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ISTANBUL AYDIN UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

HIGH GAIN DC-DC CONVERTER WITH SWITCHED CAPACITOR FOR SOLAR PV APPLICATIONS

THESIS

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Thesis Advisor: Prof. Dr. Murtaza FARSADI

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DECLARATION

I hereby declare with respect that the study “High Gain DC-DC Converer With Swithed Capacitor For Solar PV Application ”, which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the Project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the Bibliography. (……./…../20...)

Ayman HAJTAHER

FOREWORD

I would like to thank my supervisior for his endless passion, And also i would like to thank the institute of applied science of Istanbul Aydin University, Department of Electrical and Electronic Engineering, all of my friends and every person who gave me any support or advice which help me in my work.

December 2020 **Ayman HAJTAHER**

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ABBREVIATIONS

AC	: Alternating Current
DC	: Direct Curent
PWM	: Pulse With Modulation
SPWM	: Sinusoidal Pulse With Modulation
kW	: Kilo Watt
MPPT	: Maximum Power Point Tracker
PV	: Photo Voltaic Panel

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HIGH GAIN DC-DC CONVERTER WITH SWITCHED CAPACITOR FOR SOLAR PV APPLICATIONS

ABSTRACT

In this thesis a new method for voltage boosting is implemented with high gain DC-DC converter with switched capacitor. Comparing to the traditional DC-DC converter, this new circuit topology, voltage can be increase to extreme level, by using combining of two active components which are MOSFET and passive components like inductor and capacitor, by controlling the duty cycle ratio of each MOSFET separately, a high voltage value is reached at the output of the DC-DC converter by adding capacitor and inductor voltages. Therefore, it can reach this extreme voltage. Grid connection transformer can be eliminated by using this method, cost of PV plant will be lower.

Key Words: *Grid, Transformer, High Gain DC-DC Converter*

SOLAR APLİKASYONLAR İÇİN YÜKSEK KAZANIMLI DA/DA ÇEVİRİCİ TASARLANMASI

ÖZET

Bu tezde yeni bir metod olan yüksek kazanimlı DA/DA çevirici kullanılarak gerilim yükseltme yapılmıştır. Geleneksel DA/DA çeviricilerle kıyaslandığında, bu metod ıle gerilim cok yüksek seviyelere yükseltilebilmektedir. Bu işlem iki yarı iletken devre elemanı ve pasif devre elemenları ile oluşturulan spesifik bir devre ile yapılmaktasır. Sistemin çalışma mekanizması yarı iletkenlerin darbe genişlik modülasyonu kullanılarak farklı oranlarda açılıp kapatılmasıyla, indükör ve kapasitörler üzerinde depolanan voltajın toplanmsıyla olur. Bu metod kullanılarak şebeke bağlantısı için gerekli olan transformatör kullanımı ortadan kaldırılabilir. Bu durum fotovoltaik tarlaların maliyetini önemli ölçüde azaltacaktır.

Anahtar Kelimeler: *Şebeke Transformer Yüksek Kazanımlı DA / DA*

1. INTRODUCTION

1.1 Introduction

Energy is one of the key needs of human existence and the demand for energy sources in the world. The electrical energy is produced by using such resources as chemical (fossil fuels), nuclear sources, gravitational fields (tidal waves), wind power and solar power. The block diagram for producing the electrical energy is shown in Figure 1.1. [1]

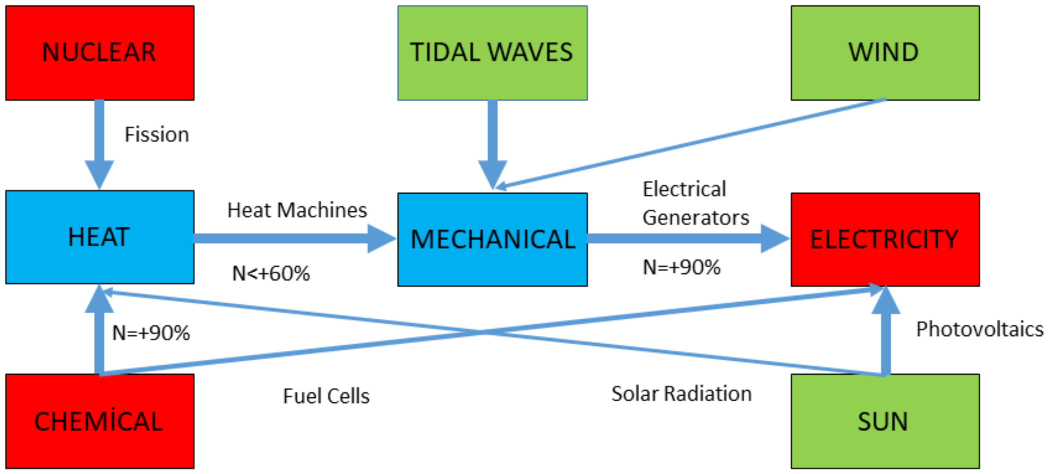

Figure 1.1: The energy conversion of different energy sources to Electrical Energy

Most of the electrical power is produced from chemical and fossil sources such as petroleum and natural gas. It is known that the development of these sources in nature takes a long time and the rapid consumption of fossil fuels constitutes negative effects on the environment and human health. The developing technology and the industrial production increase the energy consumption. Therefore, the likelihood of a possible energy crisis also increases. The International Energy Agency (IEA) estimates that the demand for energy in the world will increase with an amount of 55% by the year 2030, and the fossil fuels would take part in this increase with an amount of 84%.

In this context, the depletion of the fossil-based fuels increases the concerns over the global warming and leads people towards finding alternative energy sources.

Solar, wind, geothermal and wave energies can be given as examples of alternative energy sources. The PV energy which is one of the alternative power sources is a result of the fusion reactions that takes place in the Sun. The radiation that comes out of these reactions is named as solar energy. About half of the solar power reaches to earth passing through the atmosphere, resulting in the increase of the temperature of the Earth and the continuation of life. As a result of the variation in the temperature, the wind and the movements in the ocean occurs. The amount of the solar power s about 1370W/m^2 just outside of atmosphere and between 0 and 1100 W/m^2 at the surface of the Earth. In this context, it can be said that even a small portion of the energy that reaches to the Earth is more than the total energy consumption. The literature shows that the studies for producing electrical energy with solar energy increases after 1970's. The eco-friendly solar energy systems which are also named as photovoltaic (PV) systems, has been less expensive over the last technologic developments and it had made itself accepted as a new and renewable energy source.

The known energies in the world convert into different energy sources through different conversion processes. The sources such as the Sun, tide and the center of the world constitutes a source for energies such as PV, wind, tide, geothermal and other renewable energy sources. The technologies that are used in these processes are shown Figure 1.2. [3] [2]

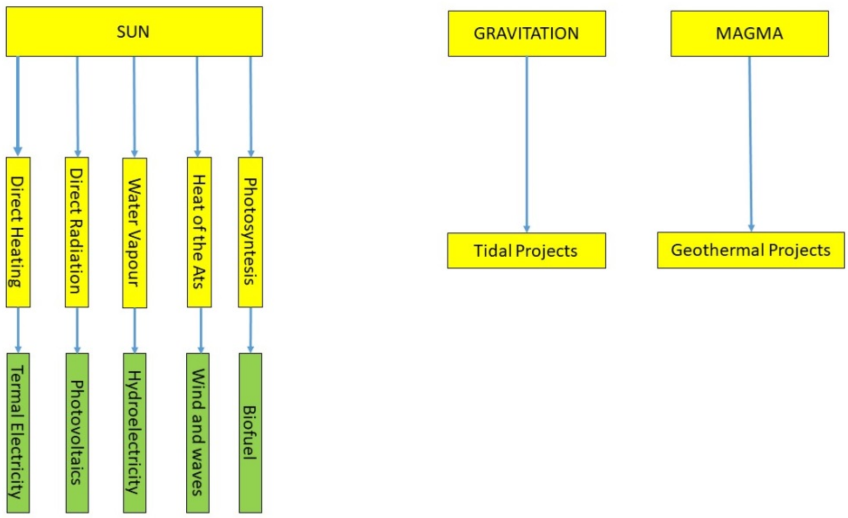

Figure 1.2: Renewable energy formation in world

1.2 Problem Statement

The DC-DC converters are very promising devices for power electronic applications, in the industry many inverter and converter using DC-DC converters for regulating the power quality and sufficient for steady state working zone. Many high-power inverters have maximum power point tracker circuit which is called MPPT uses different type of DC-DC converter topology for reach the desired working principle like voltage has to be in interval for inverters for example between 600-1000 Volt so this voltage fluctuation can be eliminate by using proper DC-DC converter. Main problem of this circuits needs an additional big bulky transformer, this transformer is not cost effective and efficient so by changing the topology of DC-DC converter side we can reach high voltage levels which is required for grid connections.

1.3 Research Objectives

The main purpose of this study is to eliminate big bulky transformer in solar array application we will reach this desire by using new type of DC-DC converter topolgy and algorithym.

The main goals of the study are given below:

- To increase the output voltage of DC-DC converter to required grid connections voltage
- To eliminate using big bulky and not cost effective transformer in system

1.4 Scope of Work

In this thesis our main focus is to increase the generated DC voltage from pv without using transformer with high gain DC-DC converter, by using proposed topology which will we examine deeply in chapter 3. With increasing output voltage of DC-DC converter, we can eliminate transformer so this is our main desire of the thesis.

1.5 Methodology

The method has begun with studying the previous works in this field. DC-DC converters are main part of solar systems and it has some difficulties such working on high voltage levels also semiconductor switches have some limitations like limited input voltage level. MATLAB /Simulink software is used for making practical test of proposed topology. We used PV array and some MPPT algorithms for DC input side of simulation after our proposed high gain DC-DC converter topology made by using power electronic switches and inductor, capacitor.

1.6 Thesis Outline

The structure of the thesis consists of the chapters that are given below:

Chapter 1, An introduction is given in this chapter.

Chapter 2, The literature review is given in this chapter and the studies that were performed in the field of power converter topologies and their characteristics and comparisons.

Chapter 3 In this chapter, methodology of thesis given, simulation and circuit are explained briefly.

Chapter 4, Results and discussion are given in this chapter, two case compared each other.

2. LITERATURE REVIEW

2.1 Introduction

In this section of thesis therotical background of DC-DC converter types will be explained. Any section of power converters need a proper DC-DC Converter design, the design requirements decide which converter topology will be use. In Figure 2.1 presence a summary of DC-DC Converter topologies. [4]

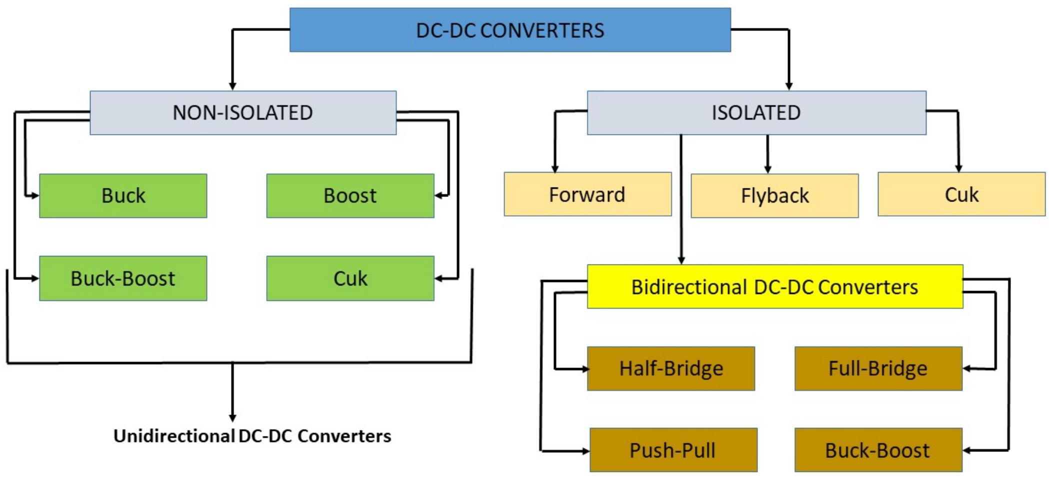

Figure 2.1: Classification of DC-DC Converters

In the Figure above DC-DC Converters classify as isolated and non-isolated branch which has same type converters, the main difference is galvanic isolation which required for some application such as consumer electronics. Some countries not allowed to use non isolated devices if they are connected electrical networks. Non-isolated converters can be used in low power and voltage systems which is already seperated from main voltage. With latest power electronic technologies DC-DC converters reachs high efficiency values like %98 percent and they are controlled with different type of switching patterns (PWM) which is called pulse with modulation technique, also semiconductor industry reach very high switching frequency like 40-50 kHz, this will make converter more efficient but it also make some problems like electro magnetic interferance (EMI) and this make stress on main voltage. Switched mode DC-DC converters non linear and systems that change over time.[5]

Converter suitable protection properties of the application specified together with the design criteria. Buck Boost and CUK converters are basic converters which are combining of some semiconductor devices. Full bridge and half bridge converters are complexier than basic buck boost type. [11]

2.2 Buck Converter

Buck Converters have a smaller DC input voltage than output voltage. Most commonly used places:

- Regulated DC power supplies.
- DC motor speed control circuits.

