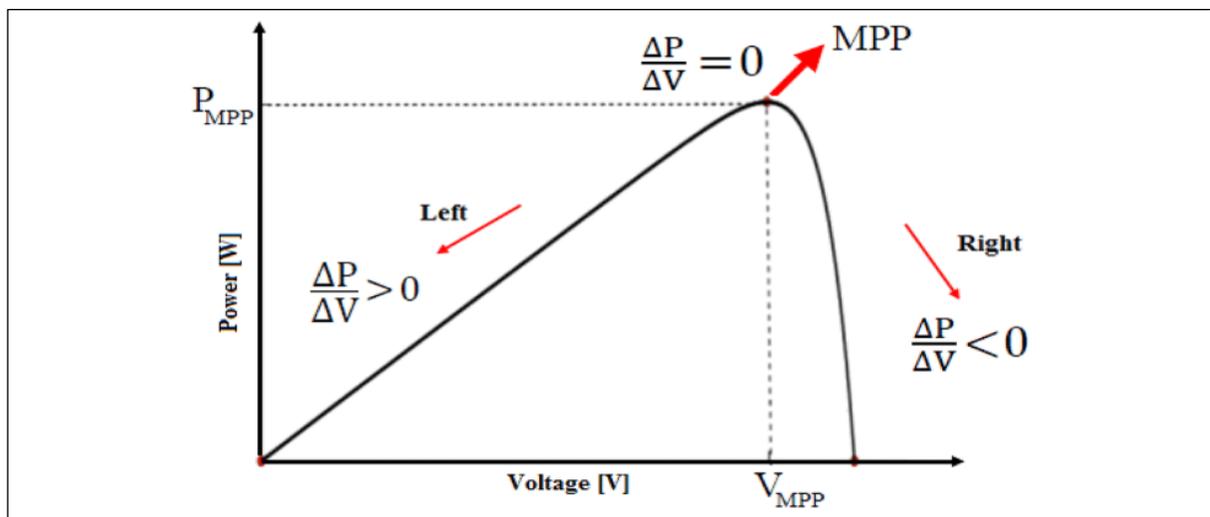

Fig 2.12: P&0 Method [59].

The concept of the perturb and observe method is to modify the operating voltage or the photovoltaic current to obtain maximum power from it.

The operation point of the PV unit is different if the load changes [59]. The P & O method contains only two sensors. Current and voltage sensing after energy is calculated, this method works on the voltage nuisance and notes the effect of the output power to obtain the required point (MPP) [60]. When the MPP is reached, the system then oscillates around the MPP. In order to minimize the oscillation, the perturbation step size should be reduced. If the operating point is away from MPP, the change in the work cycle is a larger step [57]. If dp/dv >0 , the point of action is considered to be on the left side of the MPP and to shift towards the MPP so that the disturbance path is held in the direction. The operating point is located on the right when dp/d<0 , so the direction should be reversed because it has moved away from MPP.

The maximum point can be obtained when (dp/dv=0) [61]. The algorithm can manipulate the operating voltage freely by varying the duty cycle ratio. Any change in the duty cycle will consequently have an inverse effect on the input resistance of the DC/DC converter. One disadvantage of the P&O method is the fluctuation in the case of reaching the maximum point. To eliminate this fluctuation, an improved technique should be used to increase the tracking speed. The power is therefore wasted before reaching the MPP. The solar module's efficiency for power generation is therefore reduced [62, 63].

Chapter three

The design and modeling of the modified Luo converters

Chapter Three

The design and modeling of the modified Luo converter

3.1: Introduction

This chapter presents three modifications of (POSLC), the first modification for (POSLC) circuit depend on switching inductor cell, as well as, the mathematical analysis of this modification is explained in terms of CCM and DCM. A second modification of the (POSLC) circuit based on switching capacitor cell and explaining the mathematical model for it and detailing each step of the mathematical analysis and also inferring its design of equations. The third modification is expanding hybrid switching capacitor-inductor cell as well as, the mathematical analysis of this modify is explained in terms of CCM and DCM. Finally, a mathematical analysis of the control unit and reason of use it has been presented in this chapter.
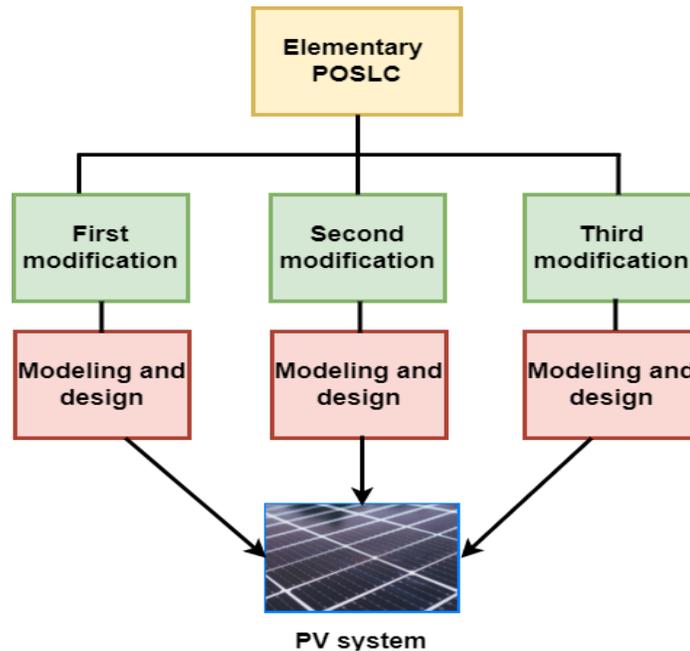

Fig 3.1: Block diagram of research method in chapter three

3.2: First modification of (POSLC) using inductor switching cell

The reconstructing of the Luo DC/DC converters raising voltages to high levels, in several ways, including increasing the duty cycle or increasing the frequency that controls the switch. Both cases get worse. The reason is that there are limits to the duty cycle that cannot be crossed. Also, there are limits to the frequency of switch. So, the best solution is to raise the voltage, which is to replace the inductor with a cell. This latter has many advantages, including the possibility to raise a high voltage without any effect on the converter, as in Figure (3.2).
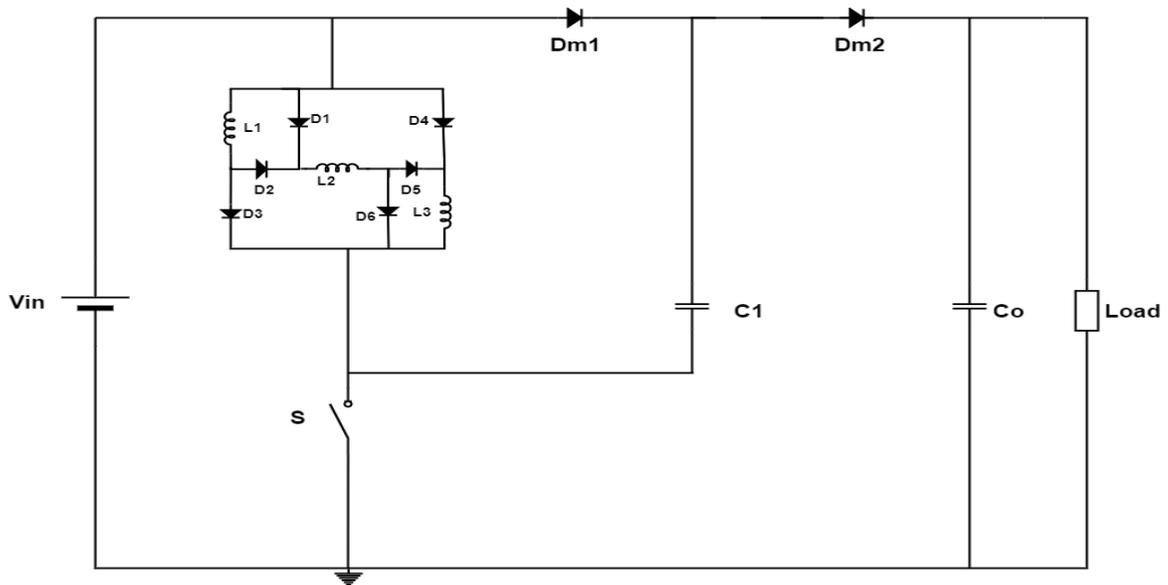
Figure 3.2: The first modification for (POSLC) using (SI) cell

The work of the cell lies in doubling the voltage many times according to the number of inductors, by the storing the voltage in its elements during the state of the switch on and releasing it at the same time during the state of the switch-off. This is observed in the case of charging (switch-on) the current path of the inductors (L1), (L2), and (L3) and the capacitor (C1) in parallel to provide speed in the charging. Either in the case of discharging (switch-off) capacitor (C1), the inductors (L1), (L2) and or (L3), respectively, in order to give the sum of charges

in the elements at once and this is the aim of the cell. This will be illustrated by the mathematical analysis of the circuit shown in Figure (3.3) and (3.4).

3.2.1. Mathematical analysis of first modification of (POSLC) for (CCM)

Mode 1: (0-DT)

Switch-ON

When the switch-on, the diode (Dm2) is in reverse bias (current cut off), and the diode (Dm1) is in forwarding bias (provides a path for the current). Therefore, inductor (L1), inductor (L2), inductor (L3) and capacitor (C1) all of these become connected in parallel, as shown in figure (3.3). Since the diodes (D1, D2, D3, D4, D5, D6) are forward bias. The inductance and capacitance are equal voltage.

$$V_{in} = V_{L1} = V_{L2} = V_{L3} = V_{C1} \tag{3.1.a}$$

Let the input voltage is the battery source with 12 V

Equation (3.1a) will be

$$V_{in} = V_{L1} = V_{L2} = V_{L3} = V_{C1} = 12V \tag{3.1b}$$

$$V_{in} = V_L \tag{3.2}$$
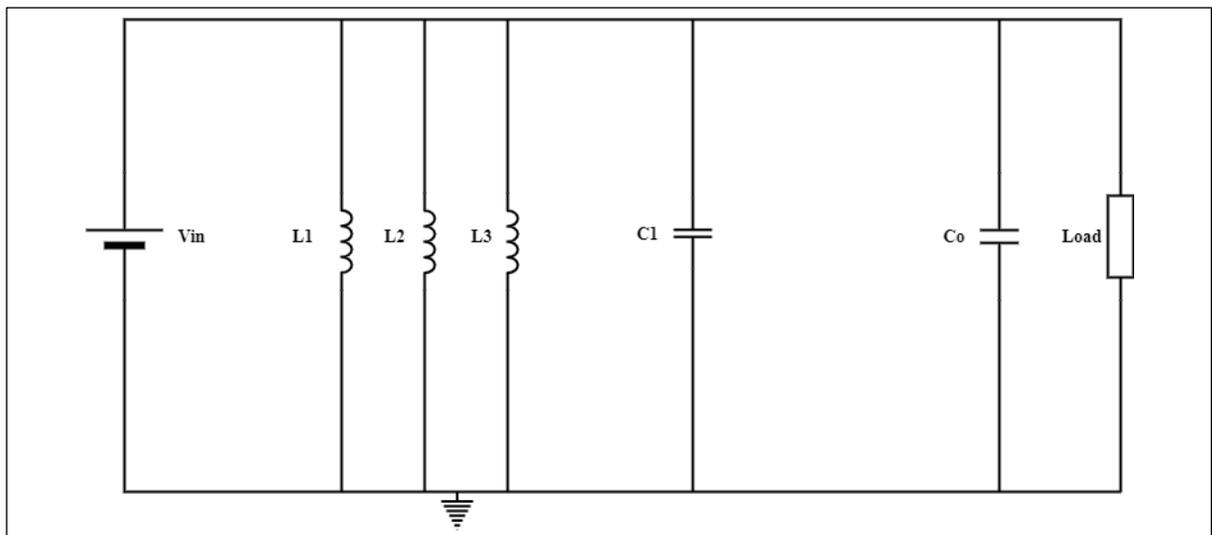
Fig 3.3: First modification of Luo converter at switch - ON

$$v_{in} = L\frac{di}{dt} = L\frac{\Delta i}{DT} \tag{3.3}$$

$$\Delta_i = \frac{v_{in}DT}{L} \tag{3.4}$$

$$\zeta_L = \frac{\Delta I_L}{2\,I_L} \tag{3.5}$$

Mode 2 :(DT (1-D) T):

Switch OFF

When the switch-off state, the energy stored in the elements will be flow to the load. The diodes (Dm1, Dm2) become in the case forward bias. so that the capacitor (C1) current path, inductor (L1), inductor (L2) and the inductor (L3) connected in series as shown in figure (3.4).
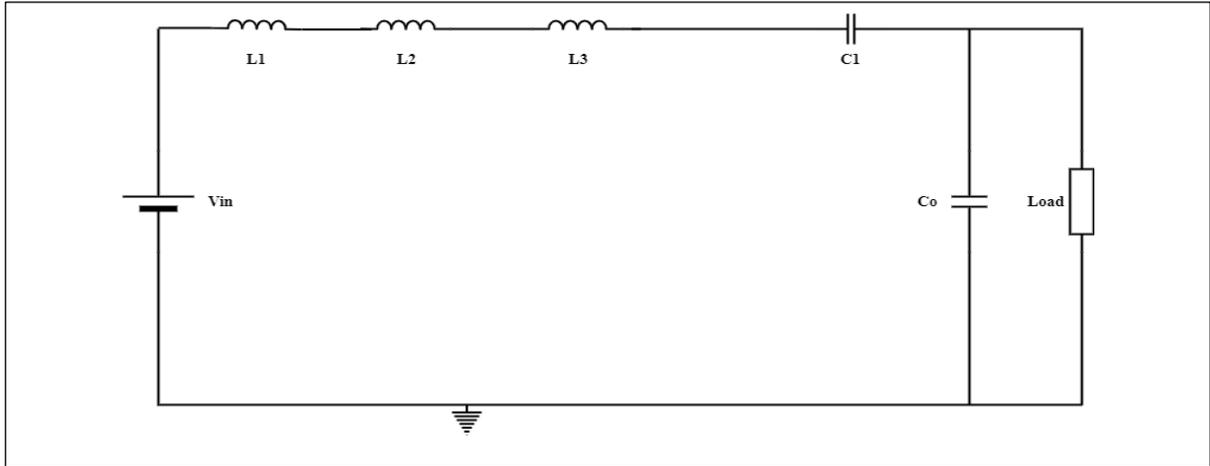
Fig 3.4: First modification of Luo converter at switch – OFF

$$3v_L = v_0 - 2v_{in} \tag{3.5.a}$$

$$3v_L = \frac{3L\,di}{dt} = \frac{3L\,\Delta i}{(1-D)T} \tag{3.5.b}$$

$$\Delta i = \frac{(V_o - 2V_{in})\,(1-D)T}{3L} \tag{3.6}$$

Figure (3.5) shows the charging time of the current is equal to the discharge time, for that the total value is zero according to the equation (3.7). From the Volt-Second balance equation:

$$VL_{on}\, DT + VL_{off}(1 - D)T = 0 \tag{3.7}$$
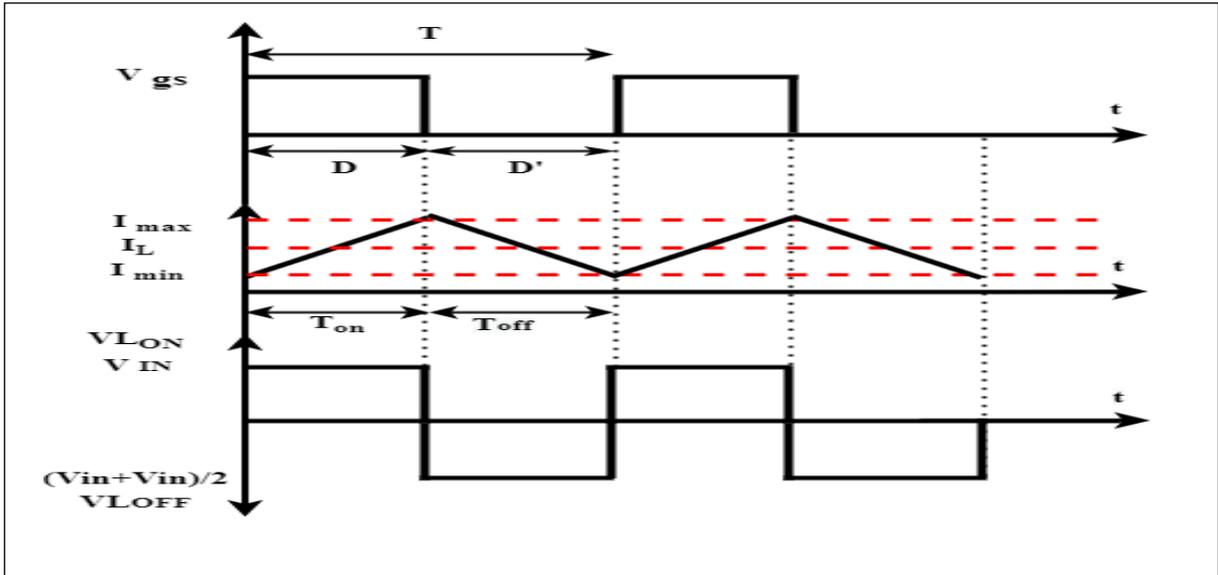
Fig 3.5: Current and voltage waveforms of the inductor for the first modification of Luo converter at CCM

By equal equations 3.5 b   and 3.6 we get:

$$\frac{Vo}{Vin} = \left(\frac{2+D}{1-D}\right) \tag{3.8}$$

The above equation is the gain formula for CCM

The equation (3.4) shows the number of lifting voltages and in comparison, with the equation (3.8), note that the numerator contains (2 + D) were the difference. Because it exceeds the ratio over the previous. In short, see an increase in gain.

