Modelling and Performance Analysis of DC-DC Converters for PV Grid Connected System

Reena Ingudam*, Roshan Nayak

***Abstract*— This paper presents the design and simulation of different dc-dc converters namely Boost, Buck-Boost and cuk converters and from the analyses of the three converters a suitable and best converter for grid connected system is chosen. The paper focus on the suitability of the dc-dc converter for Grid utility. In the design of dc-dc converters, maximum power point tracking (MPPT) is also employed for producing the maximum output power. The analyses and design of the proposed work is carried out using MATLAB/Simulink.**

Index Terms— ***Maximum power point tracking (MPPT), photo voltaic (PV), switched boost converter, Buck-Boost,cuk, grid connected system.***

I. Introduction

With global population explosion and rapid industrialisation the demand for energy has increased drastically and it cannot be made by the present power generation system which mainly depends on fossil fuels which are becoming depleted. Also the limitation of the power generating units and transmission lines has hampered the distribution of energy. Hence the focus has been shifted to the generation of electric power locally from alternate sources of energy. The concept of distributed power generation system (DGS) [1-3] has been introduced in which the main utility grid is fed with locally generated energy along its path. So more attention for generating energy locally is given to renewable and non-conventional energy sources like photovoltaic (PV), wind, Fuel cell (FC) etc. and there has been increasing developments for maximum utilization of energy. Besides the advantage of generating energy locally thereby reducing the transmission cost , the non-conventional energy sources are pollution free and most of them are available in abundance.

Among the renewable energy sources the most popular is the solar energy. The solar energy is directly converted to electrical energy using photovoltaic (PV) cells. Solar power has the potential to become one of the main contributor to the future electricity supply with several advantages, such as pollution-free power generation, low-maintenance cost, low operation cost and no supply limitations. This improvement in technology and the continuous growth of the PV market has led to drastic reduction in the cost of solar PV systems on the global market (EPIA et al, 2010).

PV system faces a lot of problems due to variation in temperature, insolation, and spectral characteristic of sunlight. It is desirable to operate the PV cell to extract maximum power. The maximum power occurs only at certain output voltage and output current from the solar panel. The optimum operating point for generating maximum power is obtained through maximum power point tracking (MPPT). The primary objective is to facilitate increasing penetration levels of PV system by analyzing and quantifying the impacts of grid connected PV system. To maximize PV energy productivity and ensure high conversion efficiency (usually above 90%) [4-6], a step- up DC-DC converter has to be used. Selection of the converter is critical for whole PV system power efficiency.

There are three basic types of PV system based on the utilization of the DC power generated from the PV module.

1. *Stand Alone – Off grid:* It consists of PV module, charge controller, batteries, and may or may not have an inverter which converts DC power to AC power.
2. *Grid Tie – Grid connected:* It consists of PV module and an inverter connected to the power grid utility.
3. *Hybrid – Grid connected with batteries:* It consists of PV module, grid-tie inverter, and batteries for storage when the grid is unavailable or for storing excess power.

In this paper the performance analysis of three different dc-dc converters through modelling and simulation are discussed. From the analysis result a converter is chosen to best suit the design of a complete PV grid connected system. The remainder of the paper is organised as follows. In section II, the related recent works in the direction of PV grid connected system is presented. In section III, the different subsystem involved in the design of PV grid connected system is shown. Section IV deals with the modelling of different DC-DC converters with related equations and the simulation result is also presented. In section V a complete PV system for grid connected system is provided and section VI concludes the paper.

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II. RELATED WORKS

The research in the field of standalone off-grid PV system has seen tremendous growth in the recent past. However research in the direction of grid connected or hybrid grid connected system is limited. Researchers have reported certain comparative analysis of different dc-dc converters for PV system incorporated with MPPT. The overall efficiency of the system depends on dc-dc converter. Some of recent related works are highlighted in this section. The output voltage of the PV panel is very low so in order to connect them to the grid utility it is necessary managed the output according to the standards followed in a country. A comparative study of different forms of DC- DC converters is presented by the authors in [7]. It was shown that the choice of a converter depends upon the application. Converters based on different types of switching cell are proposed in [8]. The design achieves high conversion ratio but the complexity of the circuit increases. Different modifications of dc-dc converters are proposed in the literatures [9-11].