In a practical circuit this system has 2 drawbacks. In reality the load may be inductive rather than fully ohmic. The switch consumes inductive energy with inductor. The output voltage oscillates between 0 and Vd. Simple scheme as concept with ohmic load in Figure 2.2. The step-down converter is stated. An ideal switch and resistor assuming a load, the instantaneous output voltage depends on the state of the switch. The output coil and capacitor is used for filtering the voltage. Filter action required depending on the state of the load provided. [4]

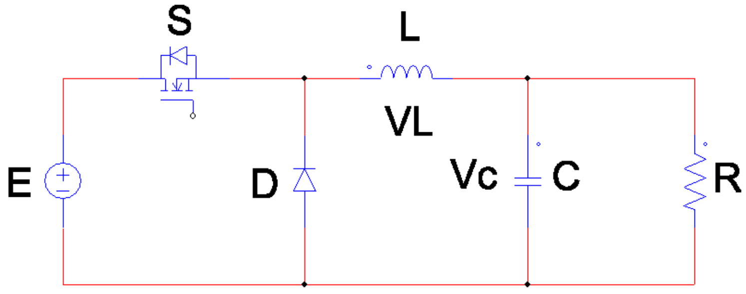

Figure 2.2: Simple Scheme of Buck Converter

If the inductance is big enough, the inductor current will never be zero. This mode is defined as continuous inductor current. The problem of stored inductive energy eliminated by diode as shown in 2.3. Filter inductor and capacitive elements also shown on 2.3 a. Figure 2.3.b in the low-pass filter output voltage is Vo. Duty cycle and switching frequency shown in Figure 2.3 b. Characteristic of the low pass filter shown in Figure 2.3 c.

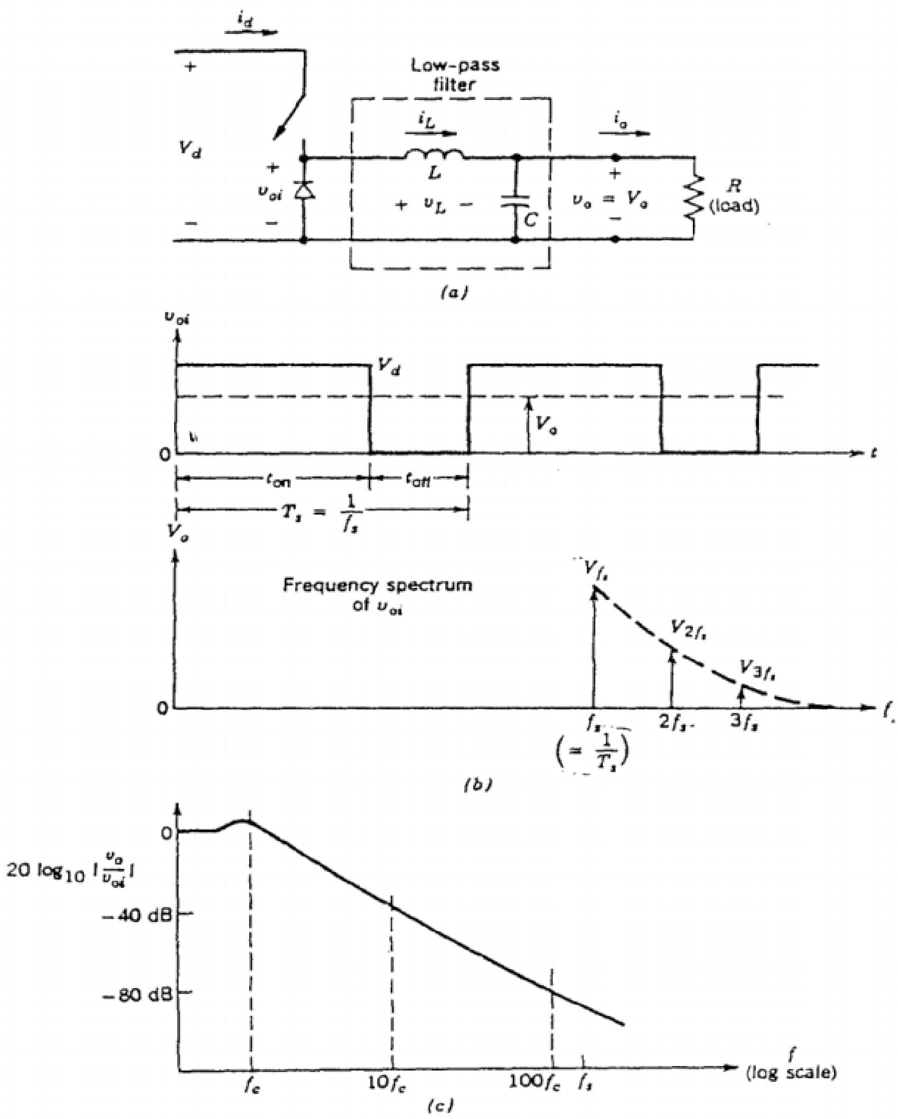

Figure 2.3: Working Principle of Buck Converter

The switch S in the circuit in Figure 2.2 is periodicly opened and closed. Total period T and switching interval multiplier is D as called duty cycle. In this case the time interval of switching multiplier is (1-D). For analysis purpose, Vc Can also be neglected. Capacitor voltage VC can be indicated with output voltage. During the time when the switch is closed, the circuit is shown in figure 2.4. (a). When the switch is open, the inductor completes its current through the diode and the resulting circuit is shown in figure 2.4. (b). The length of time the switch is closed for the voltage equality of the circuit, with equation (2.1) is given

$$E = V_L + V_C \tag{2.1}$$

$$E = L\frac{d_{i_l}}{d_t} + V_C \tag{2.2}$$

$$\frac{d_{i_l}}{d_t} = \frac{E - V_C}{L} \tag{2.3}$$

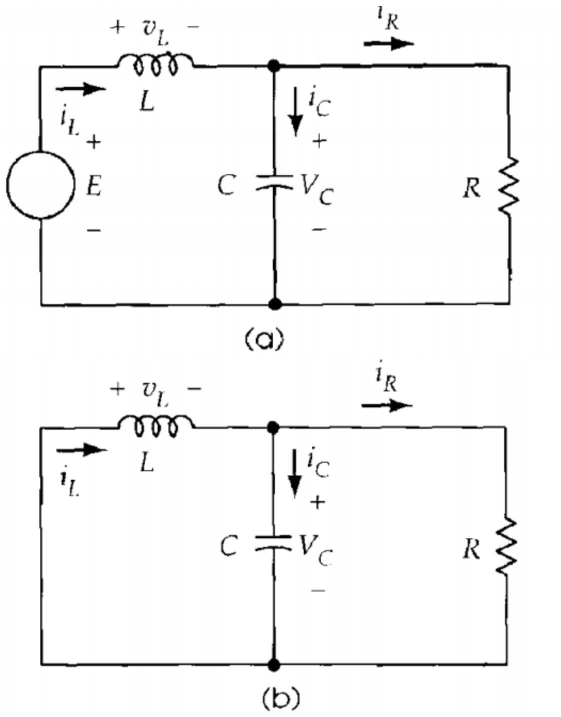

Figure 2.4: Buck Converter Close Operation

2.3 Boost Converter

These types of converters are used in regulated DC power supplies. It is widely used in dynamic braking of DC motors. When the switch is closed, the diode is not conducting because it is reverse polarized thus the output stage is isolated from the input side. When the switch is turned on, the output stage coil fed through. From the steady state analysis, a steady output voltage is obtained. The capacity of the output filter capacitor must be quite large to (Vo (t) nearly equal to Vo) during the time when the switch is closed, the inductor current is equal to increases with the given derivative:

$$\frac{d_{i_l}}{d_t} = \frac{E}{L} \tag{2.4}$$

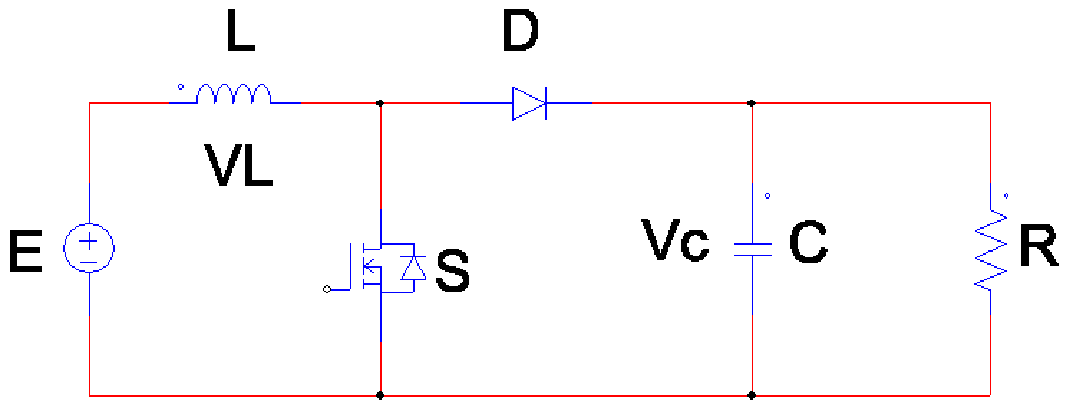

Figure 2.5: Simple Scheme of boost Converter

In this range, the diode is reversed polarized. Capacitor supplies current to the load and IC is negative. When the switch S is opened, current at the beginning of the wave will be same as the current at the end of inductor, so current will decrease in this time. For the reduction of inductor current, VC must be greater than E. During the switch is on state, the inductor derivative of the current is given in equation. [9]

$$\frac{d_{i_l}}{d_t} = \frac{E-V_c}{L} \tag{2.5}$$

IL increase while the switch is closed and decrease in open time Since it should be equal to the maximum current, it can be determined as:

$$I_{max} - I_{min} = \frac{E}{L} DT \tag{2.6}$$

$$I_{max} - I_{min} = (\frac{E-v_c}{L})(1\text{-D})\text{T} \tag{2.7}$$

According to the equation, the circuit appears to be a boosting. As D increases, VC increases, according to the equation, the output voltage is at the square (E^2) of the input voltage can be as big. Inductor resistance is important for large D values. The value of D and the amount of voltage increase, for not causing any problems D must be limited to a certain value. An increase of 5: 1 ratio is a practically important we can consider as a limit. The switch is open (with switching loss problems) the time may be very shortly at this point, and the diode and capacitor currents average may have big peaks compared to their values. The result value RMS of the capacitor current is much greater than the required capacitance value may be bigger. Besides, moderate voltage increases are acceptable but it can change with design conditions. [5]

2.4 Cuk Converter

Cuk converters are structures that convert a DC voltage into a DC voltage of different amplitude. Cuk converters basically consist of two coils and capacitors, a diode and a switching element.The circuit topology of Cuk converters is basically given in the figure below.

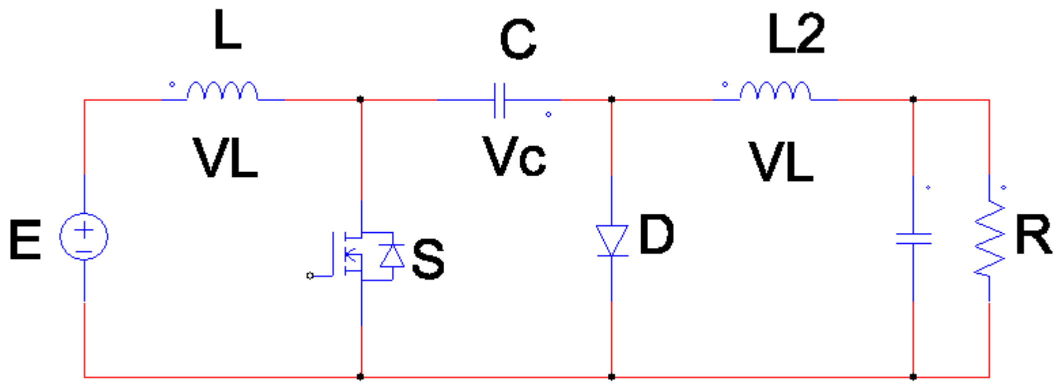

Figure 2.6: Simple Scheme of CUK Converter

The Cuk converter in particular has been used for projects such as factor correction of power for electric car battery chargers, these EVs are a trend that worldwide they have presented great reception and unlike conventional cars where It was believed that the engine was the most important thing, in EVs the battery is the one that comes into play main role since these are in charge of storing electrical energy for later transform it into mechanical energy, although the most common is to use converters elevators for the realization of the PFC, this particular application has been granted to Cuk thanks to the possibility of having lower voltage values at the output greater than entry . It has also been used in the connection of photovoltaic systems connected to the network, since it has the enormous advantage over other converters of possess the connection between the input and the load only through a capacitor which makes that the system is more efficient and presents a lower amount of losses . The topology of the Cuk converter has been considered the optimal topology for having input current non-pulsating, non-pulsating output current, minimum storage elements, number minimum switch capacity and high energy storage density using a capacitor instead of an inductor, which can be function as an up-converter or descending, this makes it a favorite when it comes to checking. The Cuk type DC / DC converter circuit was developed by Slobodan Cuk of California Institute of Technology. This type of converter has a great difference with respect to the other DC / DC converters out there and this is using a capacitor instead of a inductance for energy storage, which improvesthe energy ratio stored and circuit size. [6]