3.2.2. Discontinuous conduction mode (DCM)

Figure (3.7). Shows current waveforms at DCM state. Also analyses the converter when (DCM) state, shows its mathematical behaviour, and extracts the gain equation at the end of this case

Mode 1 :(0-DT)

Switch-ON

As the same of CCM from eq. 3.6

$$\Delta_{iL} = \frac{v_{in}DT}{L} \tag{3.16}$$

Mode 2 :(DT (1-D)T)

Switch-OFF

From equal equation 3.6 and 3.7 we get

$$(1 - D) = \frac{3V_{in}D}{V_o - 2V_{in}} \tag{3.17}$$

Equation 3.17 represents the off-time duty cycle of the converter

$$Ic_0 = I_L - I_0 \tag{3.18}$$

$$I_L = \frac{1}{2}D'\Delta i_L \tag{3.19}$$

Equation 3.19 is the area under the curve of the inductor current signal during the off-state as shown in fig (3.7)

$$I_{Co} = \frac{1}{2}D'\Delta i_L - Io \tag{3.20}$$
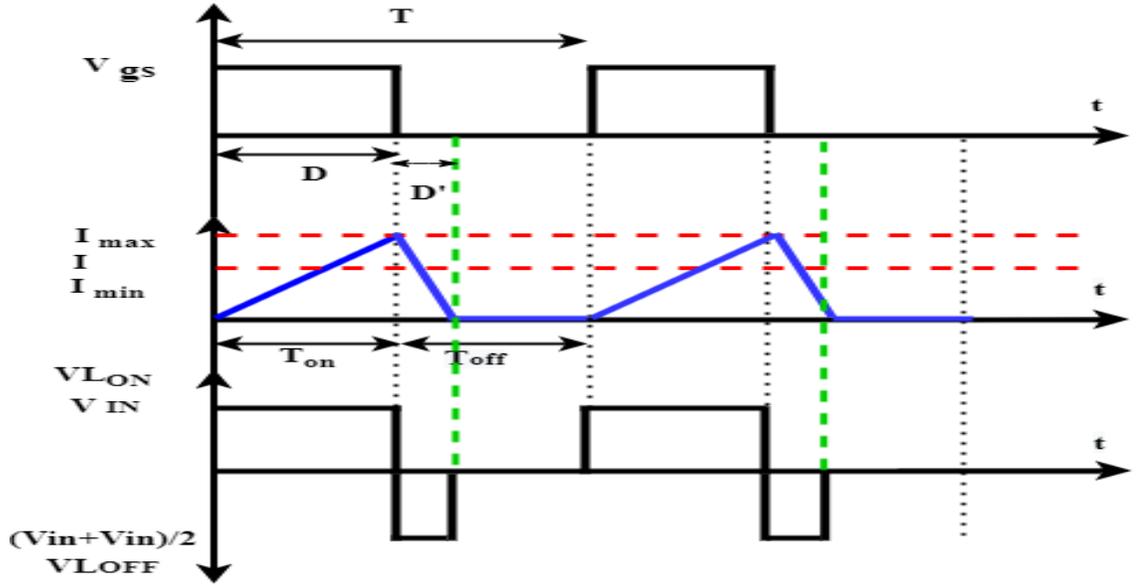
Fig 3.7: Current and voltage waves of first modification of (POSLC) at DCM

At steady state $I_{CO} = 0$

$$Io = \frac{1}{2}D'\Delta i_L \tag{3.21}$$

$$\frac{1}{2}\frac{3V_{in}D}{V_o - 2V_{in}} * \frac{v_{in}DT}{L} = \frac{Vo}{R} \tag{3.22}$$

$$\frac{1}{2}\frac{3v_{in}^2D^2}{V_o - 2V_{in}} = V_o\tau \tag{3.23}$$

$$Vo^2\,\tau - 2\,Vo\,Vin\,\tau = \frac{3}{2}\,V_{in}^2\,D^2 \tag{3.24}$$

Equation 3.24 solved by law rule:

$$Vo = \frac{2\,Vin\,\tau \mp \sqrt{(2Vin\,\tau)^2 - 4\tau(\frac{3}{2}V_{in}^2\,D^2)}}{2\tau} \tag{3.25}$$

$$Vo = 1 + \sqrt{1 - \frac{3\,D^2}{2\tau}}\ V_{in} \tag{3.26}$$

The equation 3.26 is the gain equation in DCM we get it after mathematical simplicity

Note: To minimize ripple in circuit that involve a cell, the inductance values of (L1), (L2) and (L3) must be equal value when designing. Because the ripple is the result of a switching process that occurs on inductance or capacitor. When adding a cell whose inductor are equal in values, this increases the value of the inductive impedance and thus prevents ripple. Also, for the first modification (POSLC), by equal, equation (3.8) (output voltage (VO) CCM state) and equation (3.26) (output voltage (VO) at DCM state) producing an equation (τ) (3.27), will get on Boundary condition CCM&DCM.

$$\tau = \frac{3\,D^2}{2\left(1-\left(\frac{1+2D}{1-D}\right)^2\right)} \tag{3.27}$$

Plotting equation (τ) with duty cycle (D) producing a figure (3.8) from the chart of boundary condition CCM&DCM, can note area of working of a converter. We note area DCM decreases with an increasing duty cycle (D).
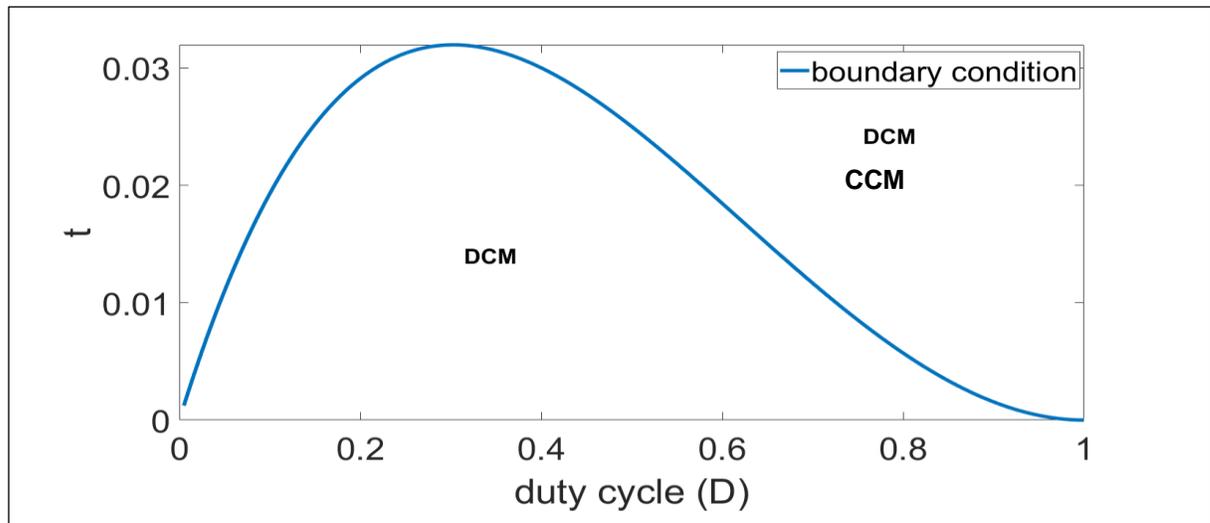
Fig 3.8: Boundary condition CCM&DCM for first modification Circuit of (POSLC)

3.3: The second modification of (POSLC) using capacitor switching cell

The second modification of the (POSLC) converter, as shown in Figure (3.9). The difference in the second cell is replacement (C1) by cell constructed from three capacitors (C1, C2 and C3). The proposed converter work as follows: at the switch-on, the passive element (inductors and the three capacitors) will be charged, the path of a current charge become as following: diode (D2) it a reverse bias, and the diode (D1) in the forward bias, the capacitor (C1), capacitor (C2), capacitor (C3) and inductor (L1) in parallel connection. At the switch-off state, the diode (D1&D2) In the forward bias, the discharge path of current C1, C2, C3, and L1 in series connection to the capacitor (Co) and then to the load. When the circuit at the steady-state, notice that the diode (D2) has a second function, which is to prevent the charge stored in the capacitor (Co) from reverse to the circuit elements. The main reason for increasing voltages more than elementary circuit that each element (L1, C1, C2, C3) storing energy as much as the source energy and then the energy combined pumped at the same time into a load.
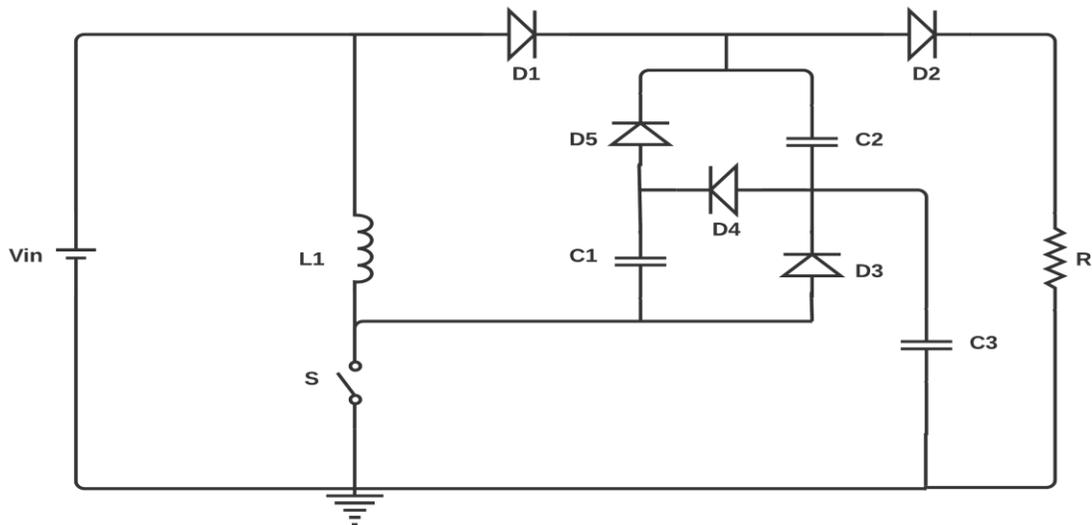
Figure 3.9: The second modification of POSLC with adding SC cell

3.3.1. Mathematical Analysis of Second Modifies positive Super Lift Luo Converter for (CCM)

Mode 1 :(0 DT):

Switch ON

$$v_{in} = v_L \tag{3.28}$$

$$v_{C1} = v_{Co} \tag{3.29}$$

$$v_L = v_{C1} + v_{C_2} \tag{3.30}$$

C1 and C2 must be equal value to reduce ripple.

According to equation (3.28) it turns out the same result at the switch-on state. Also figure (3.10) shows Current and voltage waves of the inductor for a second modified converter at CCM state.
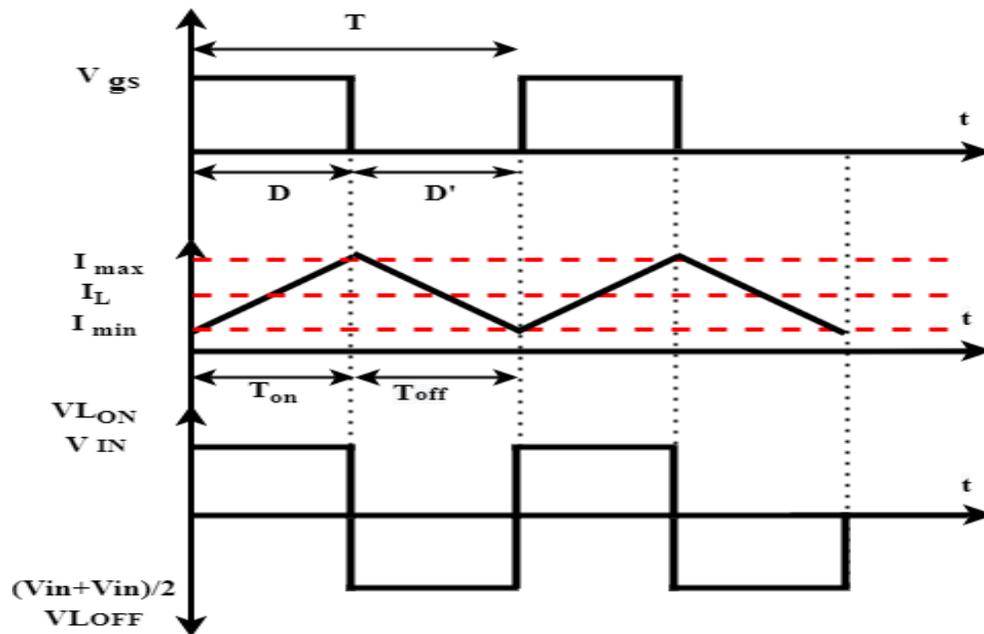
Fig 3.10: Current and voltage waves of the inductor into the second modify (POSLC) concerning CCM state
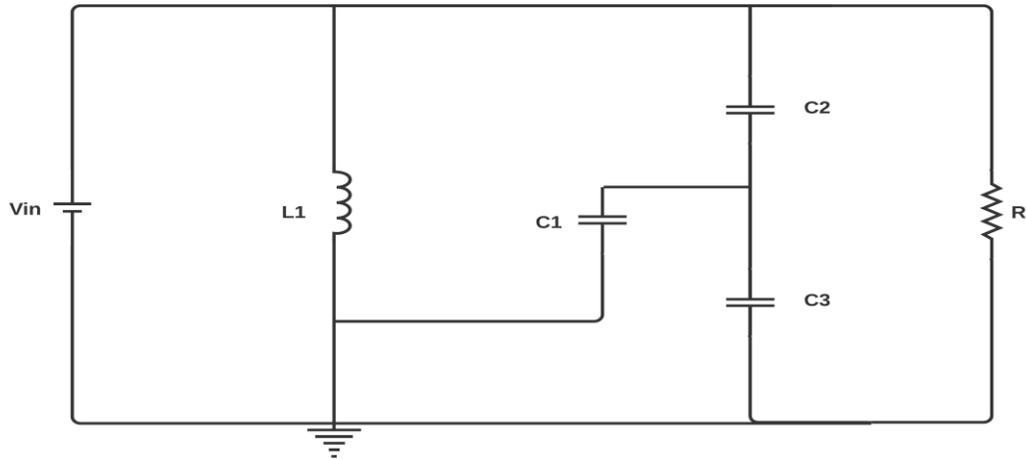
Fig 3.11: The second modification of (POSLC) with adding SC cell(s-on)

Mode 2 :(DT (1-D) T):

Switch OFF

Figure (3.12) shows the circuit at switch off with the current path and supply a load.
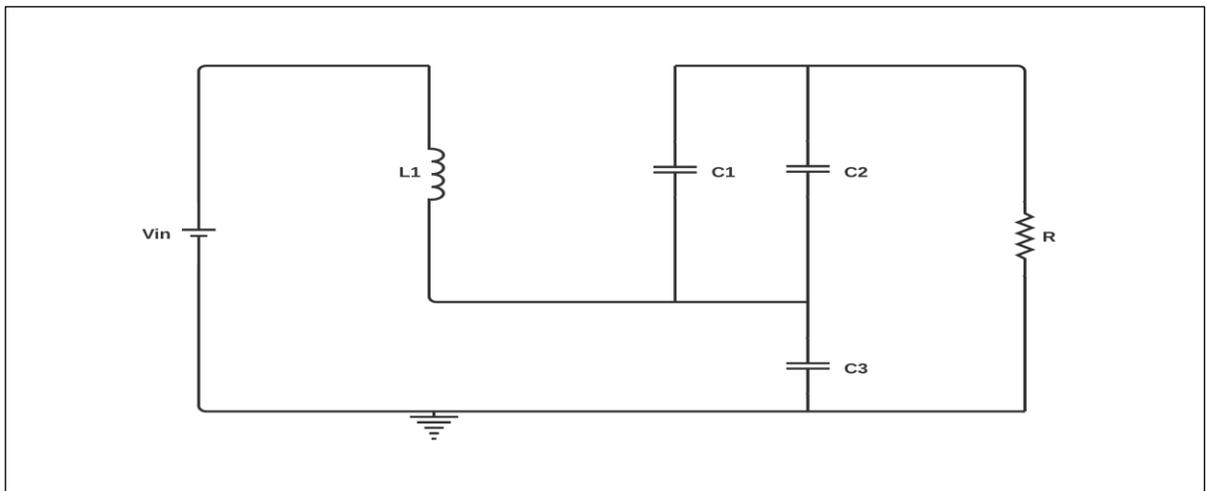
Fig 3.12: The second modification of (POSLC) with adding SC cell(s-off)

$$V_{O=}Vc1 + Vc3 \tag{3.31}$$

$$Vc1 = Vc2 \tag{3.32}$$

The average inductor voltage for a period of time is:

$$V_{in}D + (Vi - Vc3)(1 - D) = 0 \tag{3.33}$$

$$V_{in} = Vc3 - Vc3\,D \tag{3.34}$$

$$V_{C3} = \frac{1}{1-D}\,Vin \tag{3.35}$$

Sub equation 3.33 in 3.35 we get

$$Vo = 2\,Vc3 \tag{3.36}$$

Now sub equation 3.35 in 3.36

$$\frac{Vo}{Vin} = \frac{2}{1-D} \tag{3.37}$$

$$v_0 = 4v_{in} \qquad \text{At D=0.5}$$

Finally, the equation (3.37) of output voltage in the second modify and we notice that the proposed converter it gives a lower lift rate to voltage according to the original circuit.

3.3.2. The Discontinuous Conduction Mode (DCM)

Mode 1:(0-DT):

Switch ON

$$v_{in} = v_L \tag{3.38}$$

$$\Delta i = \frac{Vin\,D\,T}{L} \tag{3.39}$$

Mode 2 :(DT (1-D)T):

Switch-off

$$Vin\,D + (Vi - Vc3)(1 - D) = 0 \tag{3.40}$$

$$(1 - D) = \frac{-Vin\,D}{Vi - Vc3} \tag{3.41}$$

$$I_{C3} = \frac{1}{2}(1 - D)\Delta i_L - Io \tag{3.42}$$

At steady state $I_{C3} = 0$

$$Io = \frac{1}{2}(1 - D)\Delta i_L \tag{3.43}$$

$$\frac{1}{2}\frac{V_{in}D}{V_i - V_{c3}} * \frac{v_{in}DT}{L} = \frac{Vo}{R} \tag{3.44}$$

By simplify the equation (3.44) we get:

$$\tau = \frac{D^2}{2\left(\left(\frac{1+D}{1-D}\right)^2 - 1\right)} \tag{3.45}$$

Note: To minimize ripple in circuit that involve a cell, the capacitors values of (C1) and (C2) must be equal value when designing. Because the ripple is the result of a switching process that occurs on inductance or capacitor. When adding a cell whose capacitors are equal in values, this increases the value of the capacitance impedance and thus prevents ripple.

Plotting equation (τ) with duty cycle (D) producing a figure (3.15). from the chart of boundary condition CCM&DCM, can note area of working of a converter. we note area DCM decreases with an increasing duty cycle (D).
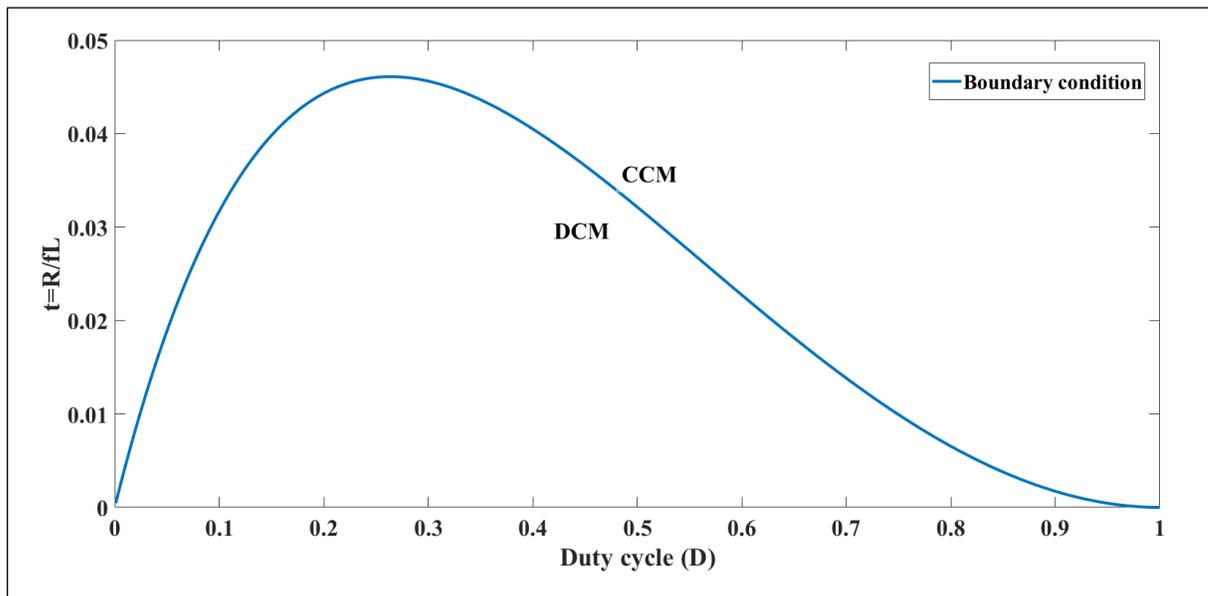
Fig 3.13: Boundary conditions between CCM and DCM of second modification
of (POSLC)

3.4: Third modification of (POSLC) using hybrid capacitor-inductor switching cell

The third modification of (POSLC) as shown in fig (3.14) has more advantage than previous modifications it considers expand cell from traditional hybrid cell it's give big rising in voltage level more than previous modifications.