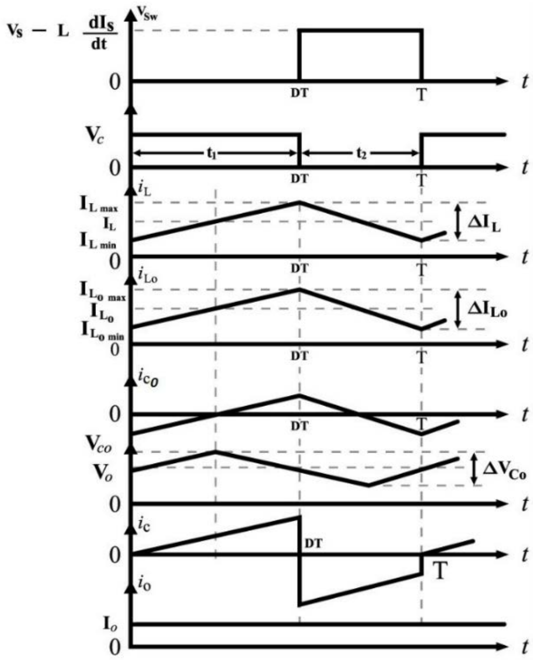

Figure 2.7: Cuk Converter Voltage Current Graph

2.5 Forward Converter

The direct converter is a converter DC-DC switch mode. The DC-DC converters are used in systems regulated DC power supply switched mode and motor drive applications. The DC-DC converters use one or more high frequency switches to convert the DC power from one level to another. The input of these converters typically be a DC voltage not regulated, which is obtained by rectifying the AC line voltage, so both will fluctuate and from changes in the magnitude of the line voltage. DC-DC converters are responsible for converting unregulated DC input to regulated DC output. Delivery systems regulated DC power switch mode often add a transformer electrical insulation as a further modification.Although the output voltage of a reverse flight converter is theoretically infinite, the forward converter is limited by the maximum output voltage transformer to turns ratio: Ns/Np [7]

$$V_{out} = D\frac{N_s}{N_p}V_{supply} \tag{2.8}$$

2.6 Fly Back Converter

Flyback converters are based on buck-boost converters. Flyback converters are an isolated form of buck-boost converters. A normal flyback converter consists of a switching element, a transformer, a diode and a capacitor. Flyback circuits can be found in many types due to their structure. These types include structures such as two-switched flyback circuit, RC reset flyback circuit. In this content, we will try to explain the flyback circuit with its simplest structure. This structure is given in the figure below. In addition, the flyback converter has a parallel magnetizing inductance visible on the left side of the transformer in the figure below. In the circuit analysis of this inductance converter, it is considered in parallel with the transformer. [8]

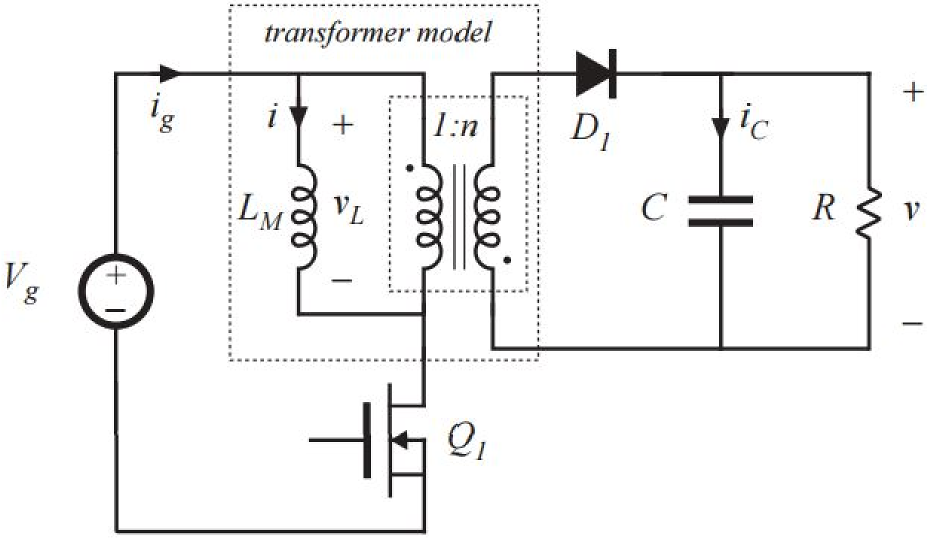

Figure 2.8: Flyback Converter Simple Scheme

Due to the use of transformers in flyback converters, restrictions occur in the circuit, which limits the load current which connected to the output of the converter. For this reason, flyback converters are generally used in applications where high output voltage is required but not high power. In buck-boost converters, the polarization of the load voltage in the opposite direction to the input voltage is eliminated in flyback converters. In flyback converters, input voltage, output voltage and load voltage is polarized in the same direction. The main current in the transformer input and output in the circuit is also the magnetizing current.

The most important factor that makes flyback converters useful is their simple structure and low cost. Transformers are known to operate with AC signals. But how is it possible that a transformer with the correct voltage applied from its input can transfer energy to the secondary side? Here, the effect of the coil at the left end of the transformer. When the switching element switches from conduction to cutoff state (since the average voltage of the coil is zero in direct current circuits), the polarity of the voltage at the ends of the coil changes and the correct voltage momentarily acts as an alternating voltage, allowing the transformer to operate. In every circuit in DC to DC converters, there are two operating cases in flyback circuits. The first of these cases is when the switching element is in transmission and the second is when it is in cut. Now we will analyze these two cases separately on the circuit. [8]

In the return circuit seen above, the switching element in the circuit is in transmission. In this operating state, the main current increases and stores energy in the transformer windings. In this mode, due to the secondary voltage being induced in reverse, the diode D1 in the circuit becomes reverse biased and switches to the cut-off state, which does not cause current to flow from the secondary end of the transformer. Since there is no secondary current, there is no power flow from the primary end of the transformer to the secondary end. The element that feeds the load in this operating state in the circuit is the “C capacity”. Above is the circuit diagram when the switching element on the flyback circuit is in cut. In this case, while current flows from the secondary, it does not flow for a while. Since the current at the primary end of the transformer can not change suddenly with the coil effect, depending on Lenz's law, the primary voltage of the transformer will be reverse induced. In the leading case, the energy in the primary could not be transferred to the secondary because the diode was reverse induced and cut. In this case, the energy is transferred to the secondary end when the diode is polarized in the correct direction and short-circuited. In this case, since the switching element is in the cut-off state, the primary end of the transformer is open-circuit and a secondary voltage, in other words a voltage dependent on the load voltage, is induced at the primary of the transformer. The conversion rate of the transformer affects this connection. Flyback converters are generally designed in the range of 50-100 watts, which can be considered as low power.

Flyback converters are frequently used in the power supplies of tools used in today's consumer electronics. The most important factor in its use is that it has the advantage of very low part count. Considering that the transformer receives the energy from the Vg source only in the first state in the flyback circuit.

3. METHODOLOGY

3.1 Introduction

In this section, the method that we follow will be held briefly. The proposed topology of high gain DC to DC converter has examine deeply.

3.2 Proposed Topology of DC-DC Converter

Figure 3.1 presence circuit diagram of proposed topology of high step up gain DC-DC converter with switched capacitor. The converter boosted voltage to the extreme levels, it contains two active switches S_1 and S_2. The inductor L_1 and capacitor C_1 are used to perform boost operation. Acoording to the proposed structure, the boosted voltage is regenerated and further stored into capacitor C_2 and inductor L_2. The energy stored in C_2 and L_2 is controlled by the switches S_1 and S_2 respectively. The detailed CCM and DCM waveforms of topology will be given. [9]

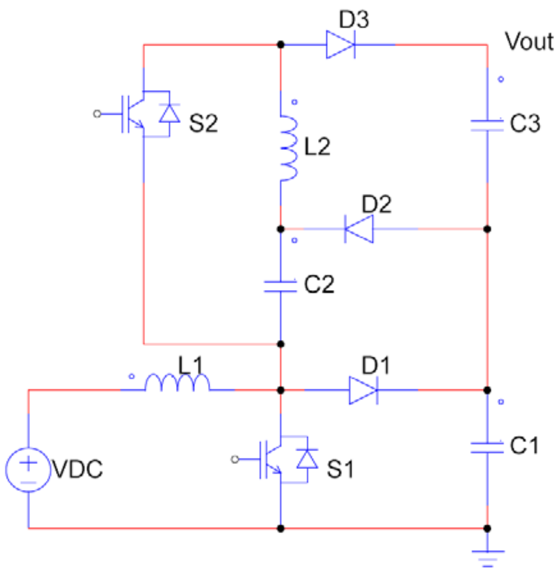

Figure 3.1: The proposed topology of converter

The steady-state analytical waveforms detailed under the operations of the CCM and DCM operations are illustrated in Fig. 3.2 Duty cycles D_1 and D_2 represent the trigger signals of S_1 and S_2, respectively. Based on the waveforms, three main modes are identified in the converter at every switching period.

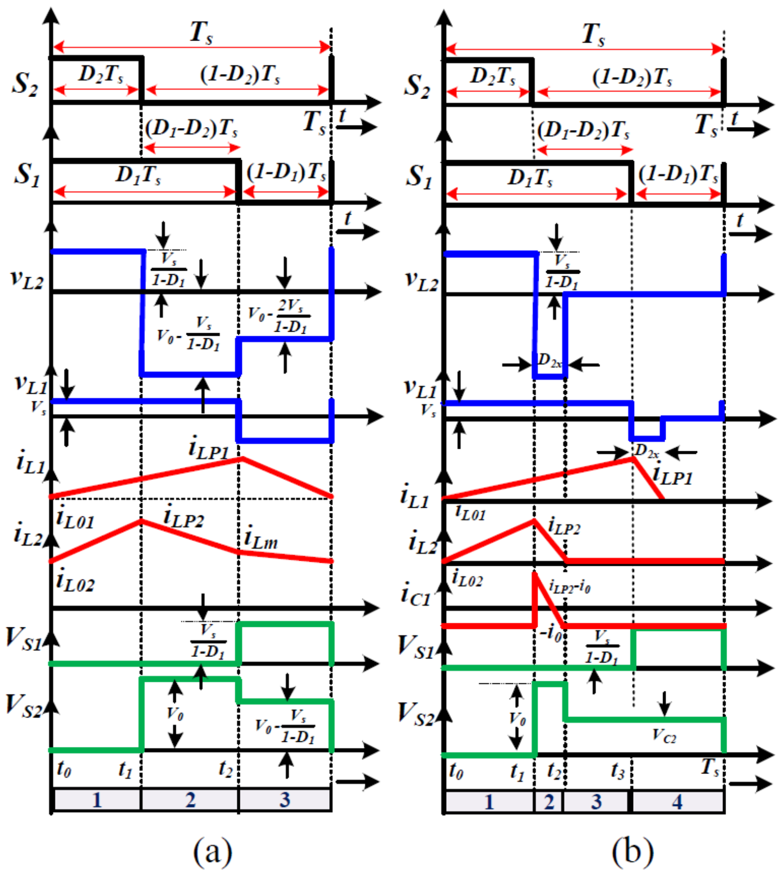

Figure 3.2: Detailed steady state waveforms of proposed high DC-voltage gain

3.2.1 CCM Operation

Mode 1: At specific time t_1, the MOSFET S_1 is starting to conduct and inductor L_1 charge energy until t_1 ,When this process happening also S_1 discharge energy to conducting the switch which is S_2, [1] This process called as regenerative step up operation, at switched capacitor operation, C1 gets discharge to C2. In Fig. 3.2 (a) clearly presence the gating signals of S_1 and S_2 , by changing the slope of L1 and L2. The Fig. 3.3 (a) shows the equivalent circuit, the voltage slightly seen on across the terminal of VL1 and VL2 are given by:

$$V_{L1} = V_S;\ V_{L2} = \frac{V_S}{1-D_1} \tag{3.1}$$

Mode 2: At specific time t_1, the semiconductor switch S_2 gets misconduct, at the same time S1 is still conducting, so L_2 and S_2 discharges their energy to load, on Fig. 3.3 (b). We can clearly see the current path of that operation. On Fig. 3.2 (a) the inductor, current and voltages drown at the same time, Vl_1 and Vl_2 can be written at that time as:

$$V_{L1} = V_s;\ V_{L2} = -\frac{V_s(1-D_1)-V_s}{1-D_1} \quad (3.2)$$

The terminal of capacitor C_1 voltage can be calculate by applying KVL,

$$V_{c1} = V_0 - v_{L2} - v_{C2} = V_0 - v_{c3} \quad (3.3)$$

Mode 3: At specific time t_1, semiconductor switch which is S2 changing its state to misconduct, The charged energy on $L_1$and L_2 , C_2 are supply their energy from source to load, according to this series operation, output voltage rised dramatically because of cascaded operation of inductors and capacitors. At the output of the system we need good filtering for eliminating in rush current and voltage spike of the system, on Fig. 3.3 (c) this filtering operation clearly shown. On figure 3.2 the capacitor between VS_1 and VS_2 switches shown and this voltage can be written separately in the formula below: [9] [10]

$$V_{L1} = -\frac{V_s D_1}{1-D_1};\ V_{L2} = -\frac{V_0(1-D_1)-2V_s}{1-D_1}; \quad (3.4)$$

3.2.2. DCM Operation

Fig. 3.2. presence discontinues conduction mode operation and shows steady state analytical waveform, at specific time t_3 we can clearly see that the inductor current goes to zero. In Fig.3.3 different operating section are shown in (DCM) mode at specific time t_0, occur likely like (CCM) operation, L_1 and L_2 gets charged. [9] [12]

$$I_{Lp2} = \frac{V_s}{(1-D_1)L_2} D_2 T_s \quad (3.5)$$

Peak current of inductor which is Lp_2 has same operation principle like classic boost converter[10], At specific time t_1 switch S_2 misconducting and process is comparable to mode 2 of (CCM) operation But here the main difference is the inductor current riches to zero at specific time t2 ,the unknown duty cycle value D_{2x}can be written as :

$$I_{Lp2} = \frac{V_0(1-D_1)-V_S}{(1-D_1)L_2} D_{2x} T_s \quad (3.6)$$

At specific time t2, system reaches to zero current till next cycle begins. L_1 Still gets charged comparable to mode 2 of CCM process, the load suppling from C_1 and C_2 simultaneously.