The proposed converter work as follows: at the switch-on, the passive element (inductors and capacitors) will be charged, the path of a current charge become as following: diode (D2) it a reverse bias, and the diode (D1) in the forward bias, the capacitor (C1), capacitor (C2), inductor (L1), inductor (L2), inductor (L3), inductor (L4) and capacitor (C3) in parallel connection.
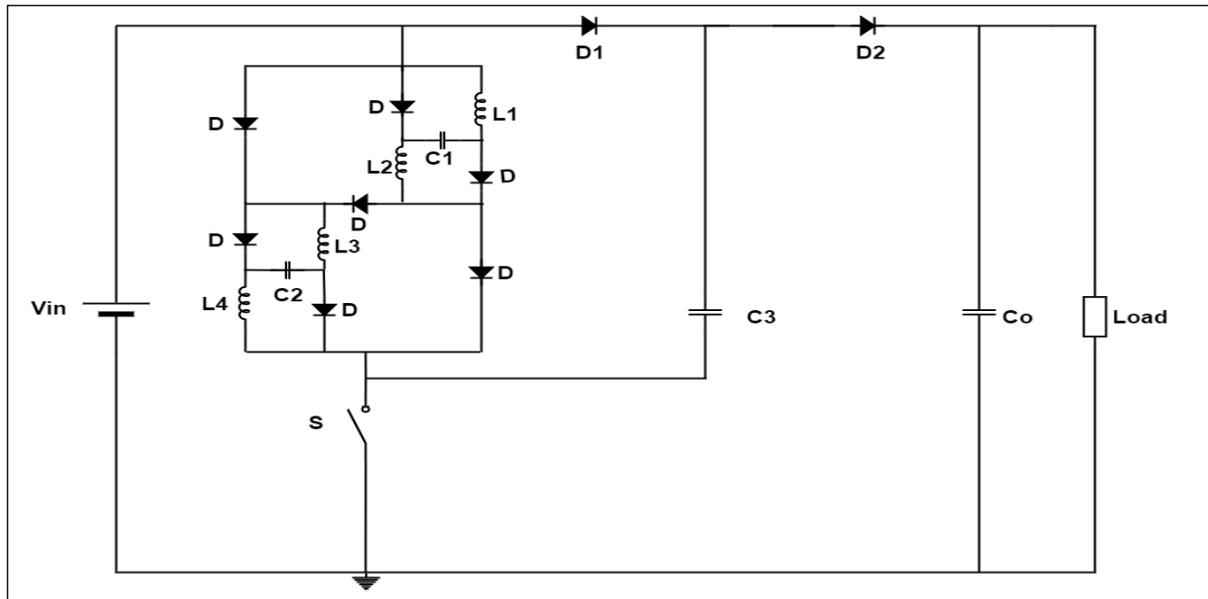
Fig 3.14: The third modification of (POSLC) with hybrid capacitor-inductor switching cell.

At the switch-off state, the diode (D2) In the forward bias, and the diode (D1) in reverse bias, the discharge path of current L1, C1, L2, L3, C2, L4 and C3 in series connection to the capacitor (Co) and then to the load. When the circuit at the steady-state, notice that the diode (D2) has a second function, which is to prevent the charge stored in the capacitor (Co) from reverse to the circuit elements.

The main reason for increasing voltages more than the previous converter is each element (L1, L2, L3, L4, C1, C2, and C3) storing energy as much as the source energy and then the energy combined pumped at the same time into a load.

3.4.1. Mathematical Analysis of third Modifies of (POSLC) for (CCM)

$$V_{in} = V_{L1} = V_{L2} = V_{L3} = V_{L4} = V_{C1} = V_{C2} = V_{C3} \qquad (3.46)$$

L1, L2, L3, L4 and C1, C2, C3 must be equal in values to reduce the ripple

$$V_L = V_{in} \qquad (3.47)$$

If compare equations (3.26) and above it gives the same result at the switch-on state. Also figure (3.15) shows Current and voltage waves of the inductor for a second modify converter at CCM state.
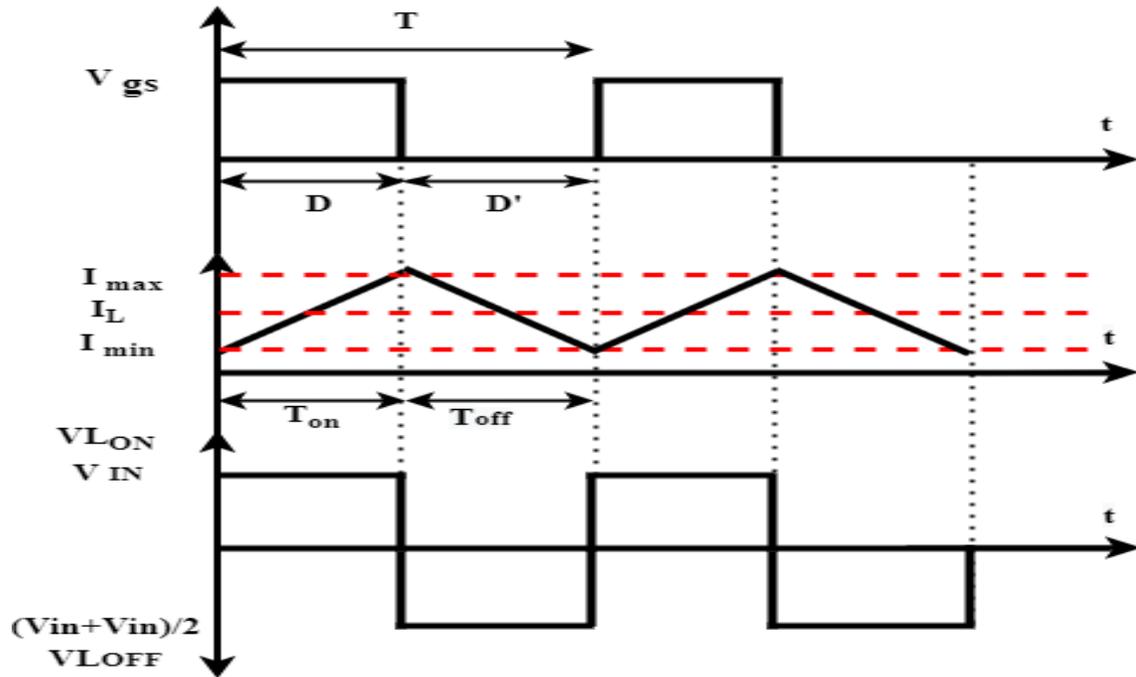
Fig 3.15: Current and voltage waves of the inductor into the third modification (POSLC) concerning CCM state
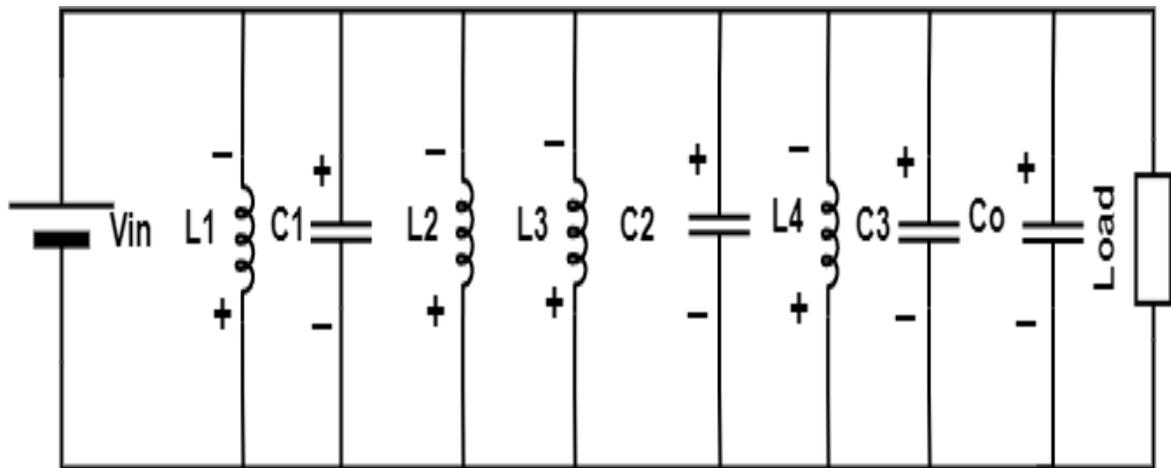
Figure 3.16: The third modification of (POSLC) with adding SCI cell(s-on)

Mode 2 :(DT (1-D) T):

When switch-OFF as shown in fig (3.17)

$$-V_o - V_{L1} + V_{c1} - V_{L2} - V_{L3} + V_{c2} - V_{L4} + V_{c3} + V_{in} = 0 \tag{3.48}$$

$$-V_o + 4V_{in} - 4V_L = 0 \tag{3.49}$$

$$V_{L1} = \frac{4V_{in} - V_o}{4} \tag{3.50}$$

If compare equations (3.37) and (3.50) it turns out (Vin) is four times in the second update at the switch-off state.

At steady-state.

From the Volt-Second balance equation:

$$V_{in}DT + \frac{4V_{in} - V_o}{4}(1 - D)T = 0 \tag{3.51}$$

$$\frac{Vo}{Vin} = \frac{4}{1 - D} \tag{3.52}$$
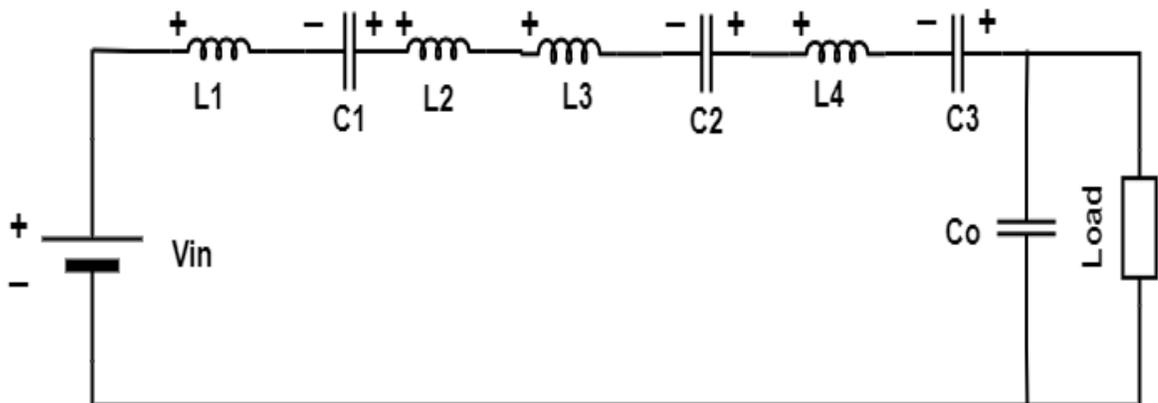
Fig 3.17: The circuit diagram of the third modification of (POSLC) when the switch-off state

Finally, if compare the gain equation of the third modify converter with other gain equations we notice that the proposed converter it gives a higher lift rate to voltage.

Respect to a duty cycle at the proposed converter. Increasing the duty cycle leads to lifting voltage.
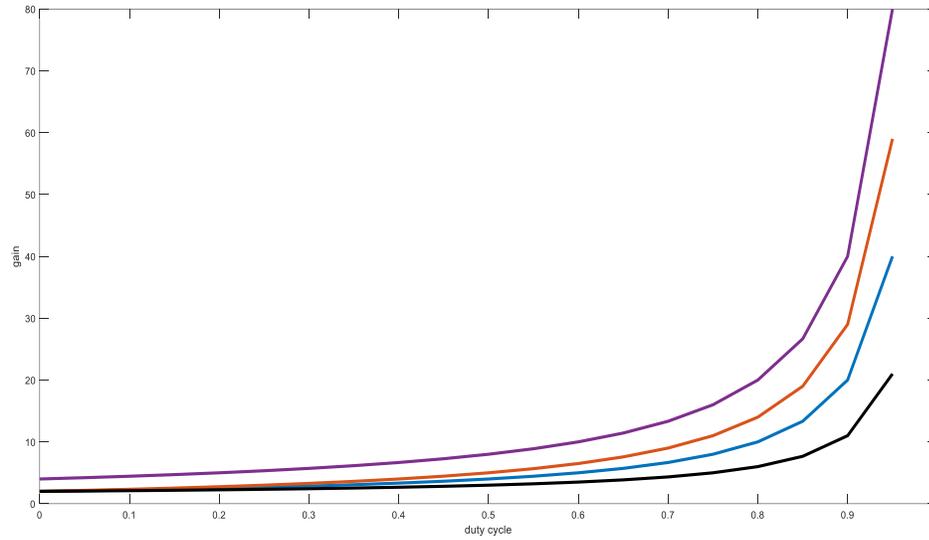
Fig 3.18: The relationship between gain and duty cycle for elementary circuit and three proposed converters.

3.4.2. The Discontinuous Conduction Mode (DCM):

Mode 1:(0 DT):

Switch ON

$$V_{in} = L\frac{\Delta i}{\Delta t} \tag{3.53}$$

$$\Delta i = \frac{V_{in}\, D}{L} \tag{3.54}$$

Since the signal is divided into Three-time zones there are switch-on time and the time of switch-off are divided into two regions time as shown in figure (3.19) in this case, it became difficult to solve by the method (CCM). Therefore, the current is calculated in the following way:
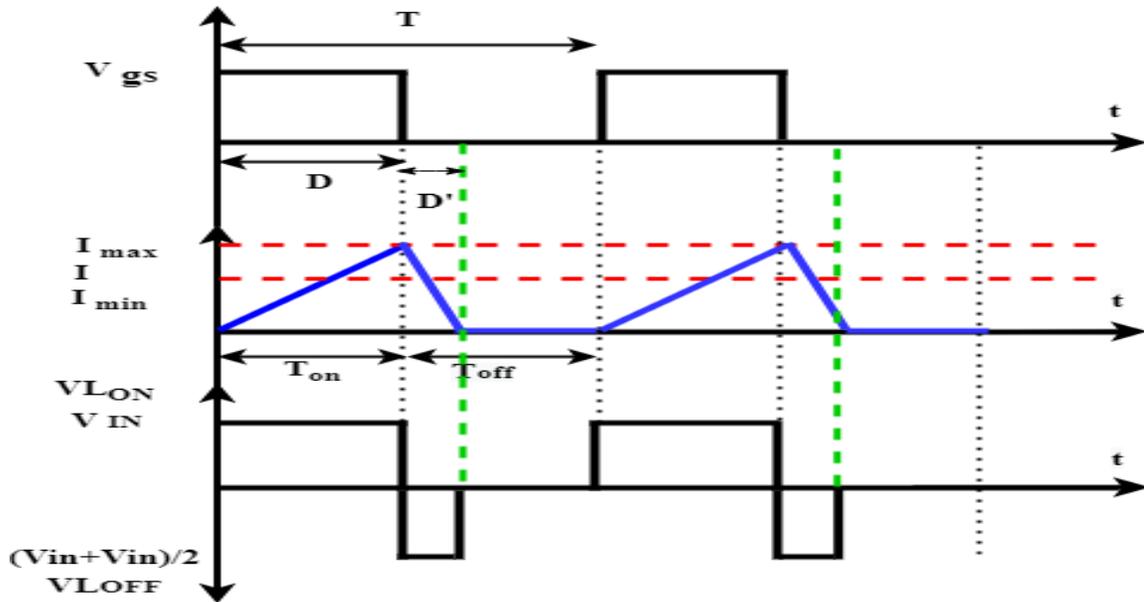
Fig 3.19: Current and voltage of inductor waveforms during DCM

Mode 2:(DT (1-D) T):

Switch OFF

$$VL = \frac{4Vin - Vo}{4} = L\frac{\Delta_i}{(1-D)T} \tag{3.55}$$

$$\Delta_i = \frac{(4Vin - V0)(1-D)T}{4L} \tag{3.56}$$

$$\frac{Vin\,DT}{L} = \frac{(4Vin - V0)(1-D)T}{4L} \tag{3.57}$$

$$(1 - D) = \frac{4\,VinD}{(4Vin - Vo)} \tag{3.58}$$

Equation (3.58) showing the duration of time at the switch-off.

$$I_L = \frac{1}{2}(1-D)\Delta i_L \tag{3.59}$$

I_L equation from the signal in current waveform, at steady state:

$$I_{co} = 0 \tag{3.60}$$

$$\frac{1}{2}(1-D)\Delta i_L = I_o \tag{3.61}$$

$$\frac{1}{2}\frac{4\,VinD}{(4Vin-Vo)} * \frac{Vin\,DT}{L} = \frac{Vo}{R} \tag{3.62}$$

$$\frac{1}{2} * \frac{4\,V_{in}{}^2 D^2}{(4Vin-Vo)} = \frac{Vo\,fL}{R} \tag{3.63}$$

$$\frac{1}{2} * \frac{4\,V_{in}^2 D^2}{(4Vin-Vo)} = Vo\,\tau \tag{3.64}$$

$$V_o^2\,\tau - 4\,V_o\,V_{in}\,\tau + 2\,V_{in}^2\,D^2 = 0 \tag{3.65}$$

The above equation solved by law

$$V_o = \frac{4\,Vin\,\tau \mp \sqrt{(4\,Vin\,\tau)^2 - 4\tau(2\,V_{in}^2\,D^2\ )}}{2\tau} \tag{3.66}$$

$$V_o = 2\,Vin \mp \sqrt{4\,V_{in}^2 - \frac{2\,V_{in}^2\,D^2}{\tau}} \tag{3.67}$$

$$\frac{V_o}{Vin} = 2 \mp \sqrt{4 - \frac{2\,D^2}{\tau}} \tag{3.68}$$

By equal the gain equation in CCM

$$\frac{4}{1-D} = 2 \mp \sqrt{4 - \frac{2\,D^2}{\tau}} \tag{3.69}$$

$$\tau = \frac{2D^2}{4-(\frac{2+2D}{1-D})^2} \tag{3.70}$$
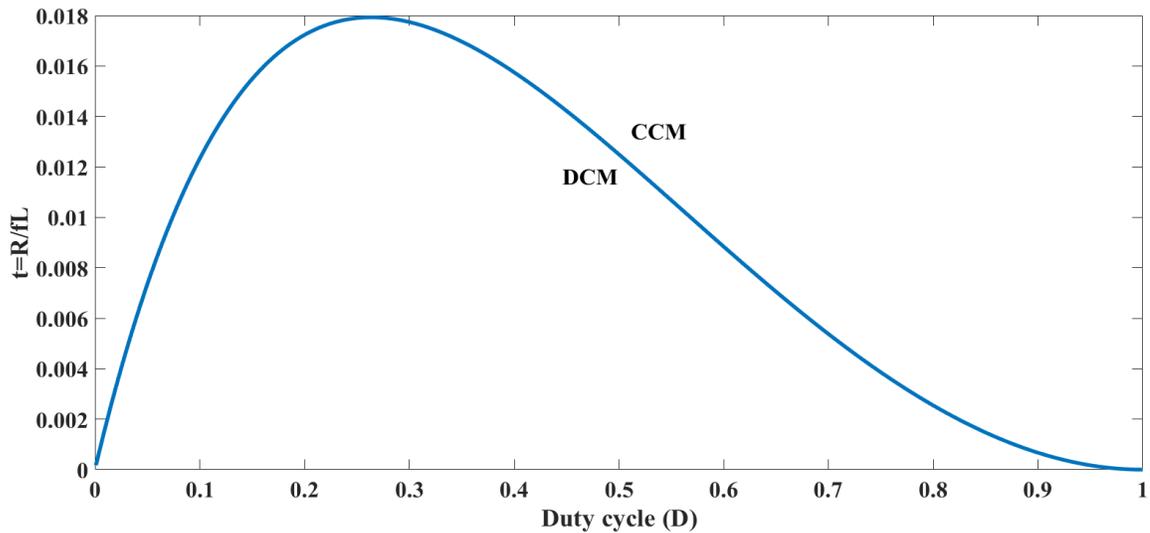
Fig 3.20: Boundary condition between CCM and DCM

Hybrid cell technique gives new advantages, i) highest level voltage, ii) removal of ripple resulting by elements, iii) faster in its geometric performance.

Table (3.1): Comparison between four circuits of primary of (POSLC), first Modify of (POSLC), second modify of (POSLC).and third modify of (POSLC

attributes	Primary circuit	Proposed converters		
		First	second	Third
Voltage gain expression	$G = \dfrac{2-D}{1-D}$	$G = \dfrac{2+D}{1-D}$	$G = \dfrac{2}{1-D}$	$G = \dfrac{4}{1-D}$
Voltage gain (G) at D=0.5	3	5	4	8
No. of switches	1	1	1	1
Component count (CC)	4	6	5	9
Number of diodes	2	8	5	9
High/low side gate driver	high	high	high	high
Common Ground	yes	yes	yes	yes
Number of inductors	1	3	1	4

According to table (3.1) the three modifications and the elementary circuit comparison in term of voltage gain and passive elements count and number of active switches , the third modification is the highest gain factor converter and smoother than other modification, while the second modification is the simplest and less cost converter which treat the input pulsating current.

3.5: Maximum power point tracker (MPPT) implementation in MATLAB

Maximum power point tracker control block in MATLAB is a MATLAB function that have two inputs (Ipv and Vpv) from solar panel and one output is duty cycle that control the MOSFET switch to operation at MPPT, the PV cell specification shown in table (3.2)
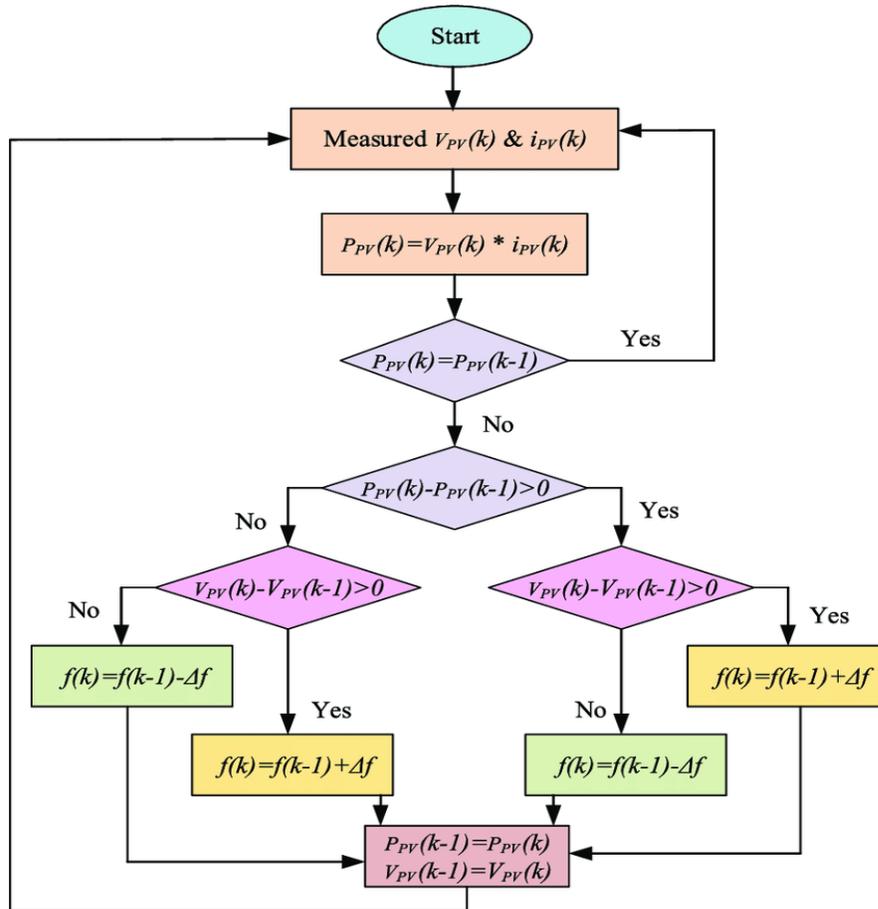
Fig 3.21: MPPT (P&O) algorithm [58]

The algorithm that controlled the circuits, the first step is defined the output with respect to inputs parameters and then specify the initial values of the duty cycle, the voltage and the power, the step of duty cycle also define and so on write the code.

Table (3.2) photovoltaic module parameters

Parameter	Value	Unit
Maximum power	213.15	W
Open circuit voltage Voc	36.3	V
Voltage at maximum power	29	V
Temperature coefficient of Voc	-0.36099	% deg.C
Cell per module	60	
Short circuit current Isc	7.84	A
Current at maximum power point	7.35	A
Temperature coefficient of Isc	0.102	% deg.C
Series resistance Rs	0.39383	Ohms
Shunt resistance Rsh	313.3991	Ohms
Diode saturation current Io	$2.9259\ e^{-10}$	A

Table (3.2) shows the parameters of the PV cell. The maximum power is 213 W. This will extracted when use the maximum power point tracker. The other parameters such as the internal resistance, open circuit voltage and short circuit current at radiation 1000 w/m^2 and temperature 25 C.

Chapter Four

The Simulation results and the discussion

4.1. Introduction:

In this chapter, the MATLAB2020a/Simulation have been used to obtain the results and different cases of the Simulink environments. The results are divided into two main groups the circuits without MPPT and the circuits with MPPT. The circuits without MPPT also divided to five sections: the output voltage gain, the output voltage ripple, the current ripple, the switches sensitivity, the equivalent resistance of the converter, the passive elements currents, and the elements counts (cost). These compared between each circuit and elementary circuit. And also, in case of use MPPT technique

4.2: Case study

(POSLC) which it is presented in chapter three the circuit of POSLC is simulated in this chapter in case of with MPPT and without MPPT. In case of MPPT the (P&O) are used under changing irradiation (1000, 800, and 600). The PV cell used is (1 soltech 1STH-215-P) in MATLAB, the PV panel voltage is (32V) and constant temperature 25 C to see the ability of the converter to track MPP. in case of simulation without MPPT the 1000 w/m^2 and 25 C temperature.

4.2.1. Parameters design of (POSLC):

From the equations that presented in chapter three, we can calculate the values of the inductor (L_{min}), boost capacitor (C_1) and output capacitor (C_O) under the following assumptions.

Assume the parameters:

D = 0.5

V_{IN} =32 V

f =60 kHz

R=50 ohm

The output voltage design can be obtained by equation (3.6).

$$v_0 = \frac{2-D}{1-D} v_i \tag{4.1}$$

V_O = 96

Design of Inductor:

Since it is the variation ripple (ζ_L) of inductor current unknown, can choose from (0.2 - 0.4).

From equations (3.16), can get the inudctor current ripple.

$$Io = \frac{V_o}{R} \tag{4.2}$$

$$Io = \frac{36}{50} = 0.72 \, A \tag{4.3}$$

$$I_L = \frac{2-D}{1-D} I_O \tag{4.4}$$

$$I_L = \frac{2-0.5}{1-0.5} (0.72) = 2.16 \, A \tag{4.5}$$

$$\zeta_L = \frac{\Delta I_L}{2 \, I_L} \tag{4.6}$$

$$\Delta I_L = \zeta_L * 2 * I_L \tag{4.7}$$

$$\Delta I_L = 0.2 * 2 * 2.16 = 0.864 \ A \tag{4.8}$$

From equation (3.6) we can calculate the value of L_{min}

$$L_{min} = \frac{V_{in} \ D}{f \ \Delta I} \tag{4.9}$$

$$L_{min} = \frac{12 \ (0.5)}{62000 \ (0.864)} = 0.112 \ mH \tag{4.10}$$

For keeping the converter is operating in CCM, we assume L >>Lmin

Let   L= 1.25 * L_{min} = 1.25 * 0.112 e^{-3} = 0.14 mH

Design of boost capacitor:

Where ripple voltage (VC1) is: $\Delta v_{C_1} = 0.05$

From equation (2. 39) we can get the value of the boost capacitor.

$$C_1 = \frac{v_0}{f \ R \Delta v_{C_1}} \tag{4.11}$$

$$v_{C_1} = v_{in} \tag{4.12}$$

$$C_1 = \frac{36}{62000*50*0.05} = 232 \ \mu f \tag{4.13}$$

This is the minimum value of boost capacitor.

Design of output capacitor (Co):

Where the output ripple (VCo) is: $\Delta v_{C_1} = 0.05$

From equation (3.53) we can get the value of the output capacitor (Co).

$$C_0 = \frac{D}{2Rf\varepsilon c_o} \tag{4.14}$$

$$C_0 = \frac{0.5}{2(50) \ (62000) \ (0.05)} = 1.61 \ \mu f \tag{4.15}$$

This is the critical value of output capacitor. The desired value it can withstand the highest output voltage (maximum value) is:

Co = 10 μf

4.2.2: Simulation results of (POSLC):

The simulation circuit of (POSLC) as shown in figure (4.1). The overall system consists of POSLC, load and input voltage which are DC input voltage from photo voltaic cell. Figure (4.2) shows the elementary circuit of Luo converter (POSLC), the elements shaded in orange are diodes (D1 and D2), the elements shaded in blue sky colour are capacitors (C1 and C3), and the inductor (L) is shaded in yellow. This circuit is elementary circuit with PV source and constant duty cycle (D) of (0.5) without MPPT controller. The irradiation in 1000 w/m^2 and the temperature is 25 C.
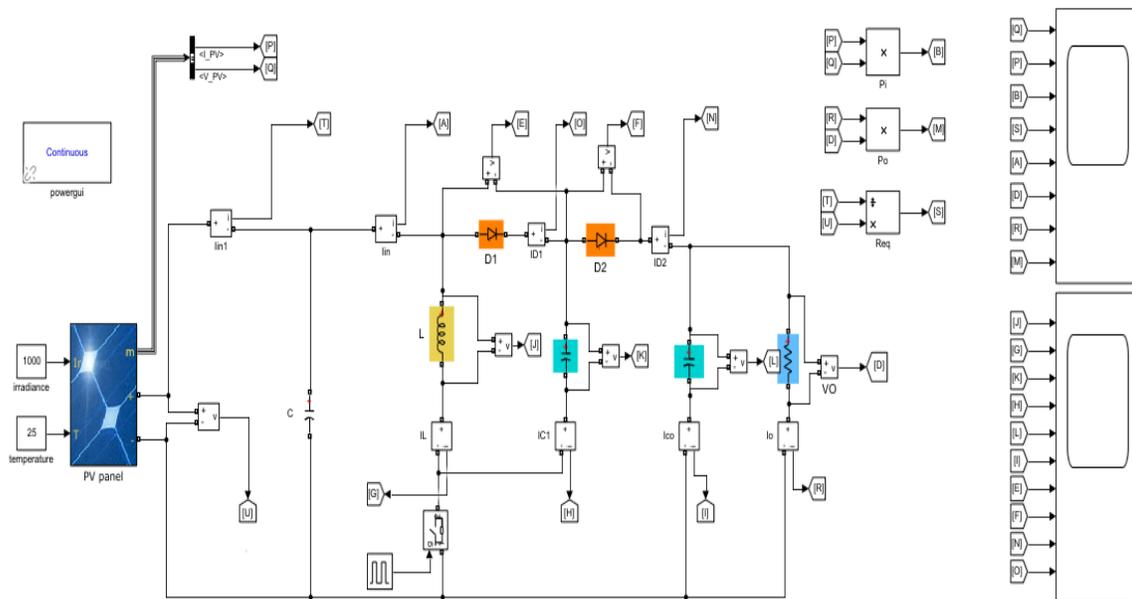
Fig 4.1: Elementary circuit of (POSLC)

Fig (4.2) General waveforms of (POSLC)

Figure (4.2) shows the waveforms of the input voltage, current, power, output voltage, output current and output power. It's also shows the input resistance and input current, all these values of waveforms satisfy the theoretical calculation.

Figure (4.2) shows the input voltage of the converter from PV panel are 32V and this voltage is boosted by the Luo converter to 96 V in the output (at the load). The inductor voltage charge and discharge continuously with the same of input

voltage (32V) The inductor charge during S-on by 32v and discharge during S-off with same value in opposite polarity.
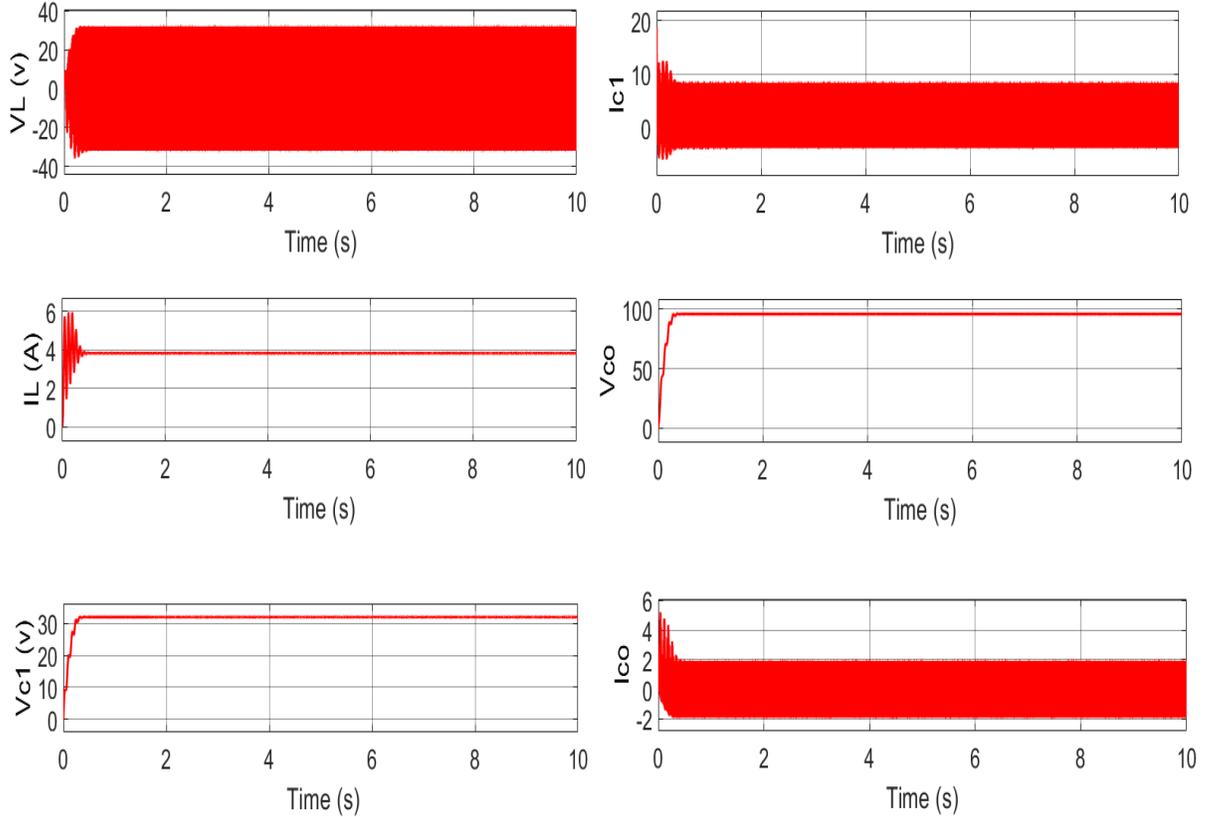
Fig 4.3: Voltage and current waveforms of passive elements of (POSLC)

Fig (4.3) shows all passive elements waveforms, current and voltage waveforms for inductor (L) and capacitors (C1 and C2). Input current pass through the inductor, and the output current reduce to one third at duty cycle 0.5. From figure (4.3) the output capacitor voltage are the same of output voltage of (96V). Note that the simulation results of the converter are same the theoretical since (32V) input to converter from PV panel boost to 96v at the load, and at 0.5 duty cycle not satisfy exactly maximum power interesting from the PV cell so the PV power is about 190w, while the MPP of the cell used in this simulation is 213w,

4.3: Simulation results of first modification of (POSLC)