At specific time t_3, S_1 switch gets misconducted and the inductor current L_1 goes to zero. At specific time t_4, after this time, load getting energy from C_1 and C_2 capacitors, which is can be clearly seen on Fig. 3.3 (b), I_1 inductor equivalent circuit reaches to zero and we can see it on Fig. 3.3(d), by using (5) and (6), D_{2x} can be shown as:

$$D_{2x} = \frac{V_S(D_2)}{(1-D_1)V_0 - V_S} \quad (3.7)$$

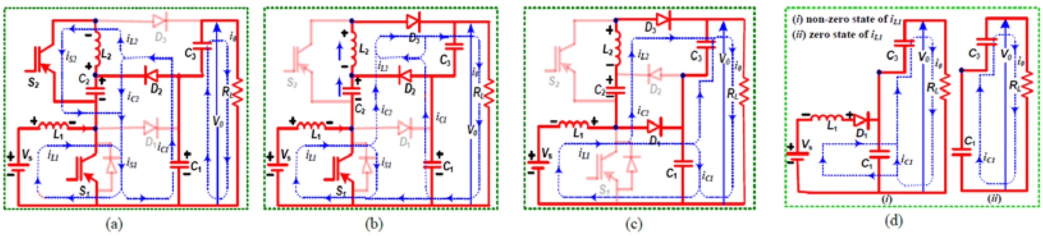

Figure 3.3: Different operating modes of proposed high DC-voltage gain DC-DC converter

i)CCM operation (a) mode 1, (b) mode 2 and (c) mode 3 ii) DCM

3.3 Simulink Simulation of Proposed Topology

In this section we will presence simulink simulation of proposed topology simulation consist of power electronic components and control elements which is solar pv array semiconductor switching elements like mosfet, passive circuit elements like inductor and capacitor inverter and proposed topology controller. Maximum power point tracking controller, scopes for measuring voltage and current value of system. In figure 3.4 presence general view of simulation. We will examine whole components of simulation one by one below.

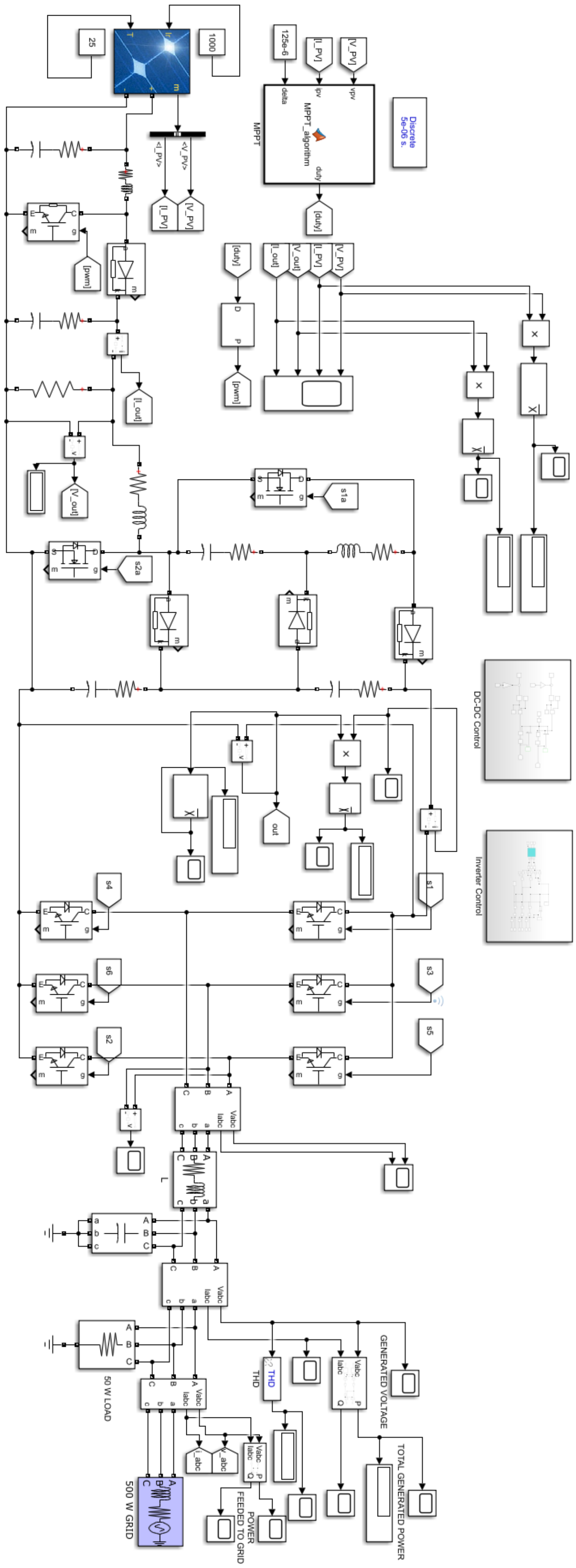

Figure 3.4: The Simulation Scheme

3.3.1 PV Array

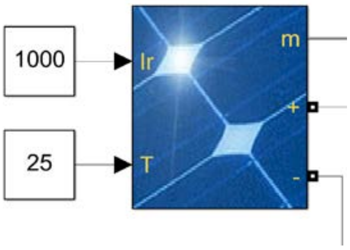

Figure 3.5: PV Array

In figure 3.5 presence PV array of system which we use Soltech 1STH 215P PV Panel 5 parallel 2 series connection for reaching required optimal voltage and power range.

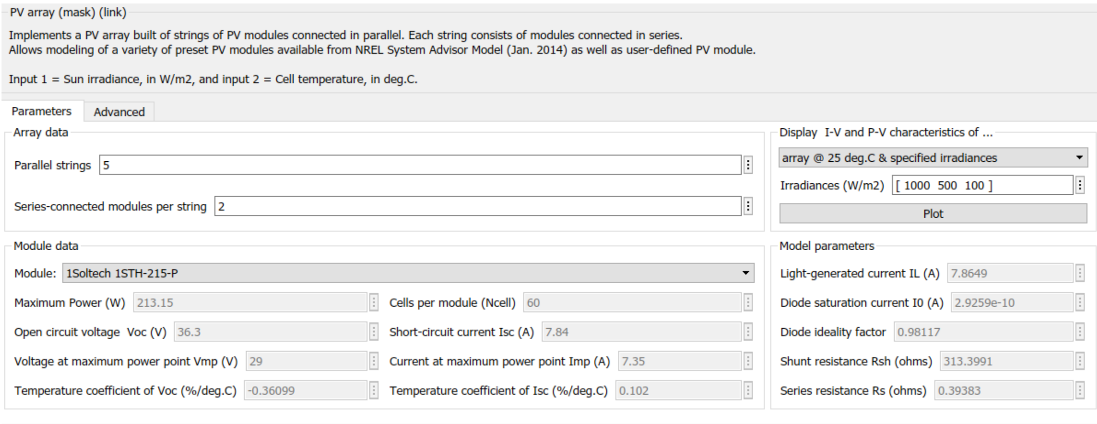

Figure 3.6: PV Array Specification

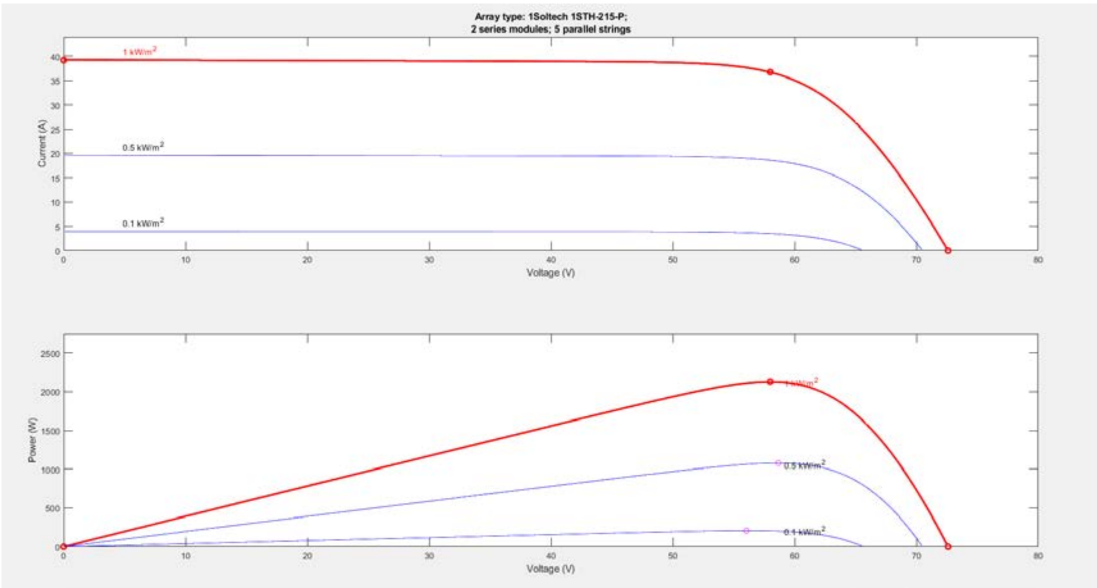

Figure 3.7: PV Array Voltage and Current Value at Maximum Points

Figure 3.6 presence PV array specification and figure 3.7 presence voltage current and power values at maximum power points.

3.3.2 MPPT Algorithm

We used P&O MPPT algorithm in this simulation for measuring voltage and current values from pv array. We can see the C code below;

```
function duty = MPPT_algorithm(vpv,ipv,delta)

I used the MPPT algorithm in the MATLAB examples

I only modify somethings.

duty_init = 0.1;

min and max value are used to limit duty between

0 and 0.85

duty_min=0;

duty_max=0.85;

persistent Vold Pold duty_old;

persistent variable type can be store the data

we need the old data by obtain difference

between old and new value

if isempty(Vold)

    Vold=0;

    Pold=0;

    duty_old=duty_init;

end

P= vpv*ipv; % power

dV= vpv - Vold; % difference between old and new voltage

dP= P - Pold;% difference between old and new power
```

```
the algorithm in below search the dP/dV=0
if the derivative equal to zero
duty will not change
if old and new power not equal
pv voltage bigger than 30V
he algorithm will works
if dP ~= 0 && vpv>75
    if dP < 0
        if dV < 0
            duty = duty_old - delta;
        else
            duty = duty_old + delta;
        end
    else
        if dV < 0
            duty = duty_old + delta;
        else
            duty = duty_old - delta;
        end
    end
else
    duty = duty_old;
end
%the below if limits the duty between min and max
if duty >= duty_max
    duty=duty_max;
```

```
elseif duty<duty_min
    duty=duty_min;
end
% stored data
duty_old=duty;
Vold=vpv;
Pold=P;
```

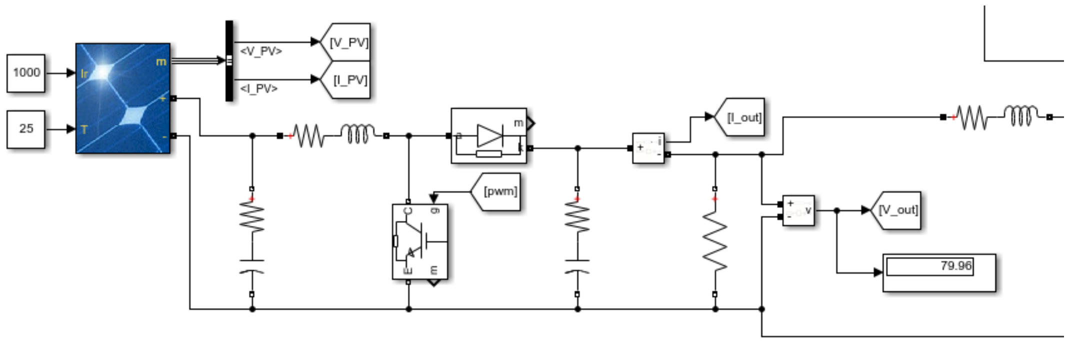

Figure 3.8: PV Array with MPPT Buck Boost Converter

In figure 3.8 presence PV array with MPPT buck boot converter, the generated signal according to the measured voltage and current value of pv array which is PWM control the maximum power point trackings.