To improve the Luo converter performance such as the voltage gain, switches stress and inductor size (cost), the first modification has been proposed to increase the output voltage and reduce the current ripple
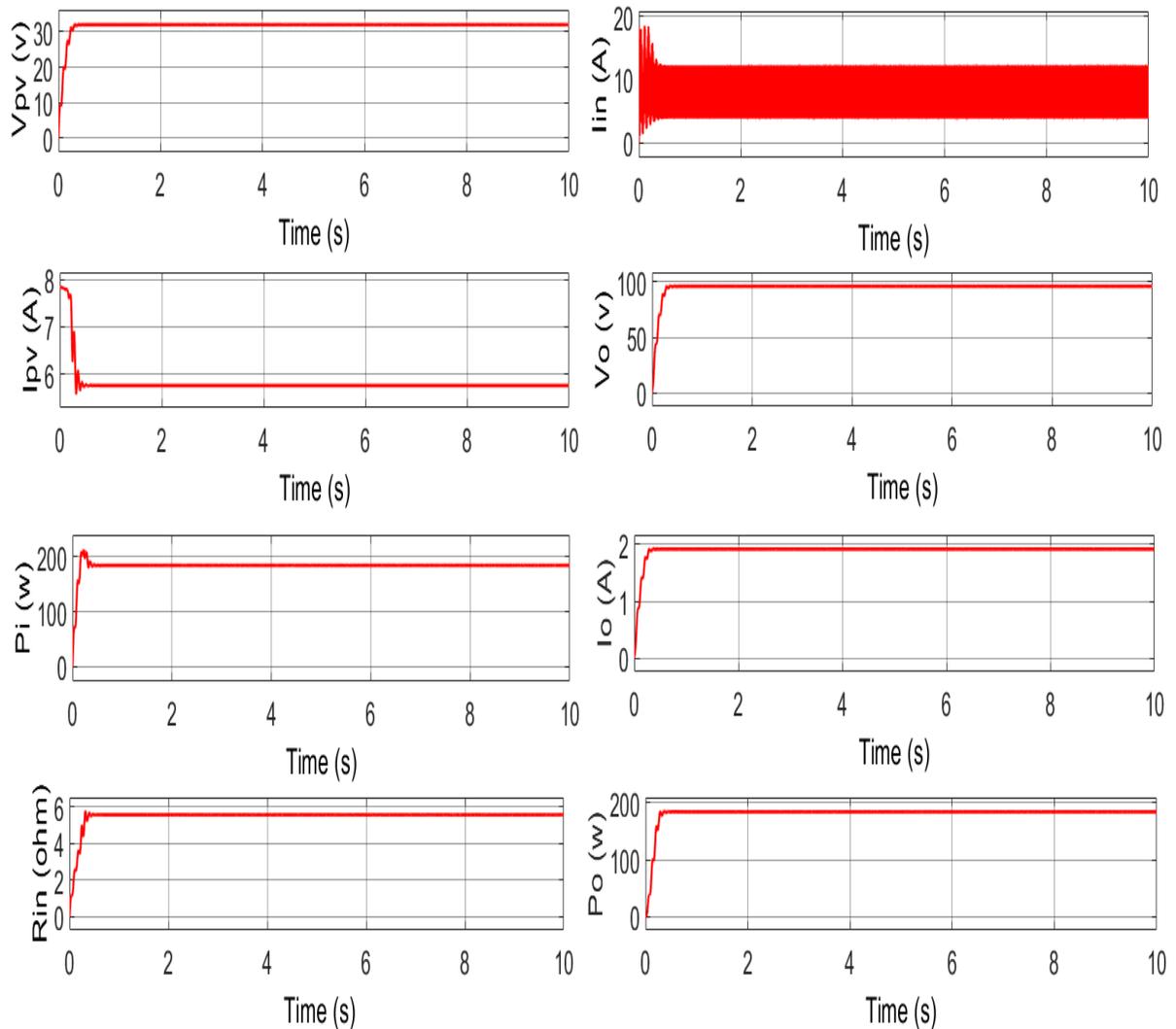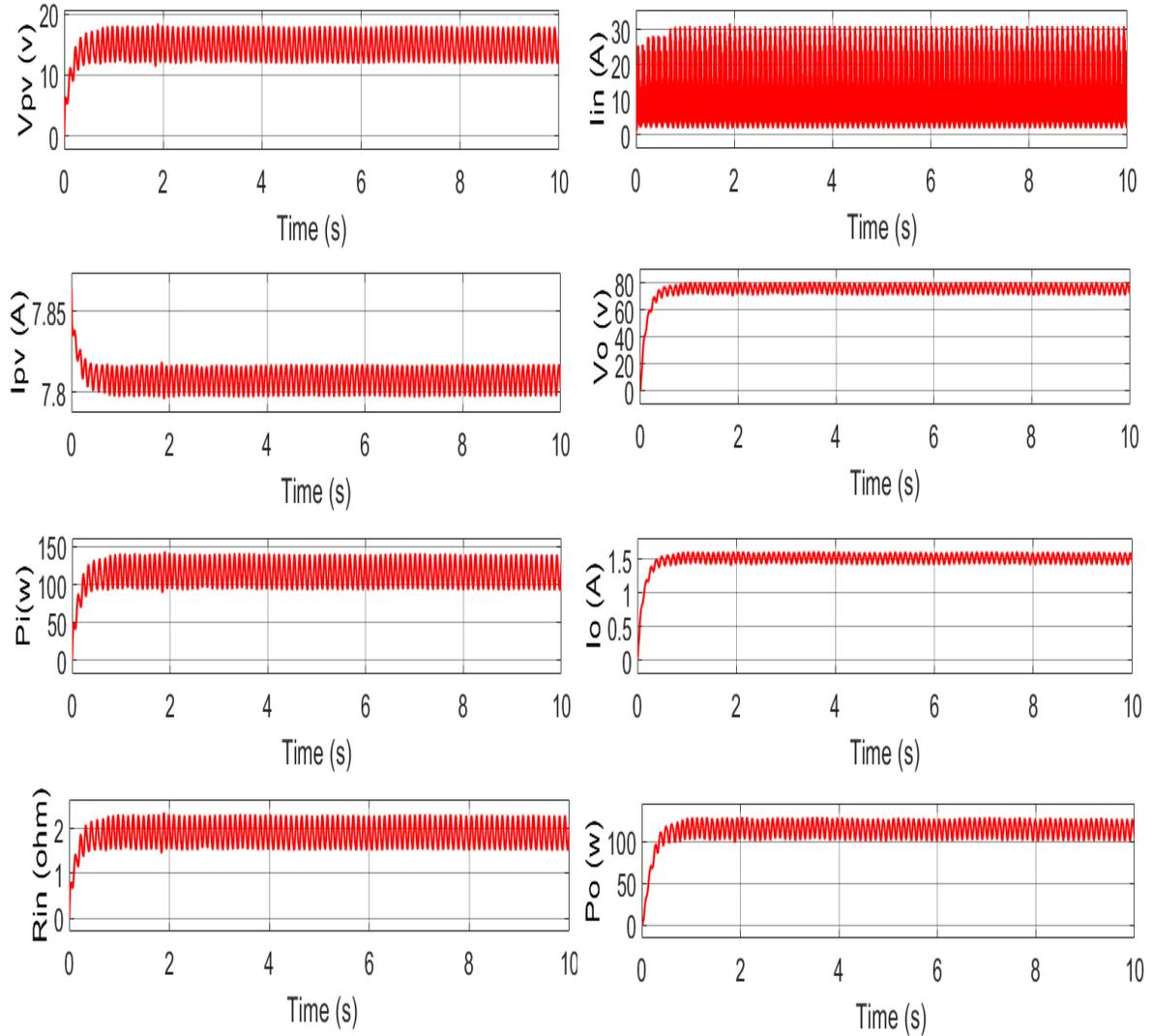

Fig 4.4: General waveforms of 1st modification of (POSLC)

Figure (4.4) shows the waveforms of the input voltage, current, power, output voltage, output current and output power. It's also shows the input resistance and input current, all these values of waveforms satisfy the theoretical calculation.

Figure (4.4) shows the input voltage to the converter from PV panel is 16V and this voltage is boost by the Luo converter to 80 V in the output (at the load) as. In contrast of inductor voltage charge and discharge continuously with the same of input voltage (16V) .Finally the inductor charge during S-on by 16v and discharge during S-off with same value in opposite polarity.

Figure (4.4) shows the PV power (input power) is less than elementary because the equivalent resistance reduces, and the output power 120w and high level of efficiency.
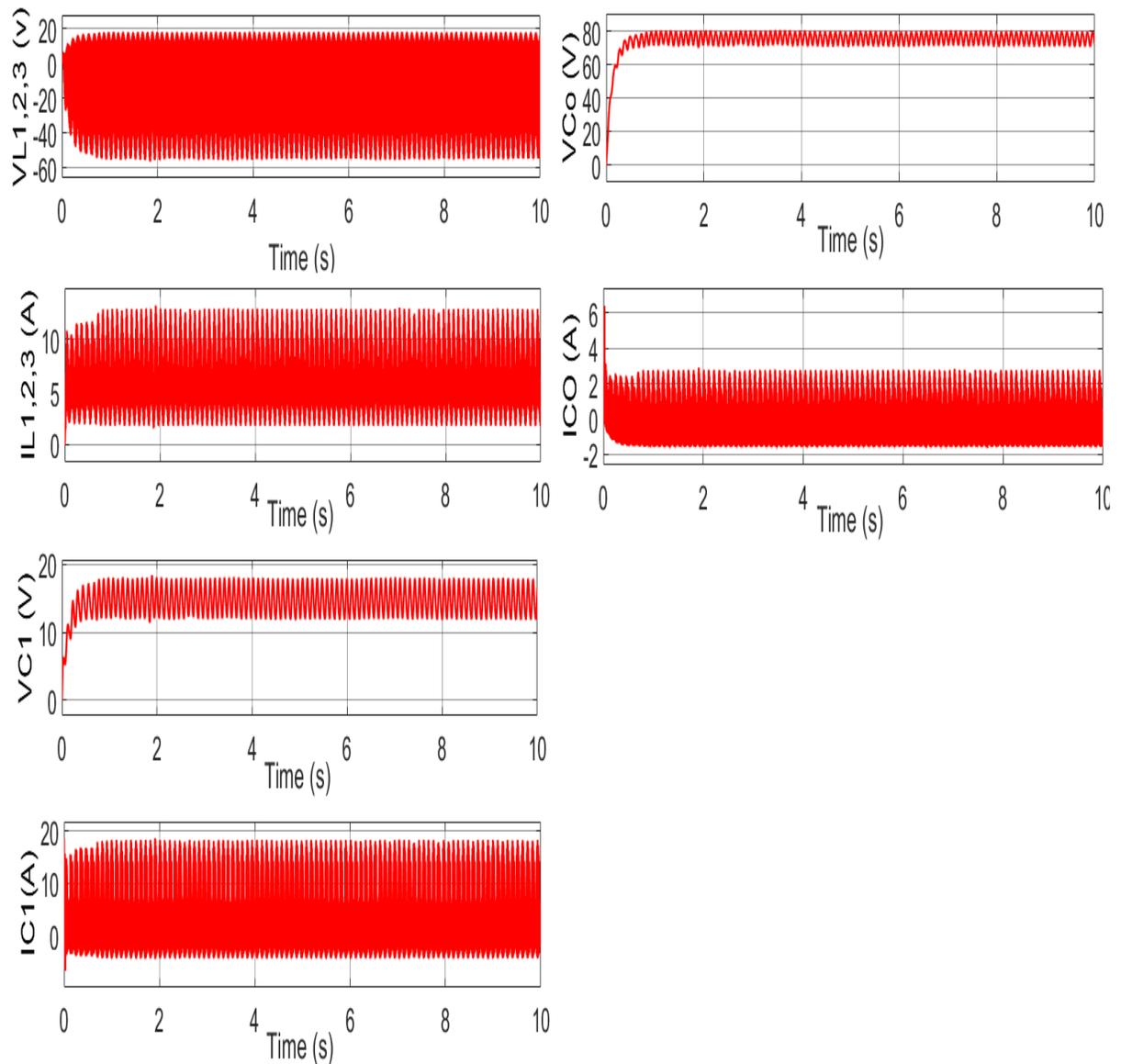
Fig 4.5: Voltage and current waveforms of passive elements of 1st modification of (POSLC)

From figure (4.5) shows passive elements waveforms, current and voltage for all inductors and capacitors. Diodes D1 and D2 that works alternatively in revers and forward biasing with value equal to twice the output current value.

The capacitor current is charged and discharged in capacitor C1 with value equal to the inductor's currents. The capacitor charge and discharge the current instantaneously because the capacitor doesn't have tendency to resist the change in current.

The current of filter capacitor Co is the same as output current about (1.6) but change in direction during switching on-off, and because the same reason the capacitor doesn't resist the sudden change in current value.

Note the input and output current that satisfy the current gain equation, and the input current divided into three values according to the numbers of inductors, that mean when number of inductors increase not only the voltage gain increase, also the low level of current pass-through inductors keeps the life of the inductor and save it from overshoot heating.

Table 4.1: Efficiency relationship with duty cycle for first modification

Duty cycle	Vin (V)	Iin (A)	Pi (W)	Vo (V)	Io (A)	Po (W)	% Efficiency
20 %	12	2.75	32.8	32	0.64	20.5	63.5
30%	12	2.991	35.87	38.09	0.7619	29.02	81.06
40%	12	3.692	44.38	45.92	0.9184	42.18	95.04
50%	12	6.08	67.66	56.37	1.123	63.56	93.94

From table (4.1) the efficiency is decrease with increase the duty cycle because the large duty cycle means more heat on the switch because the stress on the switch.

The values of the output voltage and current satisfy the gain equations.

4.4: Simulation results of second modification of (POSLC)

Another modification on (POSLC) has been proposed to increase the gain of the output voltage and reduce the stress on the switch to reduce losses as much as we could. Try to increase the gain in first modification, but now we want to avoid the inductors to reduce the cost and weight and to get rid of magnetic interference we made the modification from capacitor switching cell placed instead of C1 in elementary converter.
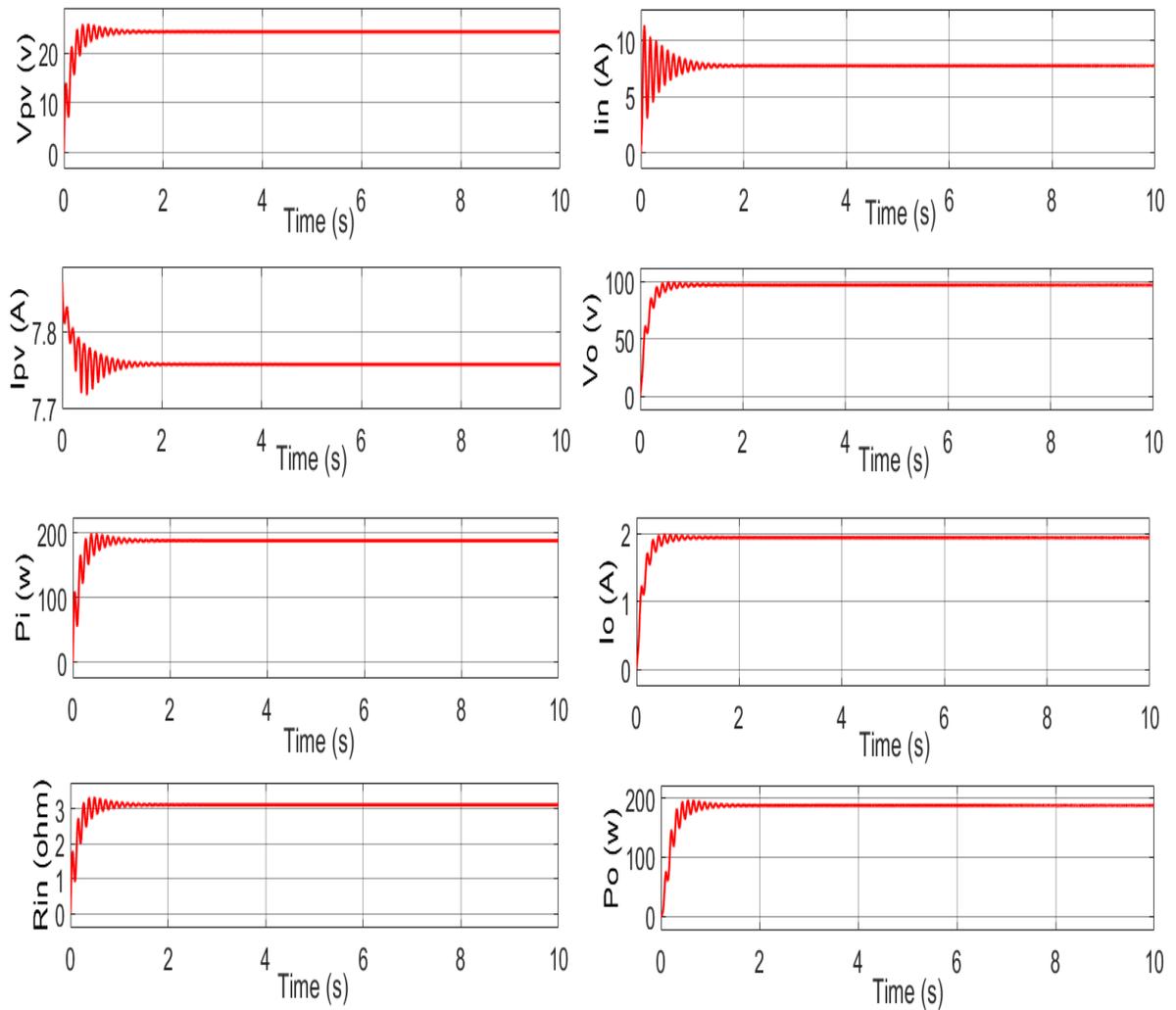
Figure 4.6: General waveforms of 2nd modification of (POSLC)

When the PV panel output current is about 7.78 the output current should satisfy the current gain equation and confirm the theoretical calculation and its value about (1.9 A).

From figure (4.6) shows the input and output current, voltage and power waveforms, also shows the input current and resistance of the converter.

All these waveform confirm with the theoretical calculation in last chapter.
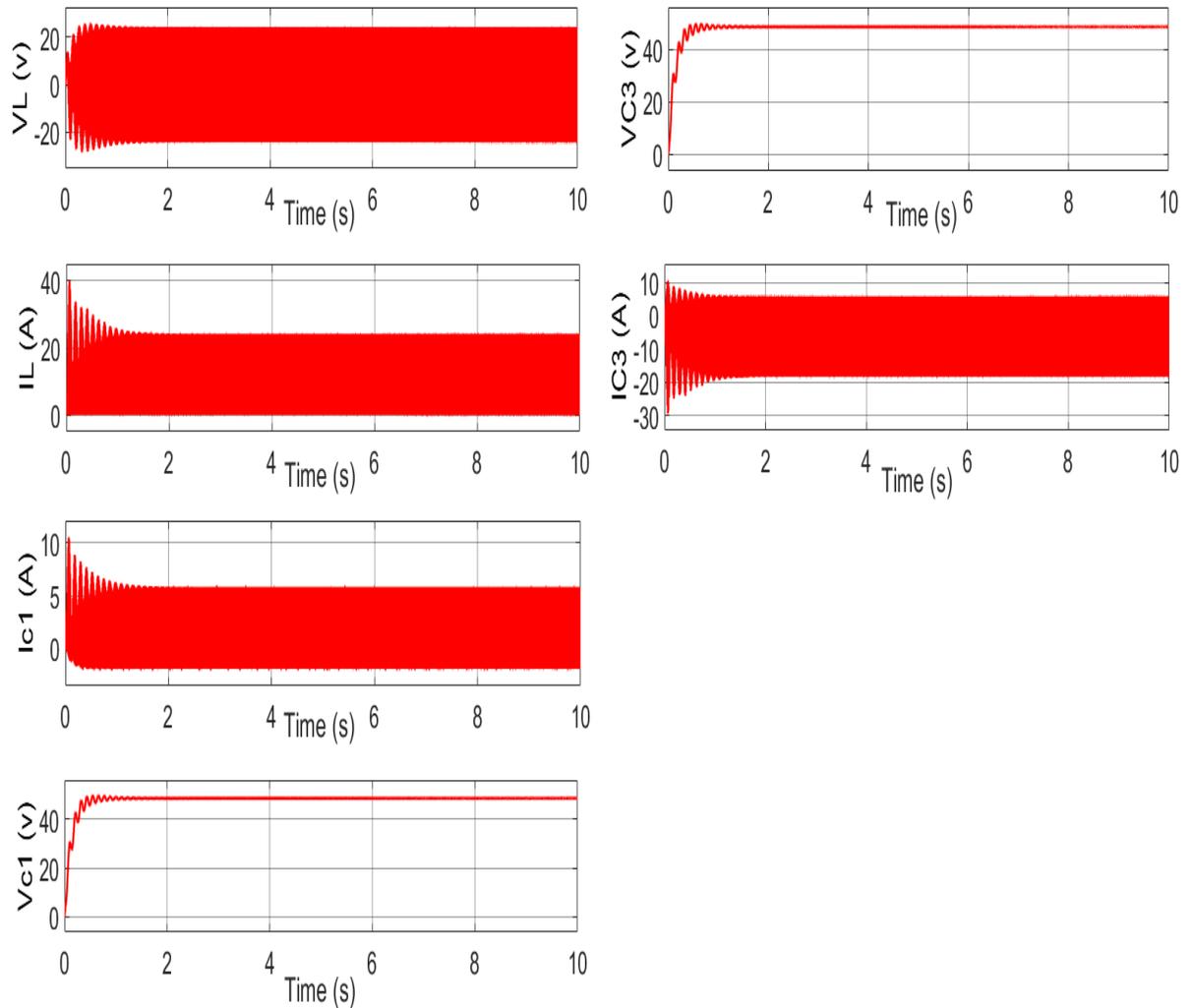
Fig 4.7: Voltage and current waveforms of passive elements for 2nd modification of (POSLC)

Figure (4.7) shows the passive elements waveforms all capacitors and inductor currents and voltages. Seen that the output current is one quarter of the PV current according to the current gain equation.

See that the output voltage is four times the input voltage at duty cycle 0.5and the output capacitor (C3) is the same as C1 and C2 and the output once sum C3 voltage with C1 voltage to get the output voltage and once sum C3 voltage with C2 voltage to get the output voltage. The D2 is always in forward bias and its work just for

protection and voltage of diode D1 is the difference between output and input voltages.

Table 4.2: Relationship between efficiency and duty cycle for second modification

Duty cycle	Vin (V)	Iin (A)	Pi (W)	Vo (V)	Io (A)	Po (W)	% Efficiency
20 %	12	2.390	28.68	29.33	0.5867	17.21	59.65
30%	12	2.59	30.22	33.51	0.6702	22.46	69.80
40%	12	3.01	36.07	39	0.78	30.31	85.55
50%	12	3.712	44.54	46.31	0.924	42.9	96.31

From table (4.2) the efficiency is decrease with increase the duty cycle because the large duty cycle means more heat on the switch because the stress on the switch. The values of the output voltage and current satisfy the gain equations.

4.5: Simulation results of third modification of (POSLC)

Inductor switching cell and capacitor switching cell has been proposed in chapter three, the results get in the beginning of this chapter. We see all the advantage and disadvantage of every proposed Luo converter cells, so we made third modification that combined from ideas of first and second modification. Hybrid capacitor-inductor switching cell results will be clear in next page.

The implementation of the converter circuit in MATLAB and all the meters such as voltmeter and ampere-meter and oscilloscope to study the waveforms of the converter. All these used in figure (4.8).

The third modification is constructed as mentioned, from four inductors and two capacitors, in switching cell replaced by the main inductor,
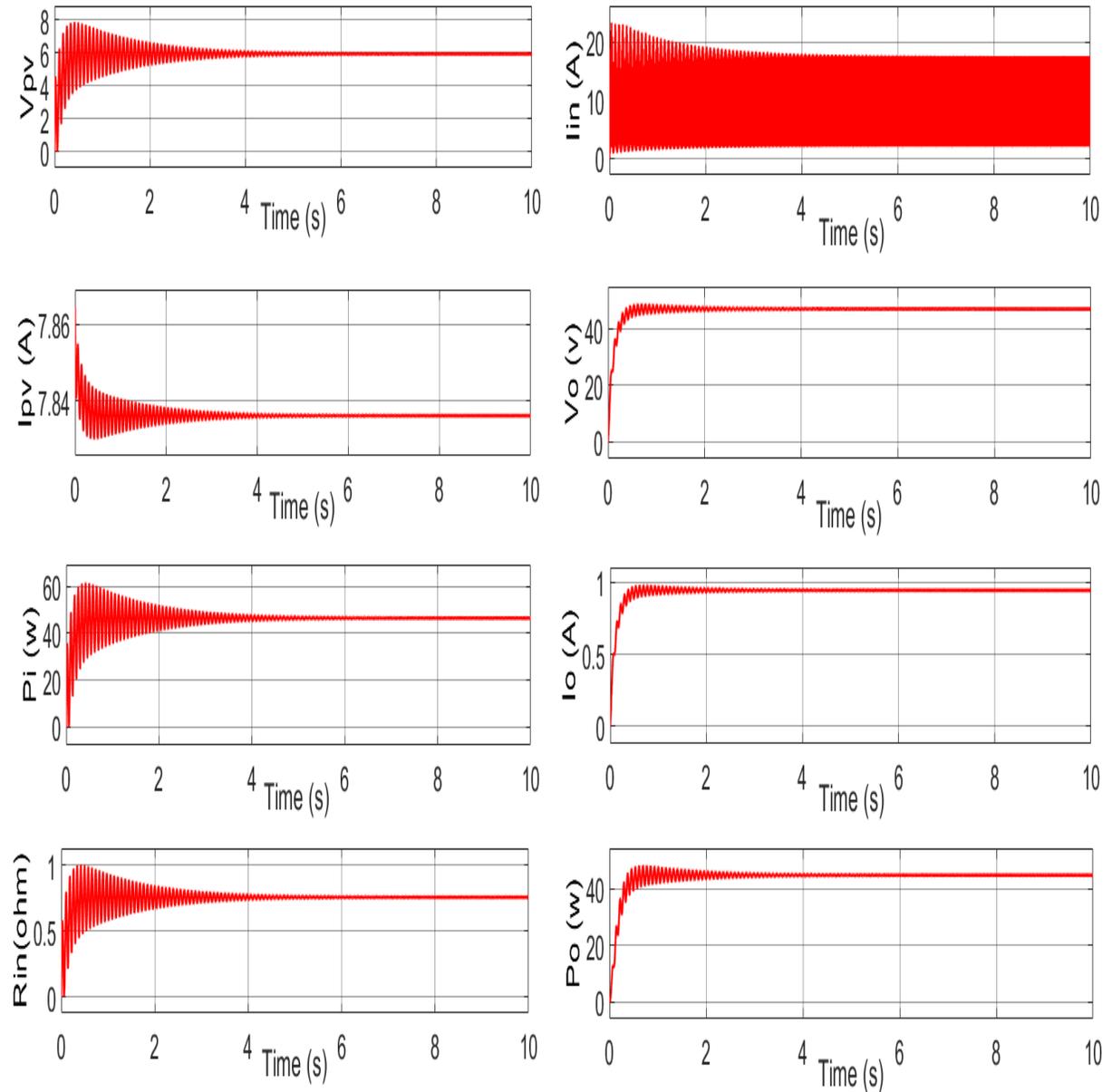
Fig 4.8: General waveforms of third modification of (POSLC)

From figure (4.8) the equivalent resistance is than other two modifications about 1.5 ohm that because large number of passive elements in parallel this lead to reduce losses and work in small duty cycle if we used MPPT.

Figure (4.8) shows that the simulation results confirm the theoretical results and satisfy the gain equation of the output voltage since the input voltage 6V and the duty cycle is 0.5 that mean the output voltage will be eight times the input voltage (48V).
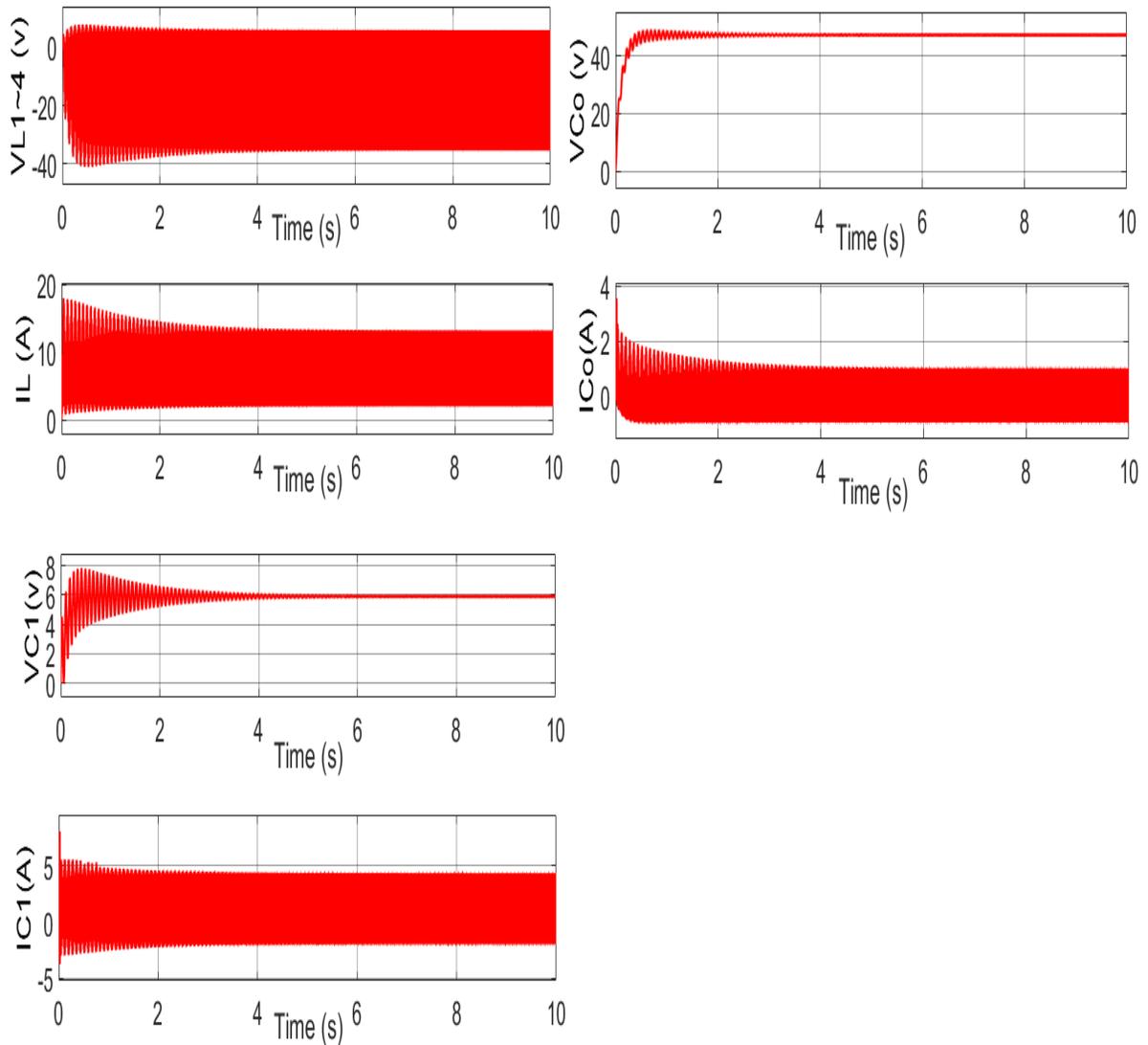
Fig 4.9: Voltage and current waveforms of passive elements of 3rd modification of (POSLC)

From fig (4.9) notice that the input power (the output power of PV panel) is less than output power of PV panel in first and second modification but the efficiency is still good. Figure (4.9) is the diodes D1 and D2 voltages but they work alternatively in forward and revers biasing during ON and OFF switching. Figure (4.9) shows the capacitors voltages since the voltage of Co is the same of output voltage and voltage of C1 and C2 is the same of input voltage the reason is the capacitors in general has tendency to resist the change the voltage.

Figure (4.9) shows the inductors voltages (VL1, VL2, VL3, VL4) that charged and discharged with every switching ON-OFF with the same input voltage (6V). input and output current of third modification of (POSLC) and that results satisfy the current gain equation that derived, the PV panel current is about (8 A) and the output current is about (1 A). The inductors current, that the same input current divided by four inductors so every inductor will take 2 amperes, that the most important aim from this modification, to reduce the size of inductors. The current of capacitors C1, C2 and C3 charged and discharged with 2A current, because the tendency of capacitors to store the voltage (resist the change in voltage). The diodes D1 and D2 currents and they work alternatively with each on-off switching (2A) because they before Co in one step.

Table 4.3: Relationship between efficiency and duty cycle for third modification

Duty cycle	Vin (V)	Iin (A)	Pi (W)	Vo (V)	Io (A)	Po (W)	% Efficiency
20 %	12	9.123	109	51.67	1.033	53.39	48
30%	12	8.5	103.5	59.66	1.193	71.13	68.7
40%	12	9.248	111	68.85	1.377	94.83	85.43
50%	12	12.83	154	80	1.603	128.5	83.44

From table (4.3) the efficiency is decrease with increase the duty cycle because the large duty cycle means more heat on the switch because the stress on the switch. The values of the output voltage and current satisfy the gain equations.

4.6: Elementary circuit with MPPT
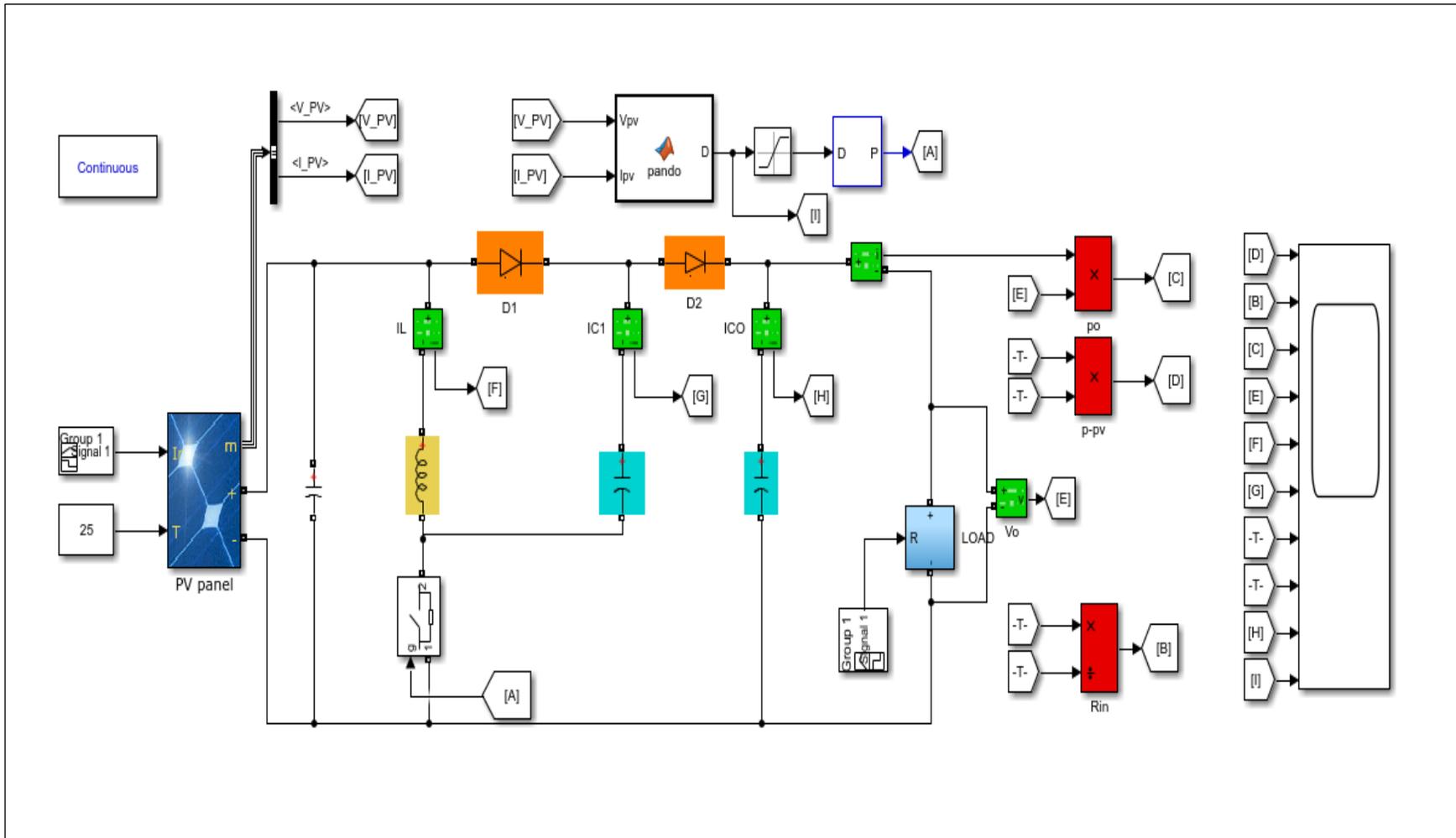
Fig 4.10: Elementary (POSLC) with MPPT

The circuit in fig (4.10) represent the elementary circuit of positive output super lift Luo converter which is implemented in MATLAB and controlled with Perturb and observe algorithm in MATLAB (m-file) and the source is PV panel.
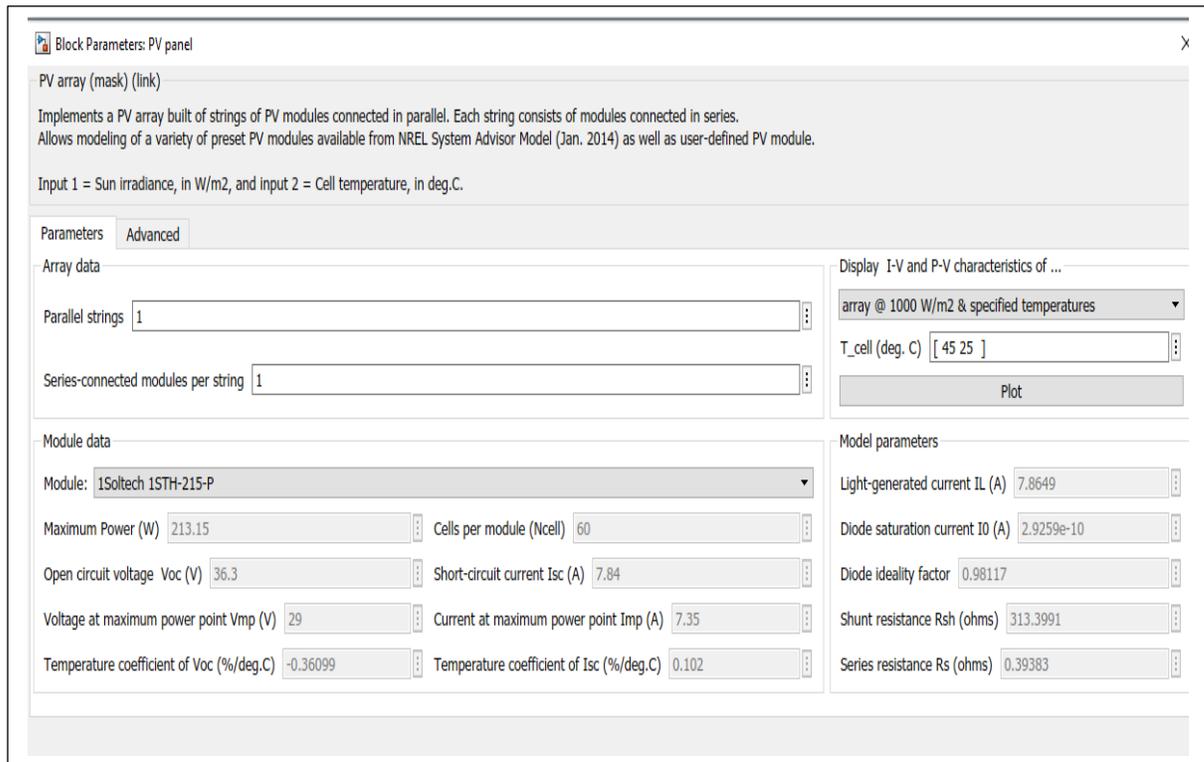
Fig 4.11: Block parameters of PV panel specification in MATLAB