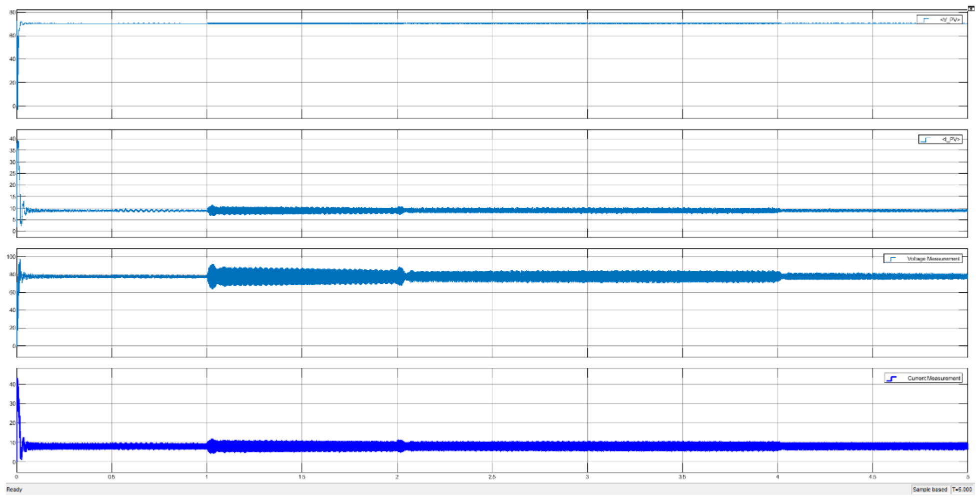

Figure 3.9: Measurement of Input and Output of MPPT Converter

In figure 3.9 presence input and output voltage and current of MPPT Converter

3.3.3 Proposed Topology of DC to DC Converter

In figure 3.10 we can see the proposed topology of DC-DC converter which is in simulation process.

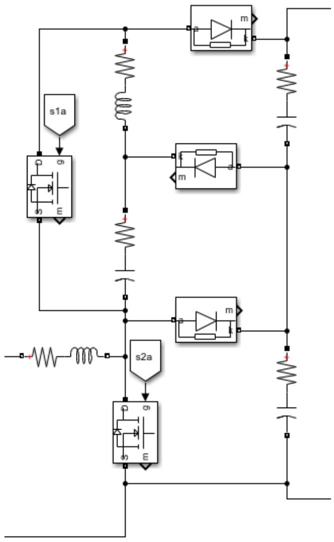

Figure 3.10: High Gain DC-DC Converter

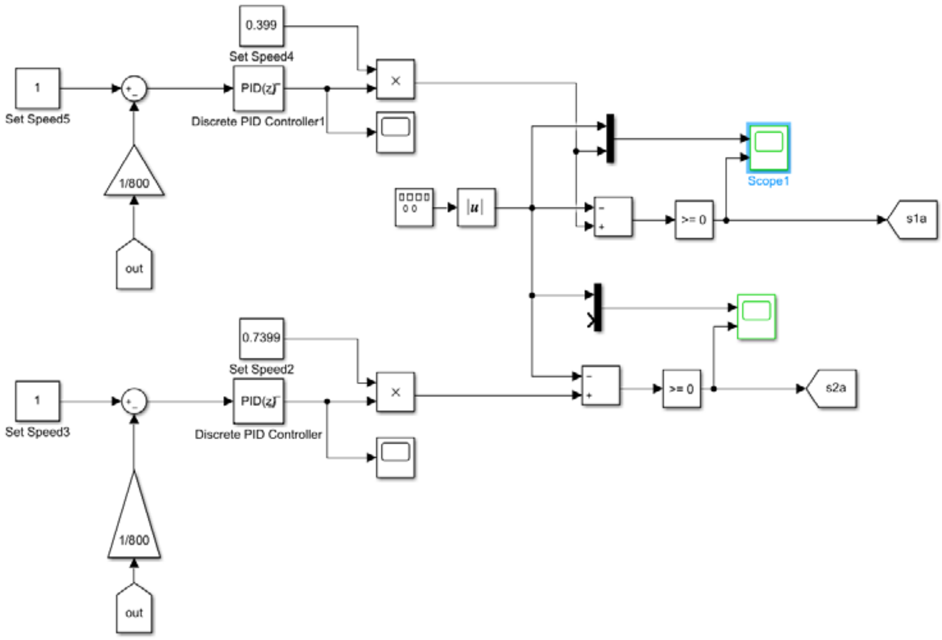

Figure 3.11: Control Algorithm of High Gain DC-DC Converter

On figure 3.11. presence control algorithm of high gain DC-DC Converter proposed topology.

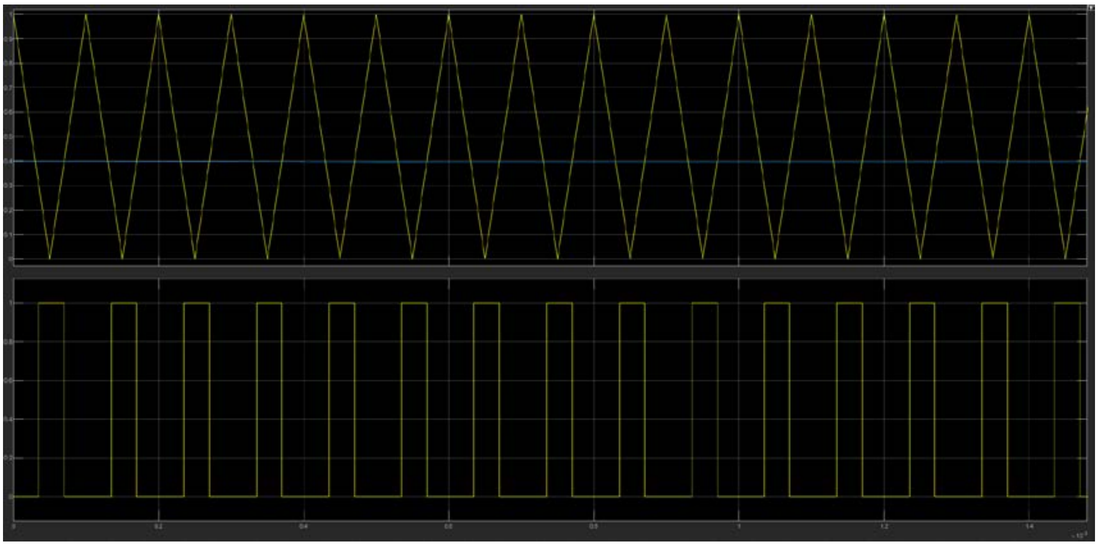

Figure 3.12: Generated Gate Signals

For controlling of high gain DC-DC converter, two MOSFETS on converter has to be control on different duty ratio for reaching desired voltage, for close loop control, mean voltage value of proposed converter (reading and entering) discrete time PID controller. Output of PID controller compared with fixed 10 KHz triangular wave and difference of this comparison give us pulse width modulated signals for driving MOSFET gate.

3.3.4 Inverter Section of Simulation

After proposed DC-DC converter we used three phase inverter bridge for generating three phase AC voltage Figure 3.13 presence inverter bridge.

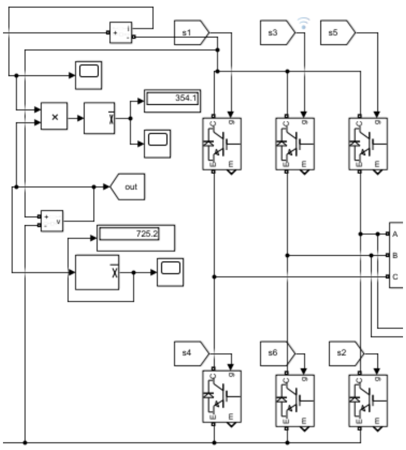

Figure 3.13: Inverter Bridge

In Fig 3.13. there is 6 MOSFETS for generating AC signal each half MOSFET pair should not be open in same time for generating AC signal, we used the Table 3.1. for showing the switching sequence.

Table 3.1: Switching Sequence of Inverter

Mode	S1	S2	S3	S4	S5	S6
1	ON	OFF	OFF	OFF	OFF	ON
2	ON	ON	OFF	OFF	OFF	OFF
3	OFF	ON	ON	OFF	OFF	OFF
4	OFF	OFF	ON	ON	OFF	OFF
5	OFF	OFF	OFF	ON	ON	OFF
6	OFF	OFF	OFF	OFF	ON	ON

The Table 3.1 presence switching sequence for six MOSFETS in inverter bridge on 120 degree conduction mode.

3.3.5 .Inverter Controller

In this section presence control algorithm of three phase inverter which is controlled by sinusoidal PWM signal. Sinusoidal PWM signal is different from classic one such as different pulse time in different times for generating pure sine on inverter output. In Figure 3.14 presence controller of inverter.

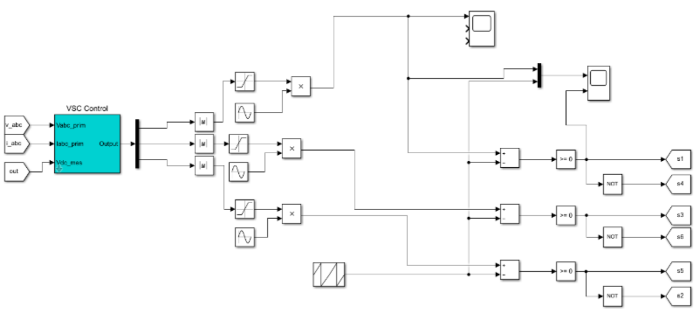

Figure 3.14: Inverter Controller for SPWM Generation

Generating SPWM signal is similar to generating normal PWM signal, in normal PWM we are using constant voltage as reference but in SPWM we are using pure sine wave block as an reference signal. For generating three phase we are using three reference sine wave which is 120 degree different from each other.

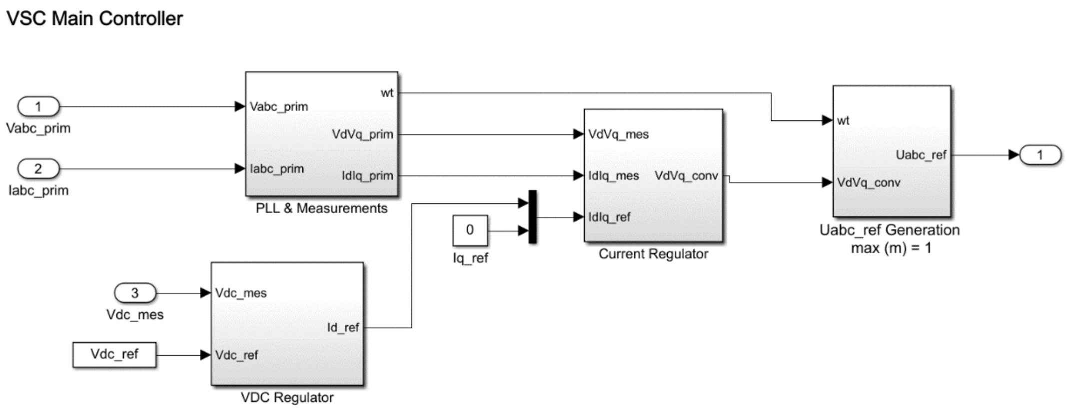

Figure 3.15: Inverter Controller with PLL

For making inverter output closed loop system we used ready matlab inverter controller which already has Phase lock loop and current regulator controller getting measurement from output of inverter which is current and voltage of sysytem also getting measurement from DC input and generating referance sine for gate pulses figure 3.15 presence inside of VSC controller.