Figure (4.11) shows the PV panel parameter such as maximum power extracted and open circuit voltage and short circuit.
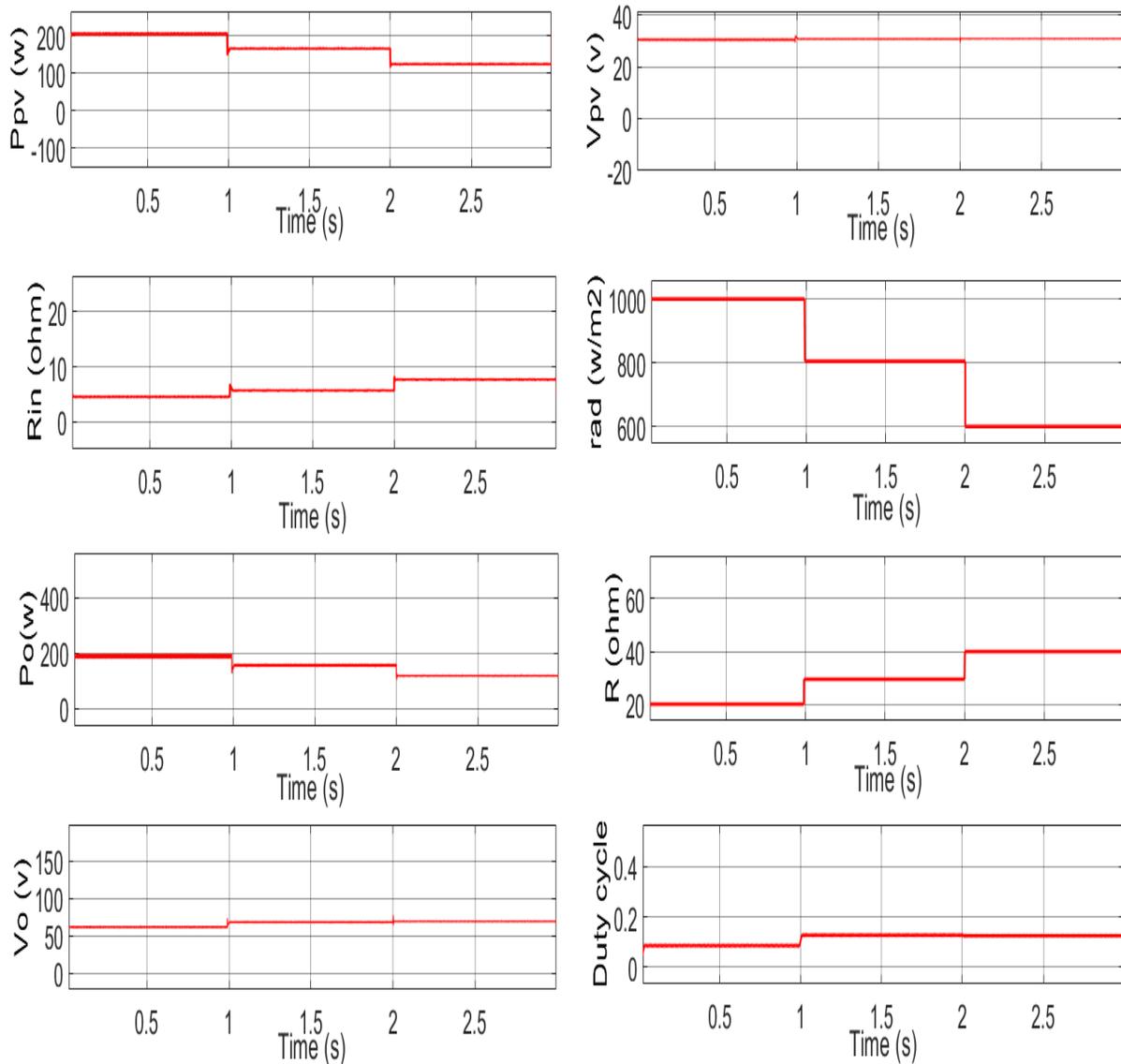
4.12: waveforms of (POSLC) with MPPT in MATLAB

Figure (4.12) shows the changing in irradiation on PV panel to notice the response of the controller to change the duty cycle, because the change in irradiation lead to change in internal resistance of the PV panel and as a result the equivalent resistance change.

It can be seen from the input power of the converter, in case of 1000 w/m^2 and 25 C that the MPPT work properly and extract all the possible power from the panel

and high output power with good efficiency.   The duty cycle that changing with every change in irradiation and that lead to change in equivalent resistance. The output voltage is sure change with every changing in duty cycle

Irradiation of the sun ($1000w/m^2$) and we change the irradiation from 1000 to 800 to 600 to see the change in duty cycle that occur to keep the operation on the maximum power point.

Note that the duty cycle decreases when the radiation decreases to increase the equivalent resistance of the converter and then to satisfy matching with the internal resistance of the PV panel which already decrease with decreasing of the radiation.

Table 4.4: Equivalent resistance changes with temperature and irradiation

G / T	200	400	600	800	1000
15	20	12	8	6.2	4.8
25	20	11.5	7.5	5.9	4.5
35	20	11	7	5.5	4.4
45	20	10.5	6.6	5.3	4.2

From table (4.4) when the temperature increases the equivalent resistance decreases in the same irradiation level, and it also increase when irradiation increase with same temperature level

4.7: First modification of (POSLC) with MPPT

Fig .4.13: first modification of (POSLC) circuit in MATLAB with MPPT controller.

Figure (4.13) represent the first modification of POSLC with (SI) cell and MPPT controller to control the PV power we used the same PV panel that we used with elementary circuit as in fig (4.10). Which shows the PV panel parameters and replace the inductor by the cell shown in previous chapter fig (3.6), we connect parallel capacitor with the PV panel to filter the incoming voltage to the converter.
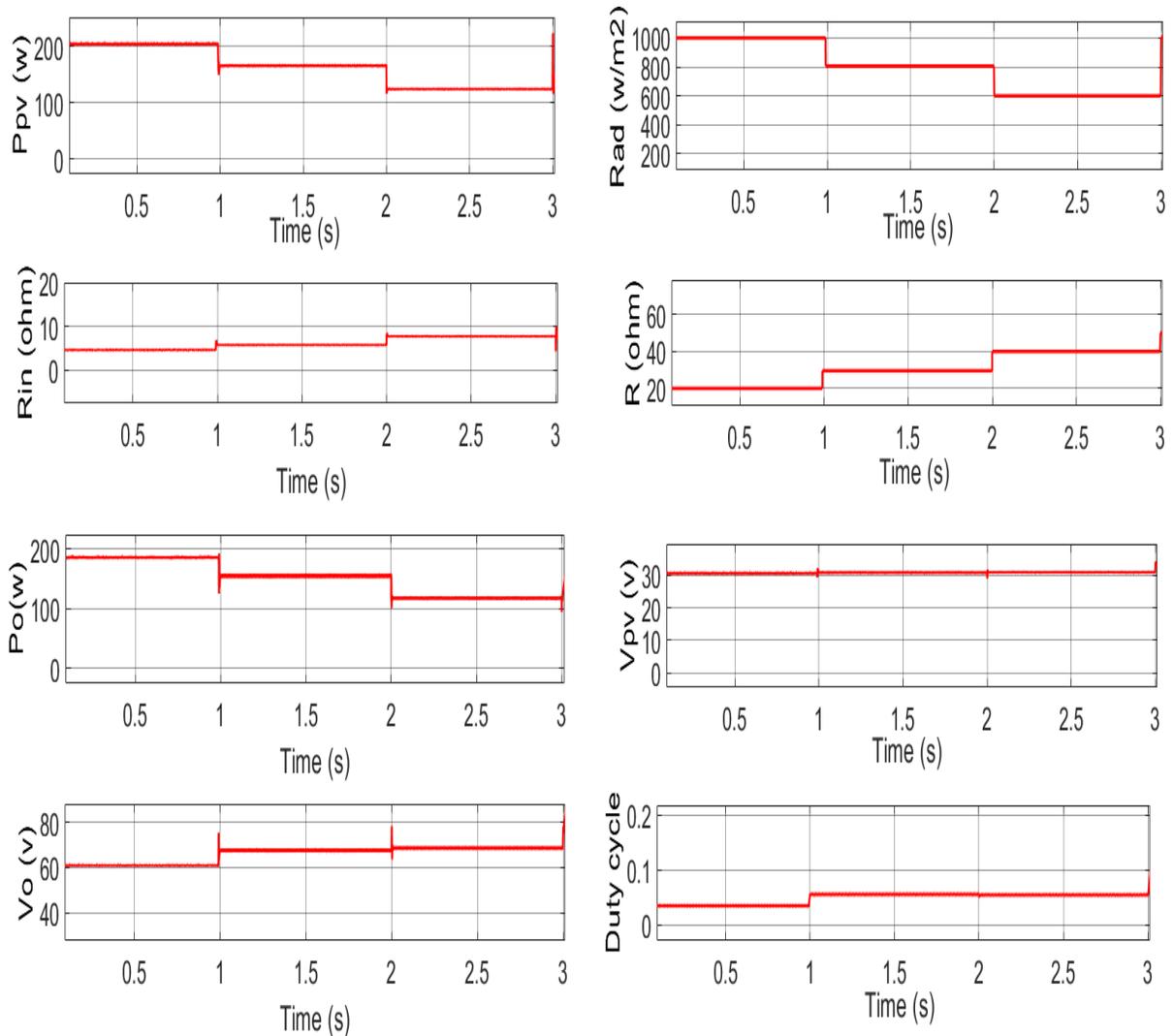
Fig (4.14) Waveforms of 1st modification of (POSLC) with MPPT in MATLAB

The changing in duty cycle from MPPT controller in figure (4.14) lead to change the input voltage to output voltage, and of course changing (Rin).

Table 4.5: values of output resistance with different irradiation and temperature

G / T	200	400	600	800	100
15	15	10.7	7.7	6	4.4
25	15	10.2	7.5	5.7	4.2
35	15	9.8	7.1	5.5	4.1
45	15	9.6	6.9	5.2	4

From table (4.5) when the temperature increases the equivalent resistance decrease in the same irradiation level, and it's also increase when irradiation increase with same temperature level.

4.8: Second modification of (POSLC) with MPPT
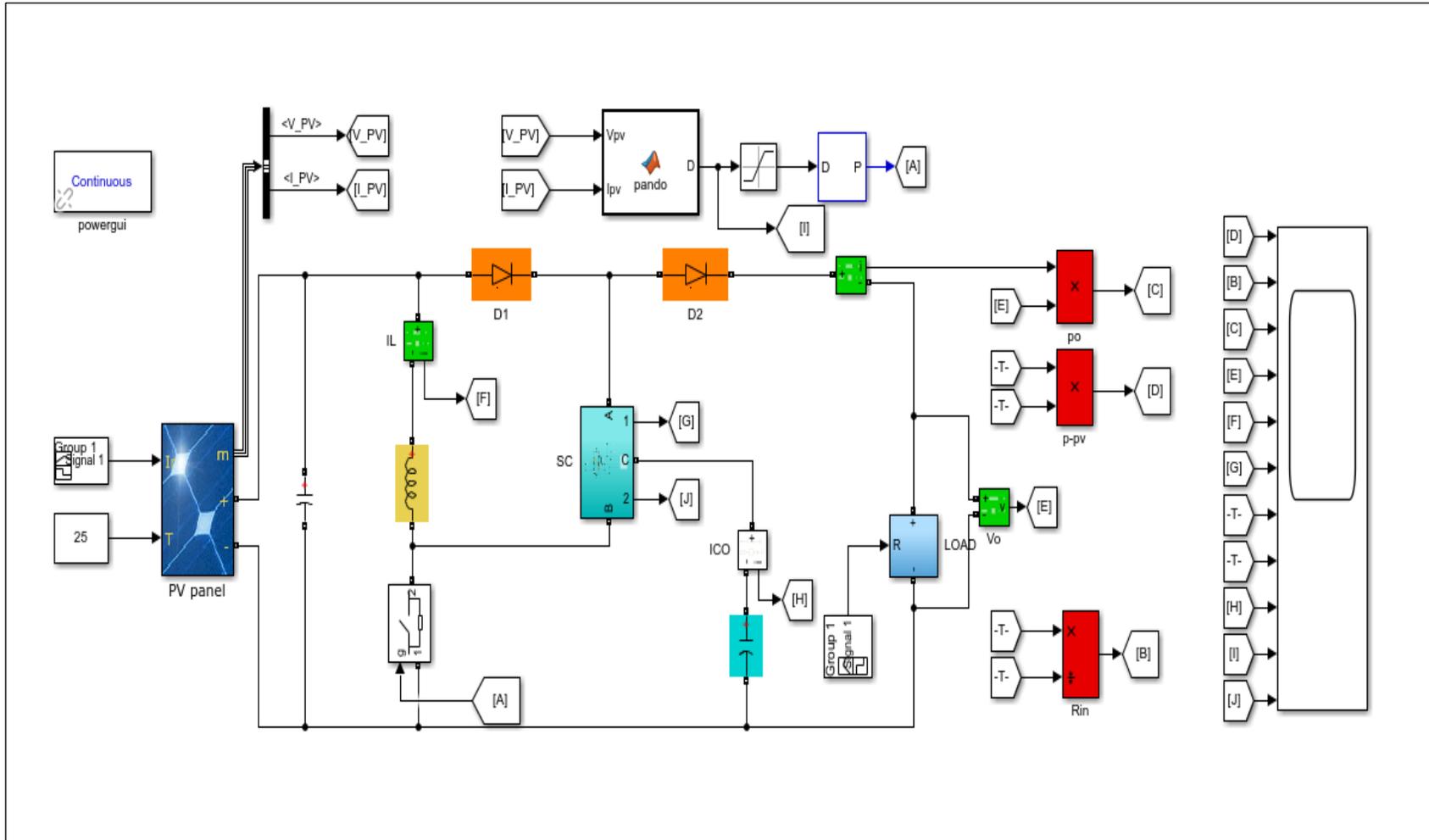
Fig 4.15: Second modification of (POSLC) circuit in MATLAB with MPPT controller.

Figure (4.15) shows the second modification of (POSLC) implementation and simulation in MATLAB and controlled by MPPT using Perturb and observe (P&O) algorithm constructed by m-file as shown below:
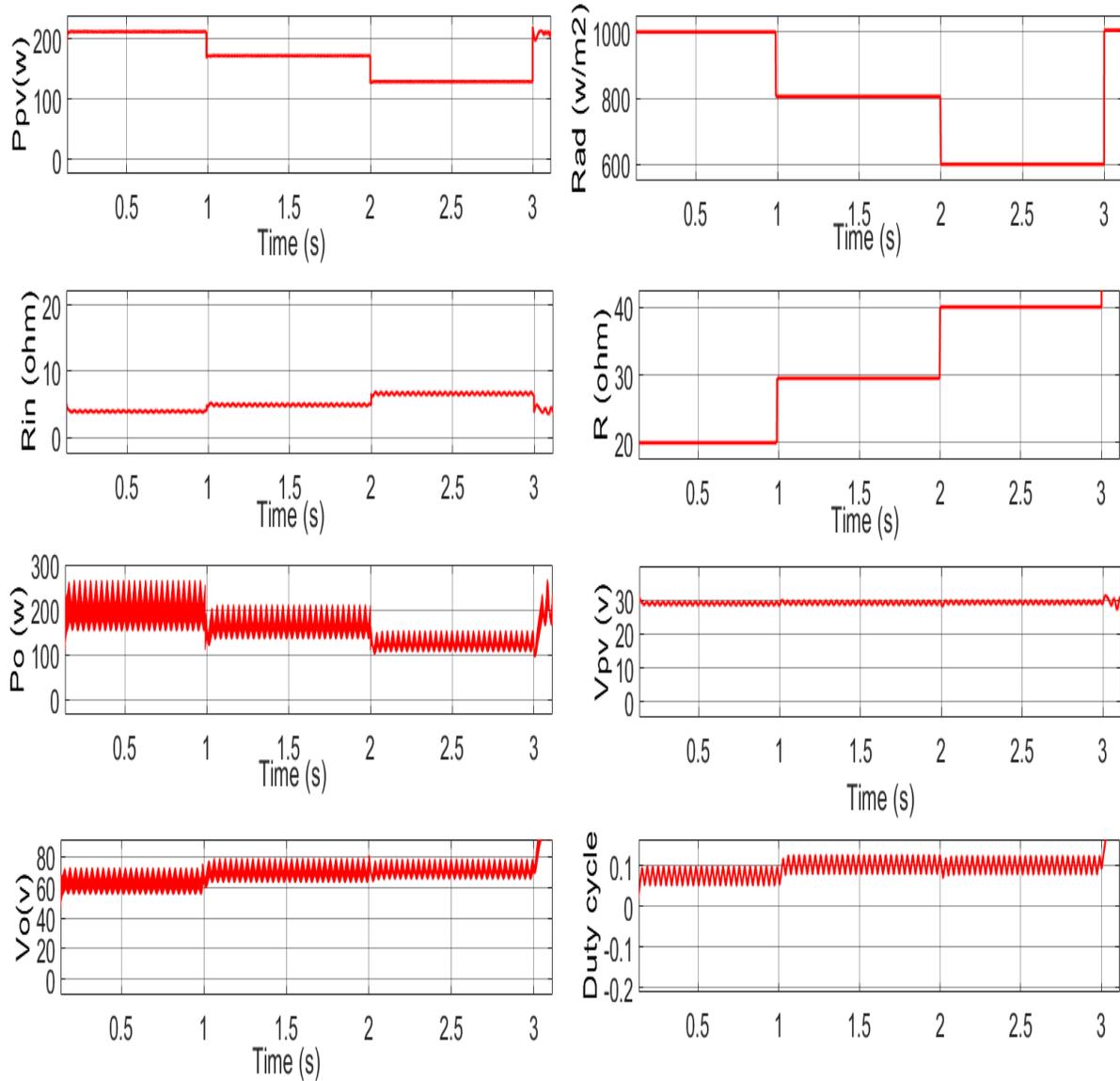
Fig 4.16 Waveforms of 2nd modification of (POSLC) with MPPT in MATLAB

Figure (4.16) shows the changing in irradiation, also shows the two value of resistive load. The input and output power respectively that clear the MPPT work properly. And track the maximum point. The duty cycle changing from MPPT

Controller to get Maximum power always. The waveforms show the input voltage to the second modification of Luo converter and the output voltage respectively duo to the duty cycle. The changing in equivalent resistance according to the changing duty cycle.

Table 4.6: Values of output resistance with different irradiation and temperature

T \ G	200	400	600	800	1000
15	18	10.7	7.2	5.25	4.2
25	16	10.5	6.8	5	4
35	15	10	7.5	4.75	3.7
45	15	9.5	7	4.5	3.5

From table (4.6) when the temperature increases the equivalent resistance decrease in the same irradiation level, it also increase when irradiation increase with same temperature level
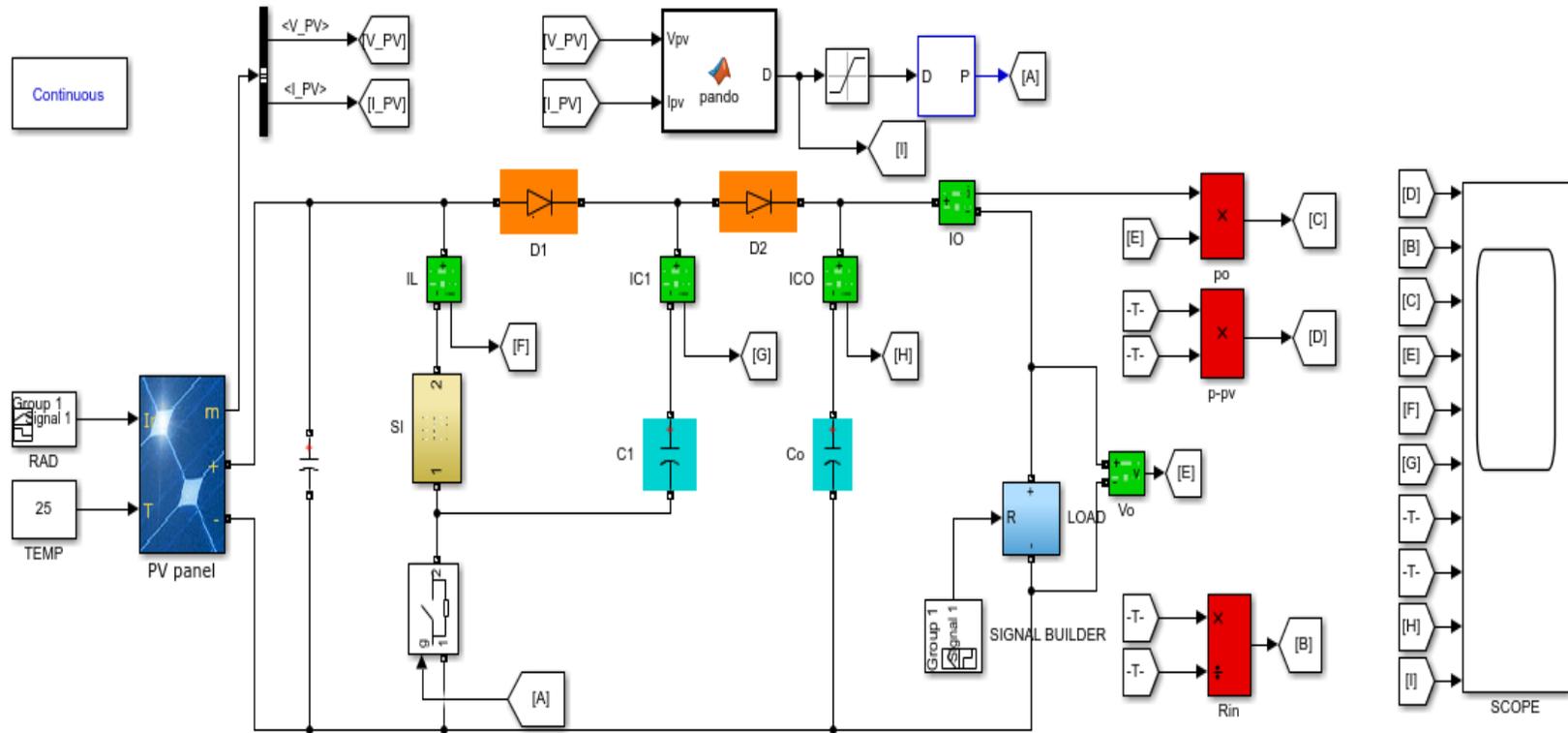
4.9: Third modification of (POSLC) with MPPT

The third modification work at very low duty cycle, this operation is very good condition of the (MOSFET) switch, because it reduces the stress on the switches more stability and less sensitivity and also can make a voltage gain at the output of the converter. The third modification of Luo converter is an implementation in MATLAB and control the circuit with MPPT (m-file) and the output parameters connected to oscilloscope to draw the waveforms.
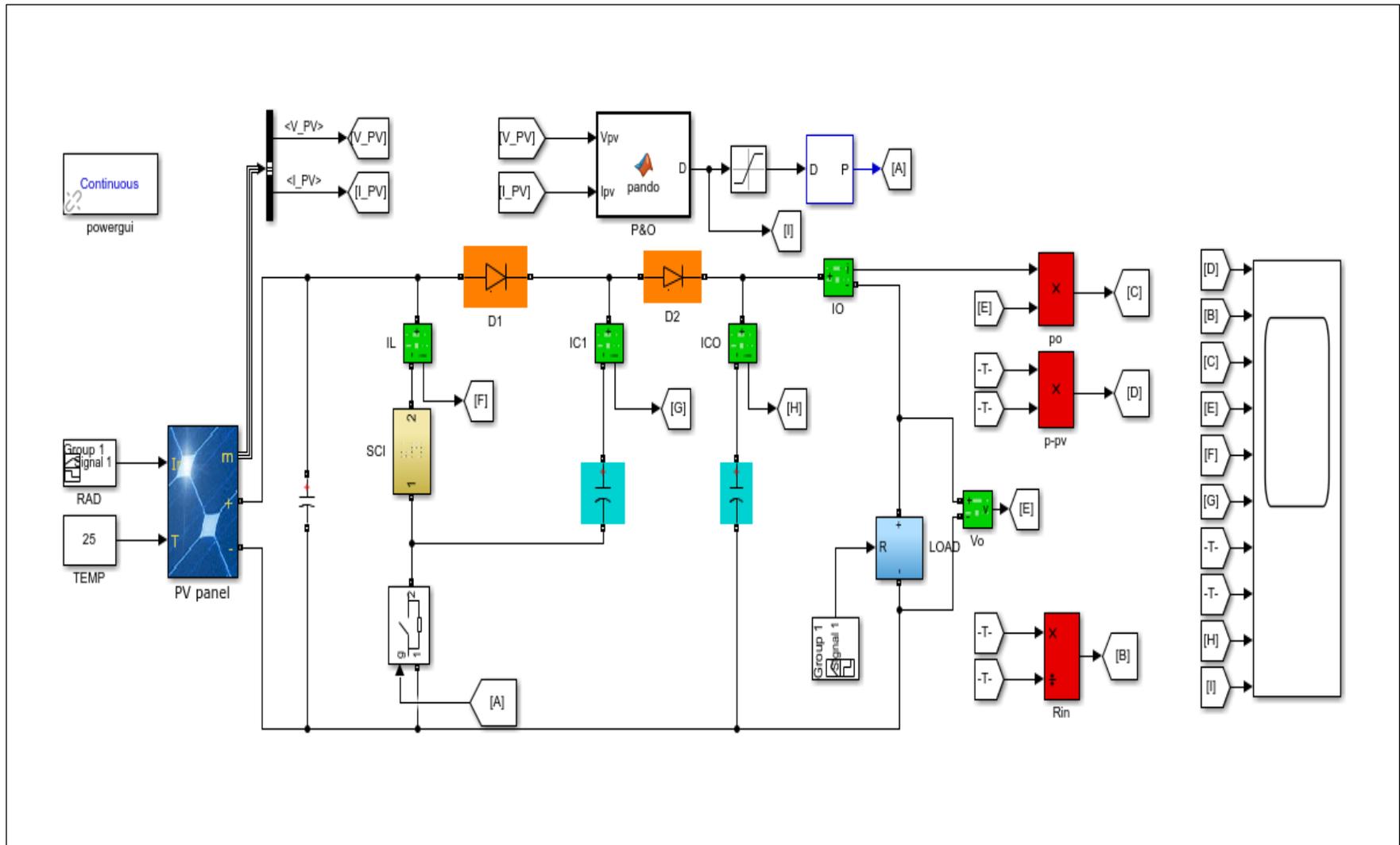
Fig 4.17: Third modification of (POSLC) circuit in MATLAB with MPPT controller.
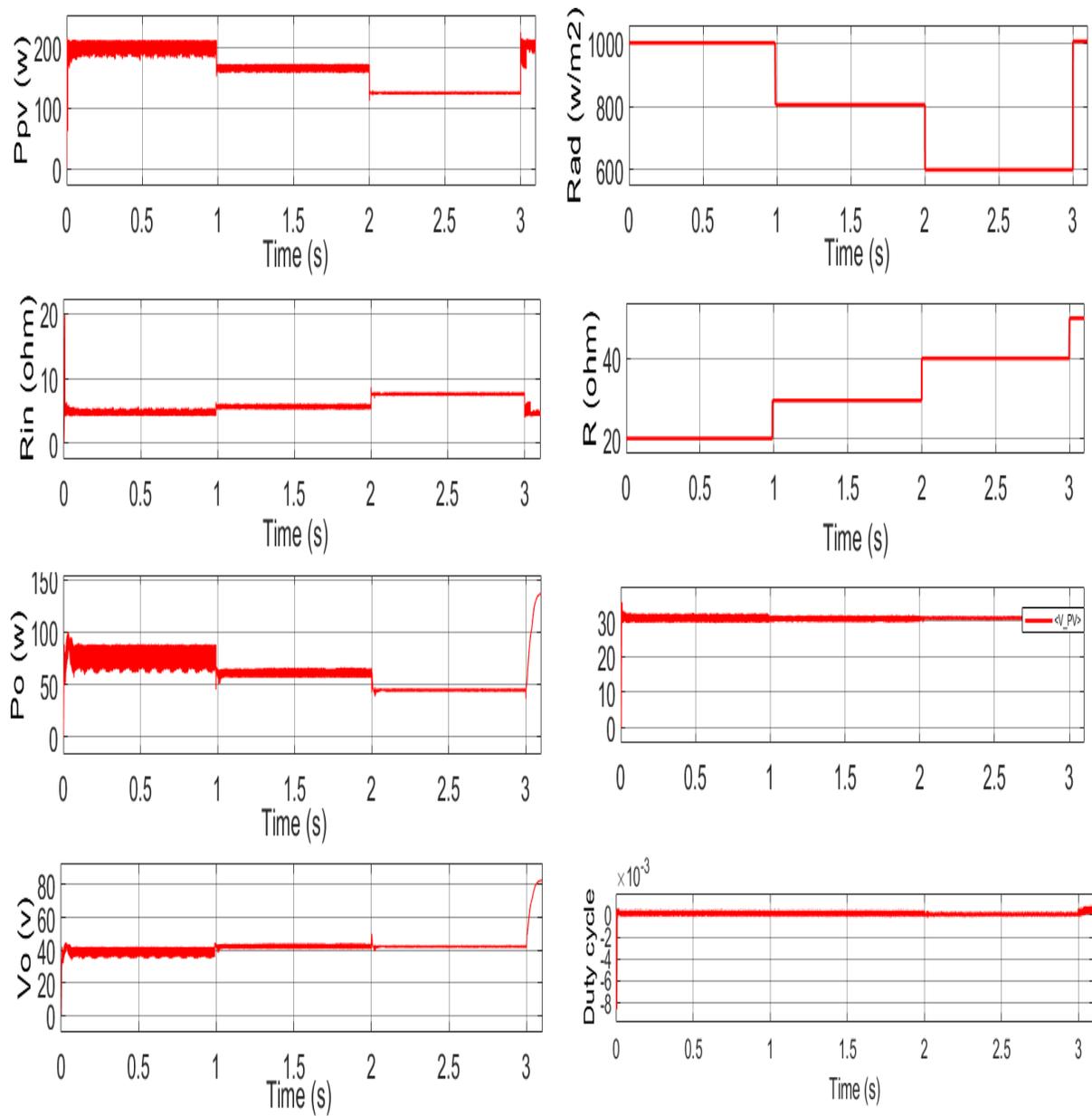
Fig 4.18: Waveforms of 3rd modification of (POSLC) with MPPT in MATLAB

Figure (4.18) shows the changing in irradiation, and shows the two value of resistive load. The input and output power respectively that clear the MPPT work properly. And track the maximum point.

Table 4.7: Values of output resistance with different irradiation and temperature

G T	200	400	600	800	1000
15	20.2	11	7.7	5.7	5.1
25	20	10.5	7.5	5.5	5
35	20	10	7.1	5.3	4.9
45	19.8	9.5	6.9	5.1	4.8

From table (4.7) when the temperature increases the equivalent resistance decrease in the same irradiation level, it also increase when irradiation increase with same temperature level.

Table (4.8): Comparison between proposed Luo converters and other high step-up converters.

Topology	Voltage gain	Gain at D=0.5	No. of (S)	No. of (D)	No. of (C)	No. of (L)	Total
Boost	$G = \dfrac{1}{1-D}$	2	1	1	1	1	4
Zeta	$G = \dfrac{D}{1-D}$	1	1	1	2	2	6
CUK	$G = \dfrac{D}{1-D}$	1	1	1	2	2	6
POLC	$G = \dfrac{D}{1-D}$	1	1	1	2	2	6
POSLC	$G = \dfrac{2-D}{1-D}$	3	1	2	2	1	6
First modifications	$G = \dfrac{2+D}{1-D}$	5	1	8	2	3	14
Second modification	$G = \dfrac{2}{1-D}$	4	1	5	3	1	10
Third modification	$G = \dfrac{4}{1-D}$	8	1	9	4	4	18

The table (4.7) shows the comparison between the three proposed converters and traditional converter and the main series of positive output super lift Luo converter from the gain and number of elements. The third modification is the highest gain converter more than any converter in other, the second modification is the simplest and low cost and treated with input pulsating current problems.

Also, the comparison shows that with every addition of elements branches the gain grow up.

Chapter five

The conclusion and the future work

5.1. The conclusion:

The most important conclusions reached by this research can be summarized in several points:

1. The increase in the voltage gain of Luo converter is associated with the increase in the number of passive elements, that mean; The greater the number of passive elements in a certain order (inductor switching cell, capacitor switching cell, hybrid capacitor-inductor switching cell), increase voltage gain.

2. By increasing the voltage gain in the three modifications, it directly contributed to reducing the stress on the switches. Because we were able to achieve a high voltage gain with a very small duty cycle on the switch

3. In these three modifications reducing the duty cycle, stress on switches and equivalent resistance all lead to increased system efficiency

4. Increasing the number of passive elements reduces the current flowing through each of them, and this helps reduce the heat of these elements and maintain their protection for the longest period of time.

5. Every expansion or addition of inductive elements must be accompanied by capacitive elements to maintain smooth voltage and current waves.

6. As the number of elements increases, this generates a small equivalent resistance in parallel (the switch is closed) and a large equivalent resistance in series (the switch is open), and this leads to a lack of change or oscillation in the duty cycle when MPPT control the system

Thus, the fluctuation in the output voltage and output power is reduced.

7. Too many components may lead to some losses in capacity and initial cost, but it will certainly maintain a longer component life and better system efficiency.

8. Approximately 25% of the power of the solar panel is lost if the maximum power point tracker is not used.

5.2. The future work

In the direction of developing converters and solar cell systems, we propose to complete the following works in the future:

1. Modifies DC/DC Luo converter by using star-delta combinations.

2. Designing an integrated power system starting from the solar panel and connecting the output of DC/DC converter to DC/AC inverter to operate an AC motor.

3. Design and implementation DC/DC Luo converter controlled by adaptive PI and P&O MPPT to keep power and voltage always suitable to the user.

4. Design and simulation of a hybrid renewable energy system from solar and wind energy

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جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة بابل / كلية الهندسة

قسم الهندسة الكهربائية

تحليل وتعديل محول ليو ذات الرفع الموجب العالي بالاعتماد على تبديل الخلايا للتطبيقات الكهروضوئية

رسالة

مقدمة إلى كلية الهندسة جامعة بابل كجزء من متطلبات نيل درجة الماجستير في الهندسة / الهندسة الكهربائية / الالكترونيك الصناعي

من قبل:

حسين عبد الخضر حسين راضي

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الخلاصة

بسبب التلوث البيئي ومشاكل الاحتباس الحراري العالمية اتجهت الجهود بالعقود الأخيرة الماضية نحو استخدام الطاقة المتجددة كالطاقة الشمسية وطاقة الرياح , وتعتبر محولات (DC/DC) ذوات الكفاءة العالية والربح العالي من اهم أجزاء الأنظمة الكهروضوئية وتطبيقات أنظمة الكترونيك القدرة.

هذه الرسالة تبدأ بالتحليل والتحقق والمحاكاة بوضع التوصيل المستمر(CCM) ووضع التوصيل المتقطع (DCM) للدائرة الاعتيادية لمحول ليو ذو الرفع الفائق الموجب الخرج (POSLC) وتم فحص اداءها باستخدام المحاكاة ببرنامج الماتلاب.

في المرحلة التالية من هذه الرسالة تم عمل تعديل على الدائرة الاصلية من اجل رفع معامل الربح , وذلك باستخدام خلية مفتاحية مكونه من ثلاث محاثات و خمسة دايودات , توضع هذه الخلية بدلاً من المحاثة في الدائرة الاصلية وتعمل عند ما يعمل المفتاح الرئيسي للدائرة بوضع التشغيل كمحاثات بالتوازي مع المصدر وعند فتح المفتاح يتم تفريغ القدرة المخزونة في هذه الملفات بالتوالي الى الحمل وبذلك يتم رفع الفولطية. تم تصميم وتحليل هذا التعديل وفحصة في برنامج المحاكاة وتطابق النتائج النظرية مع التحليلية, واصبح معامل الربح(5) عند دورة عمل (0.5)

وبنفس الطريقة تم اقتراح نموذج معدل أخر بتبديل المتسعة الرئيسية بمتسعتان وثلاثة دايودات لتشكيل خلية مفتاحية سعويه تعمل بنفس مبدأ عمل الخلية في التعديل الأول لكنها تشحن في التوالي وتفرغ القدرة بالتوازي. تم تصميم وتحليل ونمذجة التعديل هذا واثباته ومطابقته ببرنامج الماتلاب ومقارنته مع الدائرة الاصلية والتعديل الاخر. واصبح معامل الربح(4) عند دورة عمل (0.5)

ومن اجل الحصول على ربح عالي جدا عند دورة عمل قليلة جدا تم عمل توسيع كبير للخلية المفتاحية واستخدام خلية مفتاحية هجينة مكونه من اربعة محاثات واثنان من المتسعات، تم وضعها بدلاً من المحاثة الرئيسية في المحول الأساسي. وتم التوصل الى انه عند دورة (0.5) يصل معامل الربح الى (8) مرات الفولطية المدخلة وتموج قليل.

وفي النهاية تم استخدام النموذج الأفضل كمنظم قدرة لنظام الخلايا الشمسية من خلال استخدام متتبع نقطة الطاقة القصوى متحكم لعمل المحول من خلال التحكم بدورة العمل (duty) الخاصة بالمحول للحصول على أعظم طاقة من اللوح الشمسي ولان المنظومة الكاملة للطاقة الشمسية المربوطة توالي وتوزي مقيدة بقدرة اللوح الأضعف بالمجموعة فمن الضروري من الناحية الاقتصادية الحصول على اقصى استفادة من اللوح الشمسي.

تم ربط الدائرة والدوائر المقترحة جميعها مع متحكم متتبع نقطة الطاقة القصوى باستخدام برنامج ماتلاب/2020 وتم مقارنة النتائج مع وبدون متتبع الطاقة القصوى لبيان تأثير هذا المتحكم على استخراج اقصى طاقة ممكنة من اللوح الشمسي.