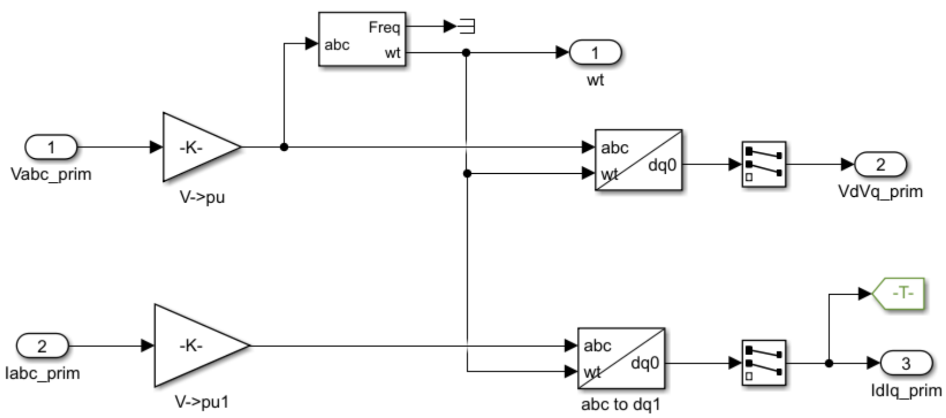

Figure 3.16: abc to dq transformation

The inverter's switching function $d_k^*(k = 1,3,5)$ is defined as

$$d_k^* = \begin{Bmatrix} 1, if\ S_k\ is\ on\ and\ S_{k+1}\ is\ off \\ 0, if\ S_k\ is\ off\ and\ S_{k+1}\ is\ off \end{Bmatrix} \tag{3.8}$$

The voltage values per phase are calculated based on switch status at that period from the Equ below:

$$e_{a-}VnN = V_{dc}(d_1^* - \frac{d_1^*+d_3^*+d_5^*}{3}) \tag{3.9}$$

Therefore, the model can be written as in Equation(eqs:3.8)

$$\begin{Bmatrix} L\frac{d_{ia}}{dt} = -i_aR - v_a + \left(d_1^* - \frac{d_1^*+d_3^*+d_5^*}{3}\right)v_{dc} \\ L\frac{d_{ib}}{dt} = -i_bR - v_b + \left(d_3^* - \frac{d_1^*+d_3^*+d_5^*}{3}\right)v_{dc} \\ L\frac{d_{ic}}{dt} = -i_cR - v_c + \left(d_5^* - \frac{d_1^*+d_3^*+d_5^*}{3}\right)v_{dc} \\ C\frac{dv_{dc}}{dt} = I_{pv-}(d_1^*i_{a+}d_3^*i_{b+}d_5^*i_c) \end{Bmatrix} \tag{3.10}$$

The positive-sequence components at the major frequency become steady and the resultant time-varying transformation is given by: (eqs:3.9)

$$T_{dq0}^{abc} = \frac{2}{3}\begin{bmatrix} cos(wt) & cos\left(wt - \frac{2}{3}\pi\right) & cos\left(wt + \frac{2}{3}\pi\right) \\ sin(wt) & sin\left(wt - \frac{2}{3}\pi\right) & sin\left(wt + \frac{2}{3}\pi\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{3.11}$$

$$\begin{bmatrix} \frac{d_{id}}{dt} \\ \frac{d_{iq}}{dt} \\ \frac{dv_{dc}}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-R}{L} & \omega & \frac{d_d}{L} \\ -\omega & \frac{-R}{L} & \frac{d_q}{L} \\ -\frac{d_d}{C} & \frac{d_q}{C} & 0 \end{bmatrix}\begin{bmatrix} i_d \\ i_q \\ v_{dc} \end{bmatrix} + \begin{bmatrix} -\frac{1}{L} & 0 & 0 \\ 0 & -\frac{1}{L} & 0 \\ 0 & 0 & -\frac{1}{C} \end{bmatrix}\begin{bmatrix} v_d \\ v_q \\ I_{pv} \end{bmatrix} \tag{3.12}$$

In figure 3.16 presence converter abc to dq frame on calculation of 3.8 to 3.12 we can see the mathematical calculation abc to dq frame. In Figure 3.17 presence generation of SPWM. The pulses near the ends of the mid-cycle are consistently narrower than the pulses near the center of the mid-cycle such that the pulse widths are comparative to the equivalent amplitude of a sine wave in that part of the cycle. For generating effcient output voltage the pulse start narrower in beginning and it gets wider at middle of cycle after that it getting narrower. This sequence help us reducing THD and it allow us to generate pure sine.

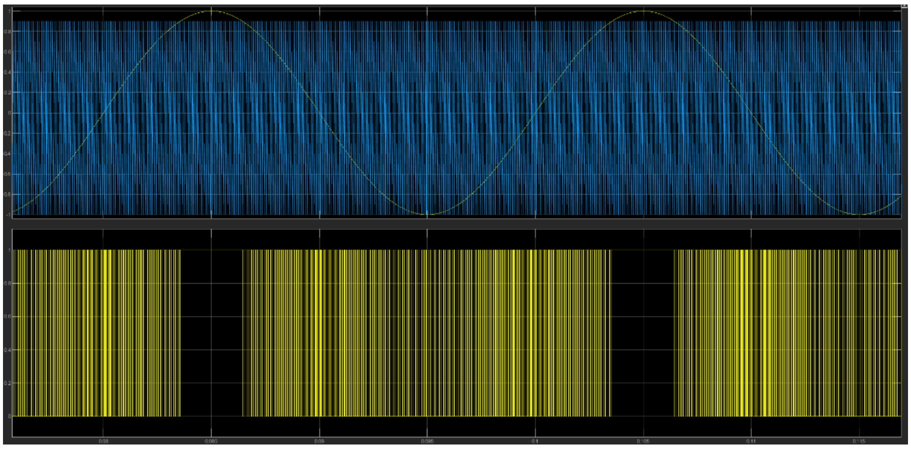

Figure 3.17: SPWM Generation

3.3.6 Measurements and Grid Connection

In this section of thesis we will examine grid connection of measurements of thesis we can all measurements from scopes including THD. We will examine and discuss output of section on chapter IV beriefly.

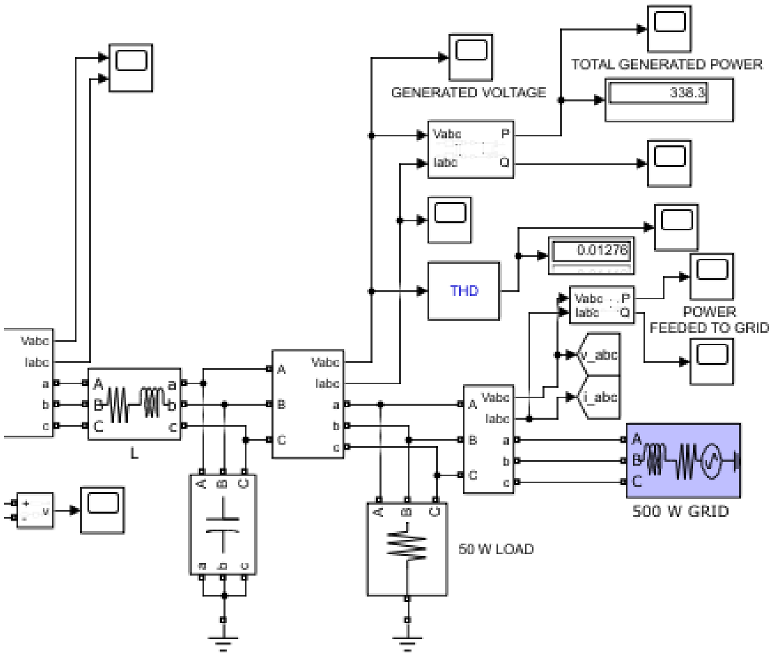

Figure 3.18: Measurements and Grid Connection

3.4 Second Simulation for Comparision

For comparision purposes and efficient test we used ready simulation from mathwork which is called 250 kW Grid-Connected PV Array which is more above our output power rating so we a bit change simulation for decreasing power output to get 350 W. Figure 3.19 presence simulation.

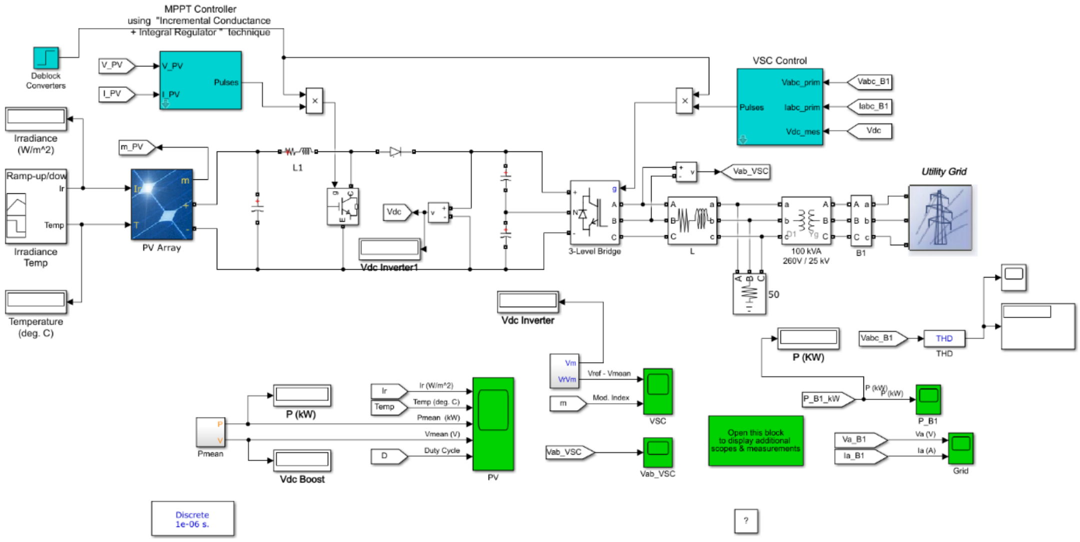

Figure 3.19: Second Simulation for Comparision

In simulation, the PV array and boost converter for regulating PV voltage on constant values and there is 3 level inverter with VSC Controller. The same PV array is used. In PV array block model menu can plot the I-V and P-V characteristics of PV array. PWM controlled 3 phase inverter block is used. The inverting inductor RL and a small harmonic filter C are used to filter the harmonics generated by the IGBT bridge. For connecting system to public grid three phase transformer is used. Inverter controller of simulation contains ready simulink controllers which has MPPT controller, VDC regulator, PLL block and gate signal generator.

Reference voltage that required for inverter is coming from current regulator with Id and Iq references. In simulation Id is set to zero. For grid synchronization PLL block is used. Gate pulses which is triggered the semiconductor devices, is generated with PWM generator.

4. RESULTS & CONCLUSION AND DISCUSSION

In this chapter firstly result of simulation will be examine and we will compare result already used system and after comparision, final review will be given in end of the section.

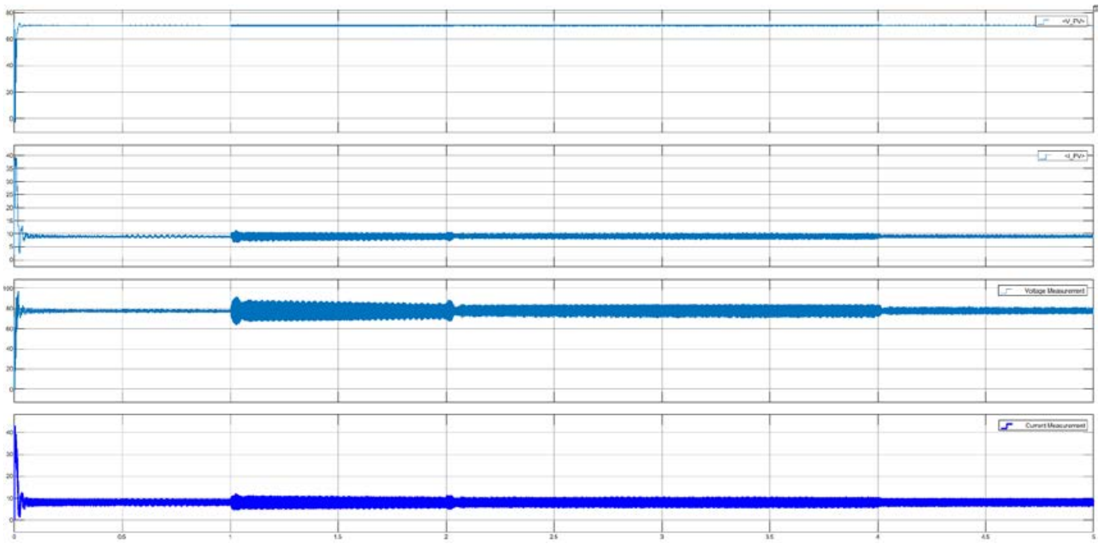

Figure 4.1: PV Input and Output Voltage and Current

In first graph on Figure 4.1 presence PV open circuit voltage nearly 75 volt and in PV array block specification we used 2 series 5 parallel PV panel one of the panel open source voltage is 36.3 so at the output we expect to see 73 volt. On second graph presence PV current one of panel open circuit voltage is 7.3 and we are getting nearly 9 amp it can be goes up to 5*7.3 which is 5 PV parallel connected. On third graph presence output voltage of MPPT converter which is nearly 80 volt. The converter increased voltage a bit via internal boost converter for maximum power at desire point, the control algorithm of MPPT converter is tracking the power output of MPPT and store the old power measurement. Therefore, if the power change gradually it is increase or decrease the duty cycle for regulating voltage to desired value.

In Figure 4.2 presence switching signal MPPT converter of MOSFET on specific time. Switching signal generated by P&O algorithm code which we examine on chapter 3, the code tracking output voltage and current of PV and it try to make voltage stable at desired interval which is already written before. The last section of graph presence the output current of MPPT converter which nearly 10 amp, the converter also increased the current for reaching the desired output power. We can clearly see that the MPPT algorithm and physical circuit for converter working well.

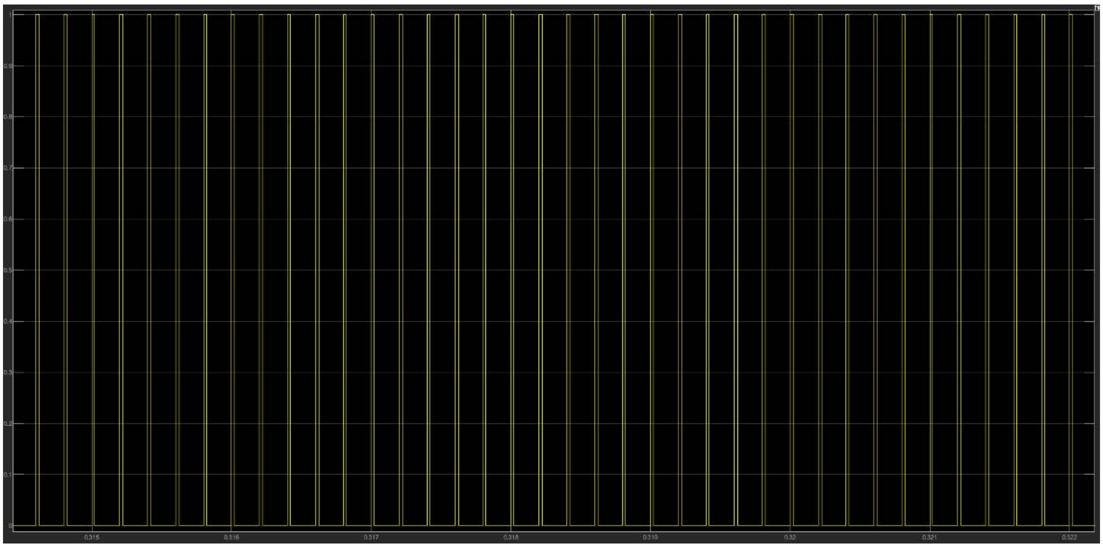

Figure 4.2:.MPPT Switching Signals

After MPPT converter, the generated voltage goes to the input of proposed converter which we describe working principle on chapter 3, it boost the voltage from 80V to 730V which is very high gap accroding to the commercial converters.

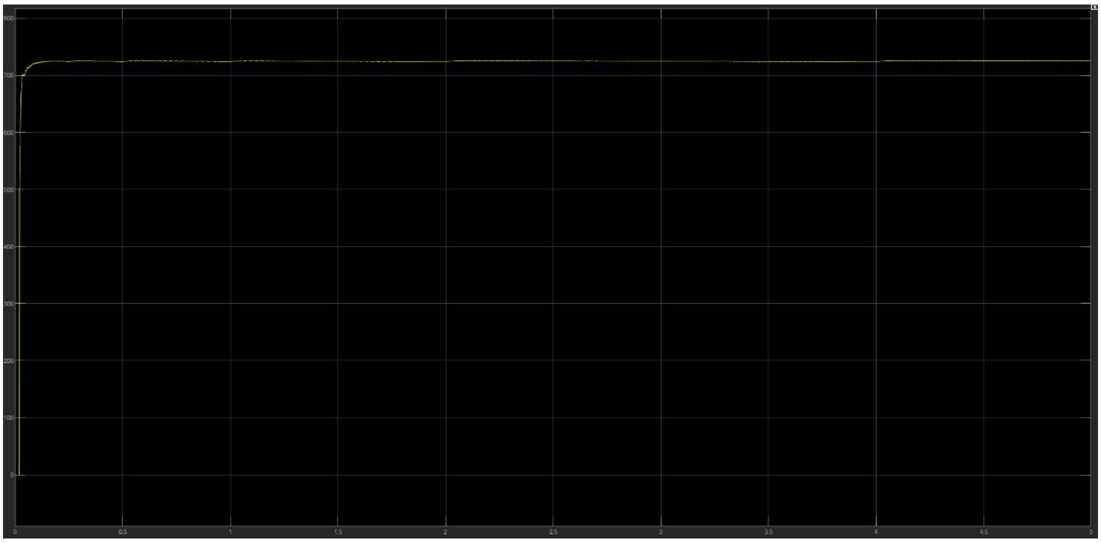

Figure 4.3: The Output Voltage of Topology

So we can clearly see that proposed topology can be increase the voltage at desired values, the adventageous of this it can be used on transformerless system but voltage has to be increased more than that. Working with such high voltage in power electronic industry cause some fatal errors, if the circuit is not designed properly, it may has a MOSFET failures, diode etc. It also important factor that choosing output capacitor for proposed converter, it has to be match and eliminate output voltage ripple and current ripple for making DC as DC as possible.

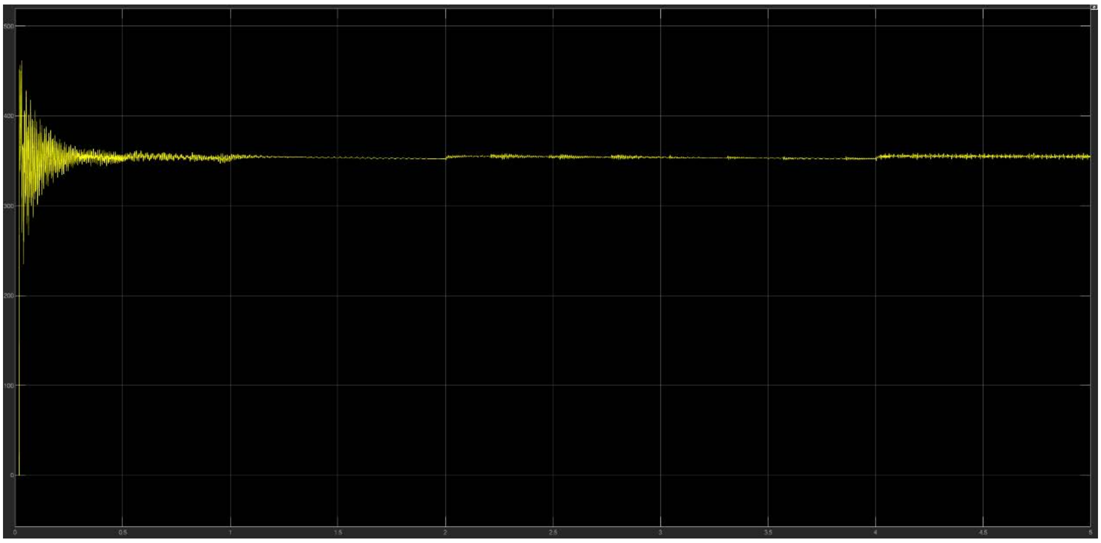

Figure 4.4: Output Power of Proposed Topology

The output power of proposed topology is given in Figure 4.4. We see in graph the circuit injecting 350W to system from PV array, and we can clearly see that the generated power from PV sources nearly 650 watt in figure 4.1. If we product output current and voltage value of converter. In proposed topology there are some of the power lossing in inductors and MOSFET. In simulation softwares we dont have chance make circuit as real as possible. Therefore, simulation can be give some problematic outcomes such as this problem as a development of this thesis, second stage can be implementing of this circuit physically.

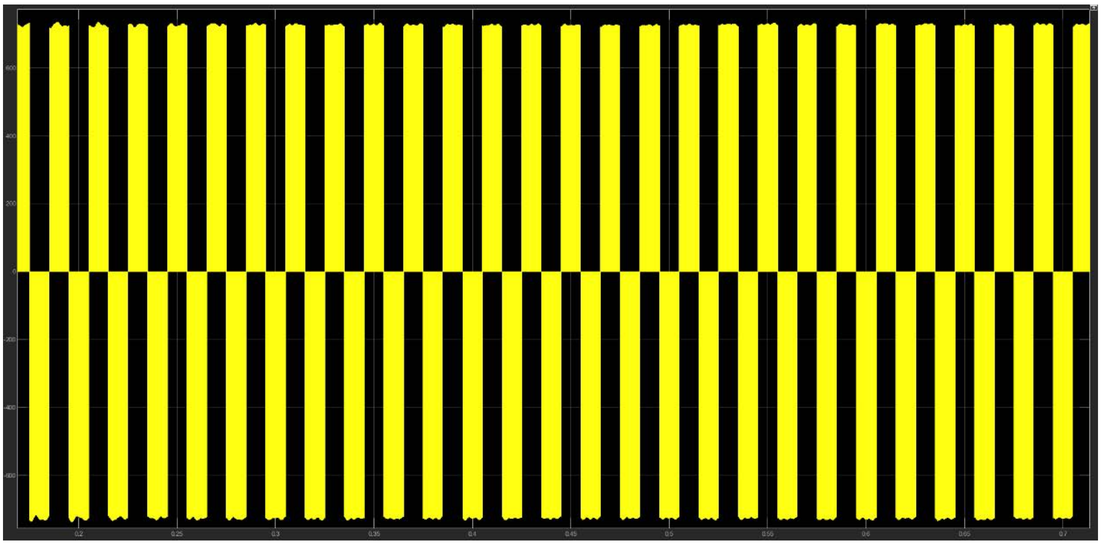

Figure 4.5: Output Voltage of Inverter Before Filter

In Figure 4.5 presence output voltage of inverter before filter, we can see in the graph the SPWM pulses switching between 750 and -750 volt for generating AC output of inverter. On matlab there is some ready inverter bridges and controller but they are switching with mathematical formulas so it is not like in real life. We implement and control the inverter circuit like in real circuits. This give us a better look and understanding of DC-AC conversion.

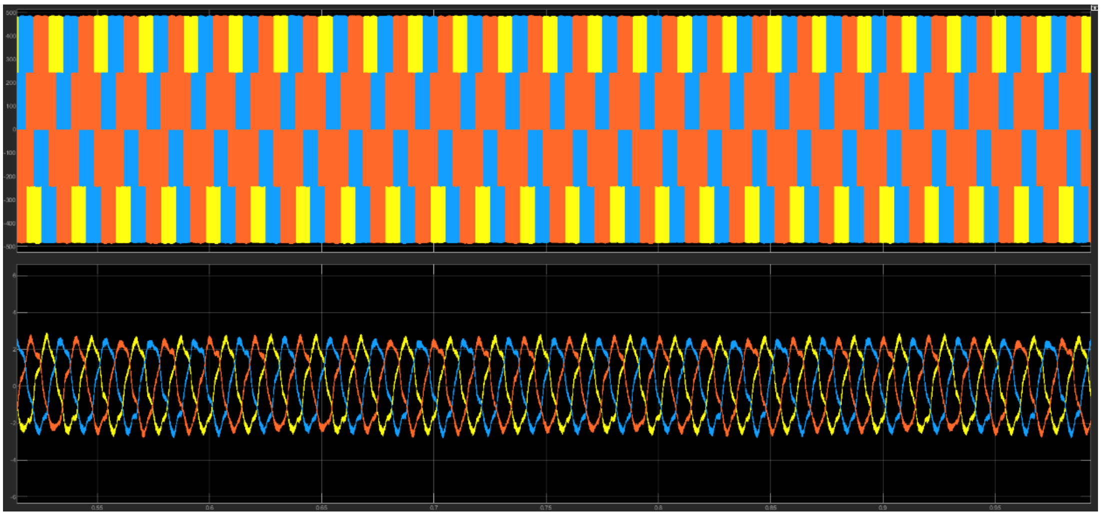

Figure 4.6: 3 Phase Voltage and Current Before the Filter of Inverter

Figure 4.6 presence three phase voltage and current before the filter of inverter and we can see on Figure each phase shifted 120 degree from each other. Also that is good sine that the current draw from inverter is close to the sine wave shape, as we can see on Figure the output voltage is between +500 and -500 peak by regulating of controller.

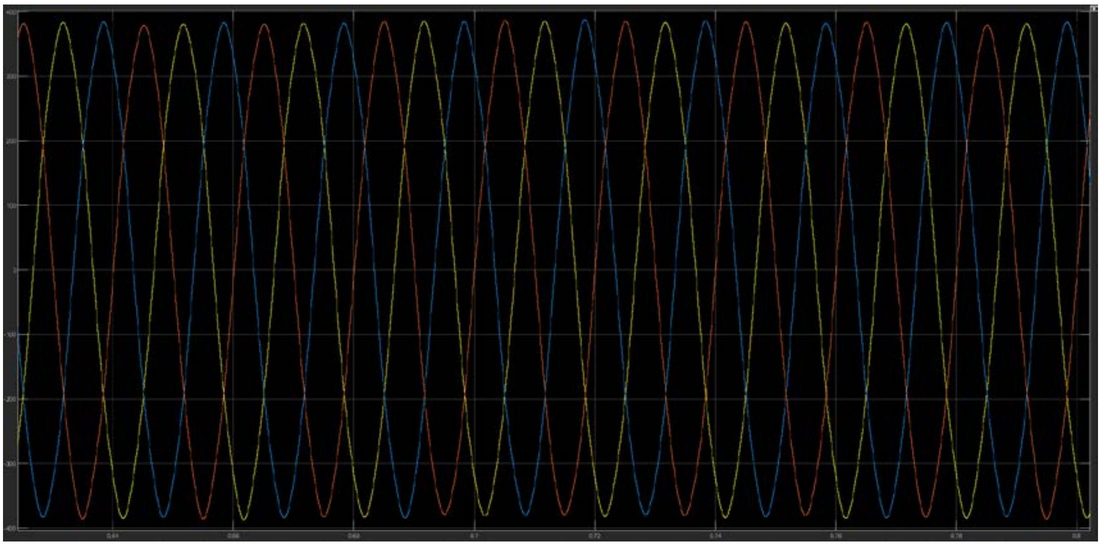

Figure 4.7: 3 Phase Voltage After Filter

Figure 4.7 presence the output voltage of inverter in sine shape after filter which is 380 Vac RMS in pure sine shape.

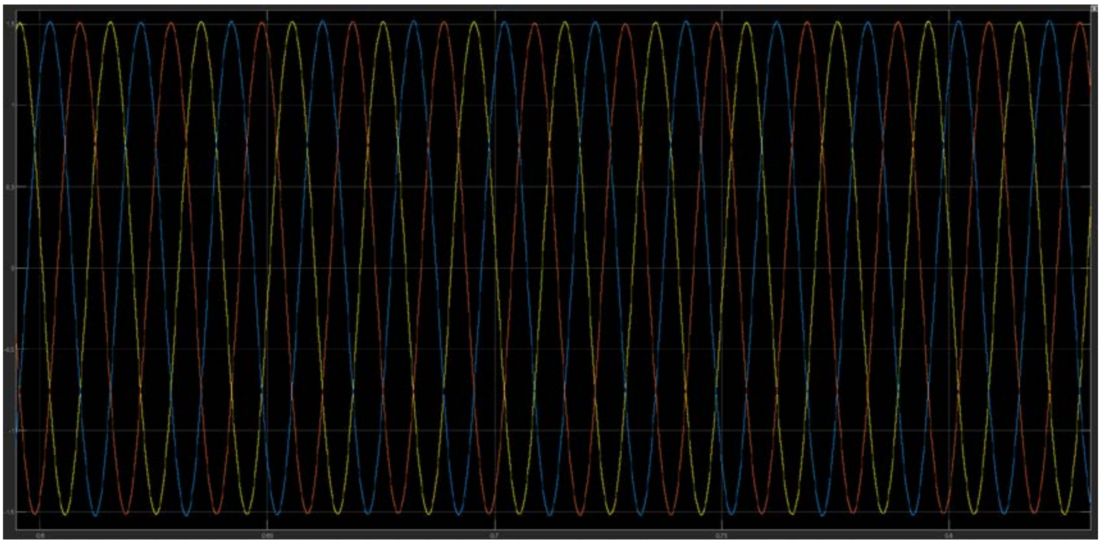

Figure 4.8: 3 Phase Current After Filter

Figure 4.8 presence the output current wave form inverter which is also in 3 phase sine wave, we can clearly see that there is no ripple at load condition.

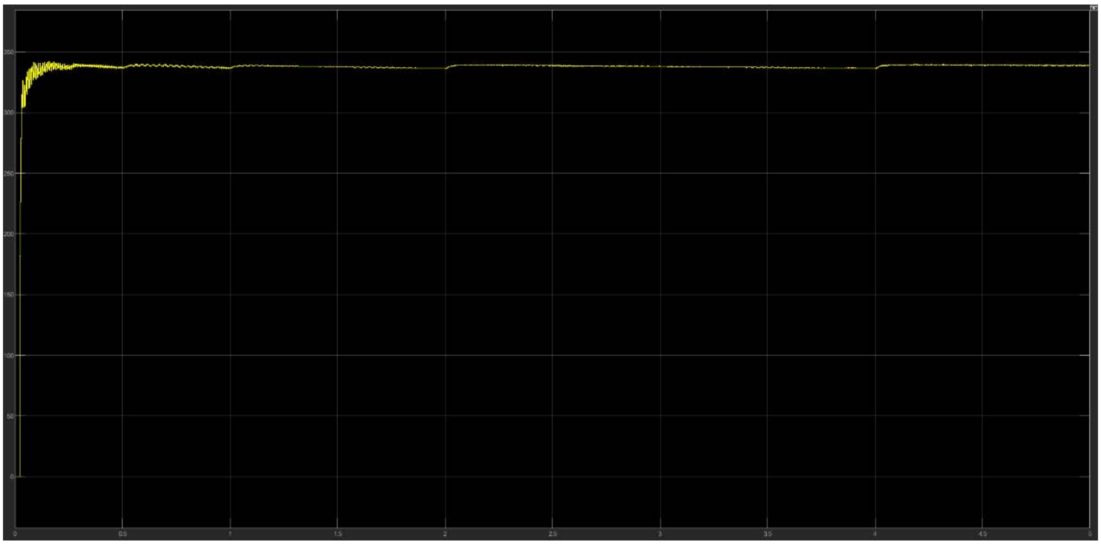

Figure 4.9: Generated Power After Filter

Figure 4.9 presence the generated power from inverter which is nearly 350 watt also the generated power after high gain DC-DC converter is nearly 350 watt so that Show after DC-DC converter efficiency level much higher. In Figure 4.9 presence the power that injecting to grid, it is above 280 W. If we sum this value with local resistive load we can clearly see that efficiency of power injecting is on very good level.

Figure 4.10. From the beginning of the simulation, there is many ripples on waveform, at that time the phase lock loop system trying to compensate power between grid and inverter side.

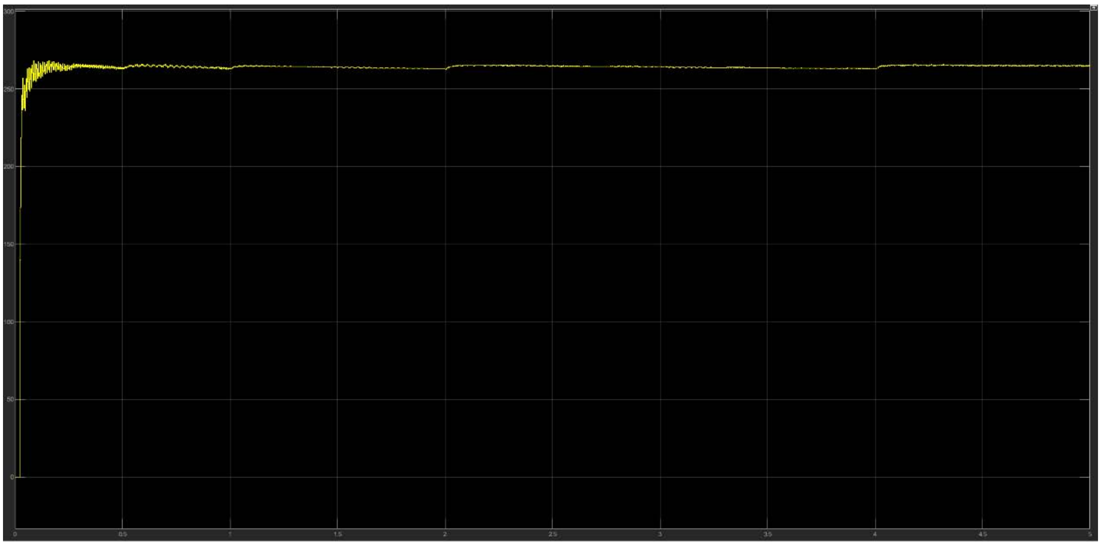

Figure 4.10: Injecting Power to Grid

In Figure 4.11 presence output total harmonic distortion percent of system which is below 1 % and better than original MATLAB simulation which we can see on Figure 4.11.

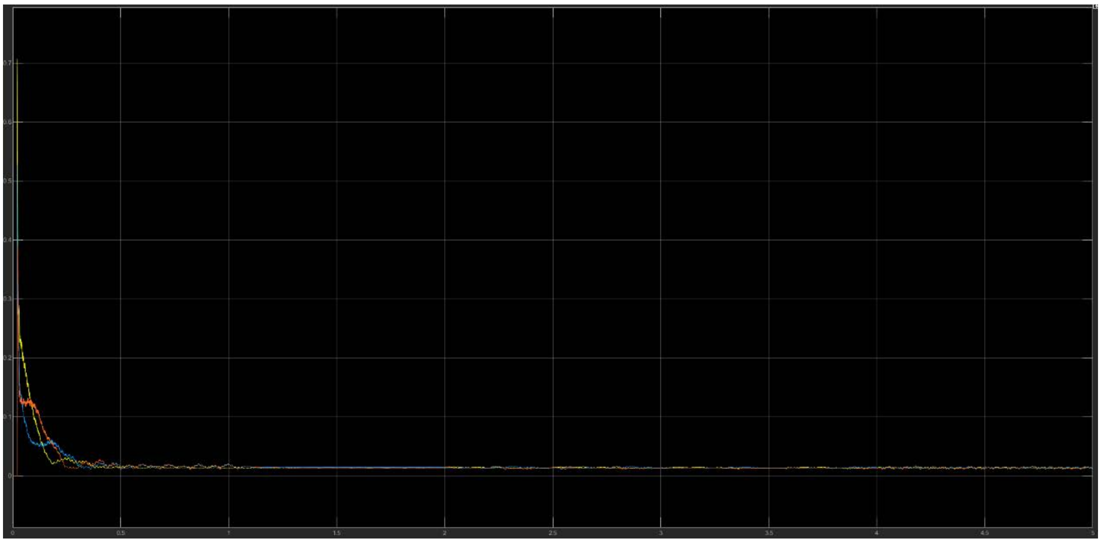

Figure 4.11: Total Harmonic Distortion of System

Figure 4.12 presence Output THD percentage of Simulink example simulation which we used for comparison total harmonic distortion of that simulation is 3 % which is 2 % high from our simulation, that situation shows us we have better control on DC-DC converter and inverter stage than Simulink simulation.

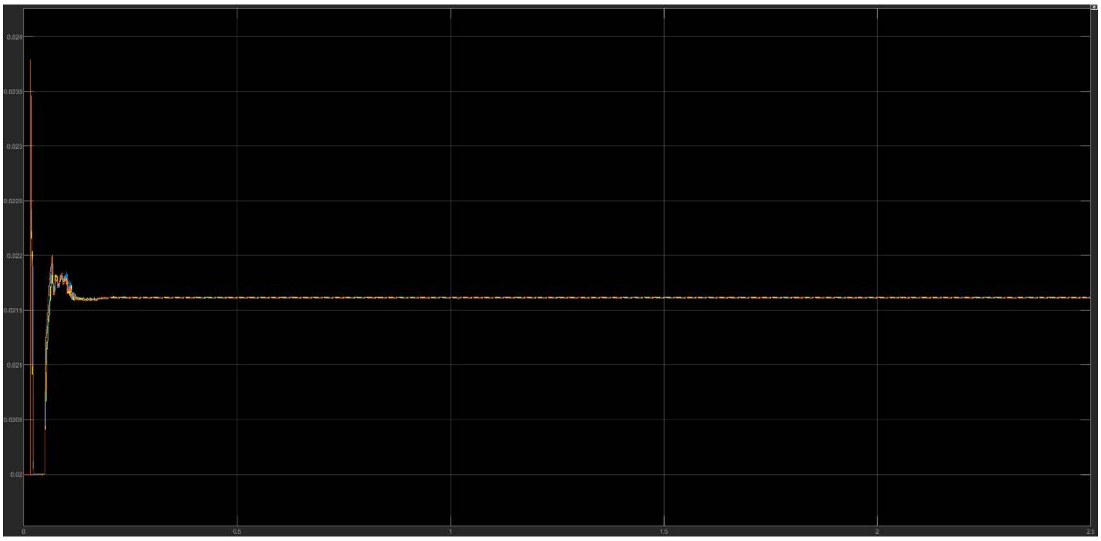

Figure 4.12: Simulink Simulatin THD Value

Figure 4.13 presence output voltage and current waveform of simulink example simulation.

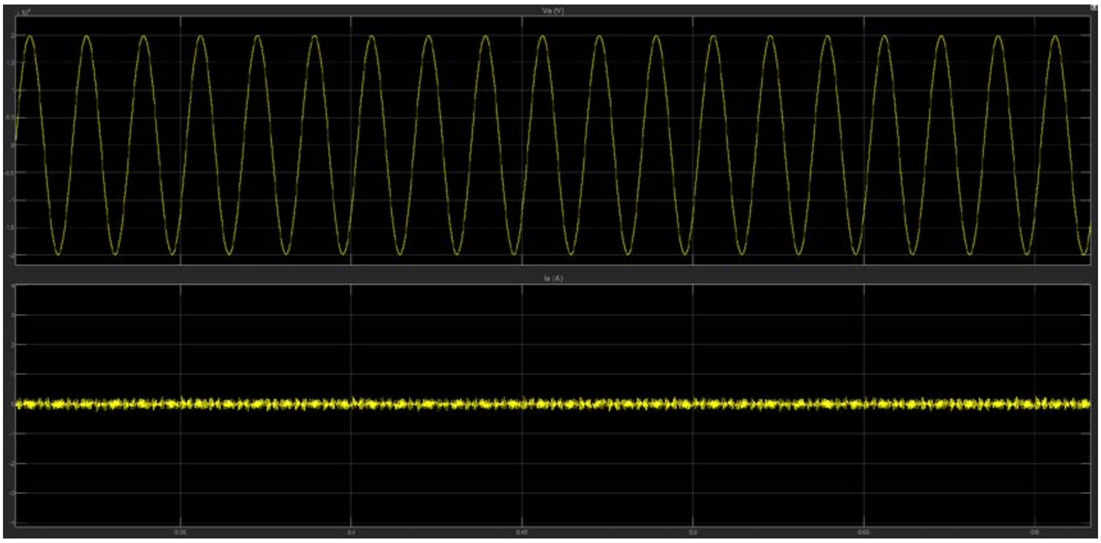

Figure 4.13: Simulink Example Simulation Output Voltage and Current

Figure shows that output voltage is good shape but current drawing from system has some ripple, this effect on total harmanic distortion in bad way.

5. CONCLUSION

In this study, a new method for voltage boosting is implemented with high gain DC-DC converter with switched capacitor. Comparing to the known DC-DC converter, this new circuit topology, voltage can be increase to extreme level, by using combining of two active components which are MOSFET and passive components like inductor and capacitor, by controlling the duty cycle ratio of each MOSFET separately, a high voltage value is reached at the output of the DC-DC converter by adding capacitor and inductor voltages. Therefore, it can reach this extreme voltage. Grid connection transformer can be eliminated by using this method, The cost of PV plant will be lower.

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