Due to varying operating conditions the power produced by the PV module varies therefore it is necessary to maintain maximum output power at all times. Maximum power point tracking (MPPT) methods are designed to tune the electrical current to the value corresponding to MPP. MPPT varies the electrical operating point of the PV module so to deliver maximum available power. MPPT is an important module in the PV system. There are varieties of MPPT algorithm developed and reported in many literatures. These methods differ in the system complexity, convergence speed, cost etc.. The most popular MPPT algorithm are perturb and observe method (P&O) and incremental conductance method (INC). Modelling and comparative analysis of different MPPT algorithms can be found in [12].The authors in [13] provided the comparison of different algorithms terms of energy generated against the variation of irradiance input. In our work we used P&O method because of its simplicity.
The output of the dc-dc converter is connected to an inverter circuit for obtaining a sinusoidal AC signal to be fed to the grid. The configuration of the inverter system should be such that the generated sinusoidal current is in phase with ac grid voltage and the power factor is unity. Different configurations and topologies of the inverter have been proposed earlier [14-16] for PV grid connected system. Some recent works on PV grid connected system with MPPT can be found in the literatures [17-20].

III. SYSTEM MODELLING AND SIMULATION OF TWO STAGE GRID CONNECTED PV SYSTEM

In this section a two stage model of the grid connected PV system is presented. The basic modules of the complete system are depicted in Fig. 1. It includes a PV panel, dc-dc converter and dc-ac converter for grid utility and are described as under.

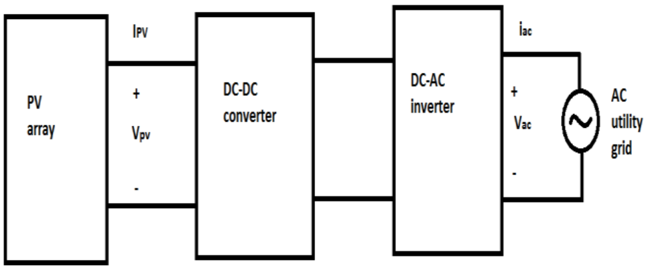

Fig. 1 Schematic of a two stage grid connected PV system

3.1 PV module

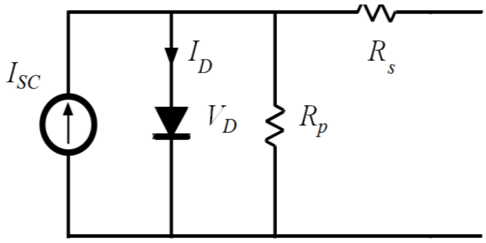

Fig. 2 Circuit diagram of the PV module

Expressions describing the nature of electrical flow in the photovoltaic array are:
KCL:

$$I = I_{SC} - I_D - V_D/Rp - I_{PV} \quad (1)$$

Diode characteristic:

$$I_D = Io\ (e^{VD}/Vt-1) \quad (2)$$

KVL:

$$V_{PVcell} = V_D - R_s I_{PV} \quad (3)$$

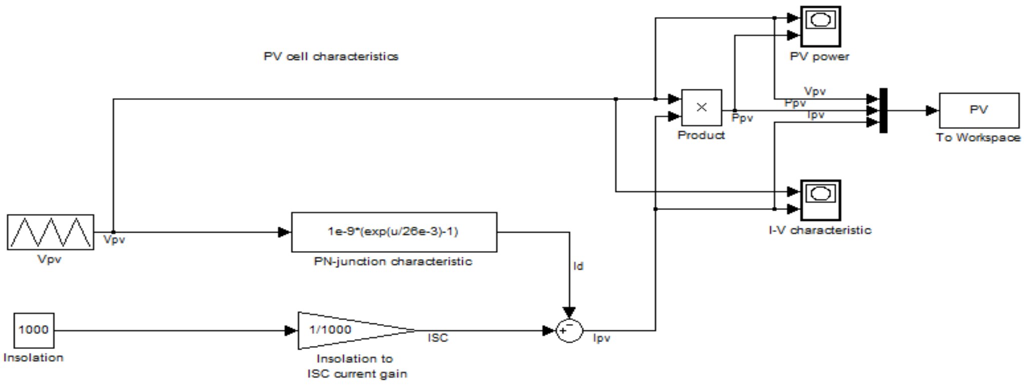

Fig.3 Simulink model of PV system

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Scope results:

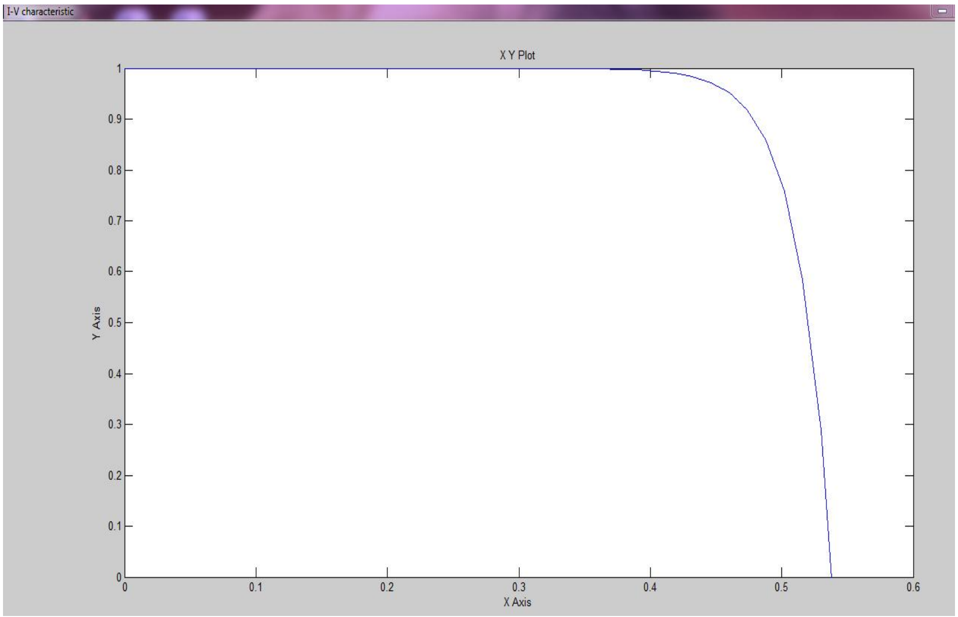

Fig. 4 Current vs. Voltage curve

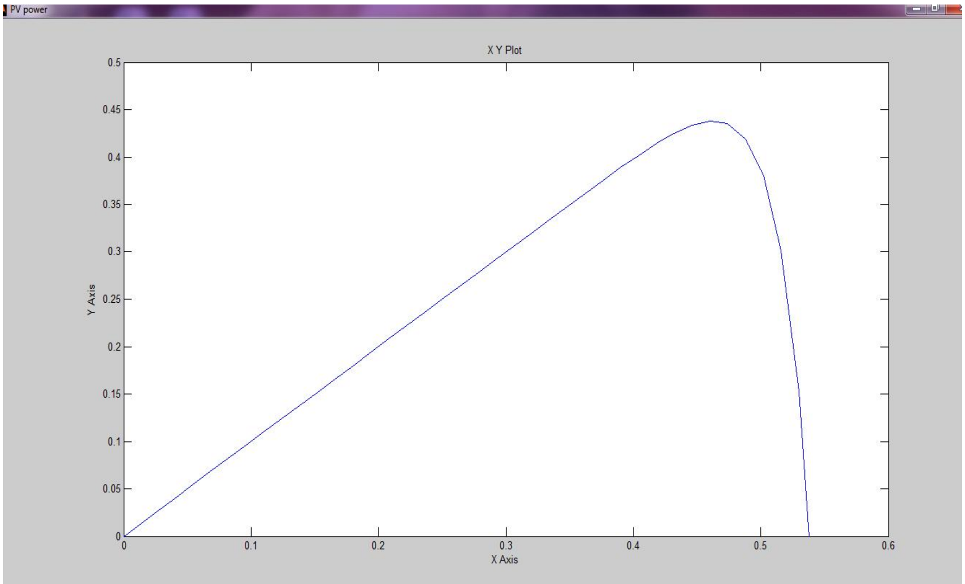

Fig. 5 PV curve

3.2 DC-DC converters: Three types of converters are considered.

3.2.1***Cuk converter*****:** The Cuk converter is shown in the Fig. below with switching period of T and duty cycle of D is considered.During the continuous conduction mode of operation, the state space equations are as follows [4].

$$\begin{cases} \frac{di_{L1}}{dt} = \frac{1}{L_1}(v_{in}) \\ \frac{dv_c}{dt} = \frac{1}{C_2}(-i_{L2}) \\ \frac{di_{L2}}{dt} = \frac{1}{L_2}(-v_o + v_c) \\ \frac{dv_o}{dt} = \frac{1}{C_1}(i_{L2} - \frac{v_o}{R}) \end{cases} \quad , \quad 0 < t < dT \quad , \quad Q:ON \qquad (4)$$

When the switch is OFF, the state space equations are represented by

$$\begin{cases} \frac{di_{L1}}{dt} = \frac{1}{L_1}(v_{in} - v_o) \\ \frac{dv_c}{dt} = \frac{1}{C_2}(i_{L1}) \\ \frac{di_{L2}}{dt} = \frac{1}{L_2}(-v_o) \\ \frac{dv_o}{dt} = \frac{1}{C_1}(i_{L2} - \frac{v_o}{R}) \end{cases} \quad , \quad dT < t < T \quad , \quad Q:OFF \qquad (5$$

The above equations are implemented in Simulink as shown in Fig. 7 using multipliers, summing blocks, and gain blocks, and subsequently fed into two integrators to obtain the states $i_L(t)$ and $v_C(t)$, [5-7].

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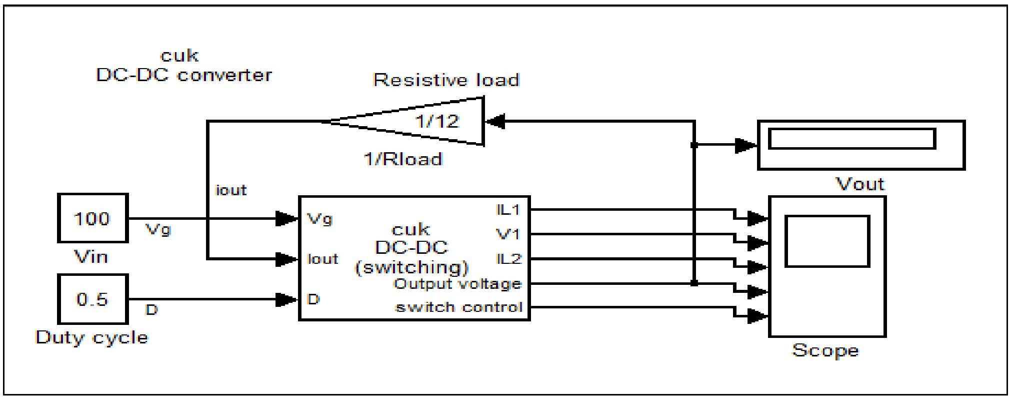


Fig. 6 cuk model

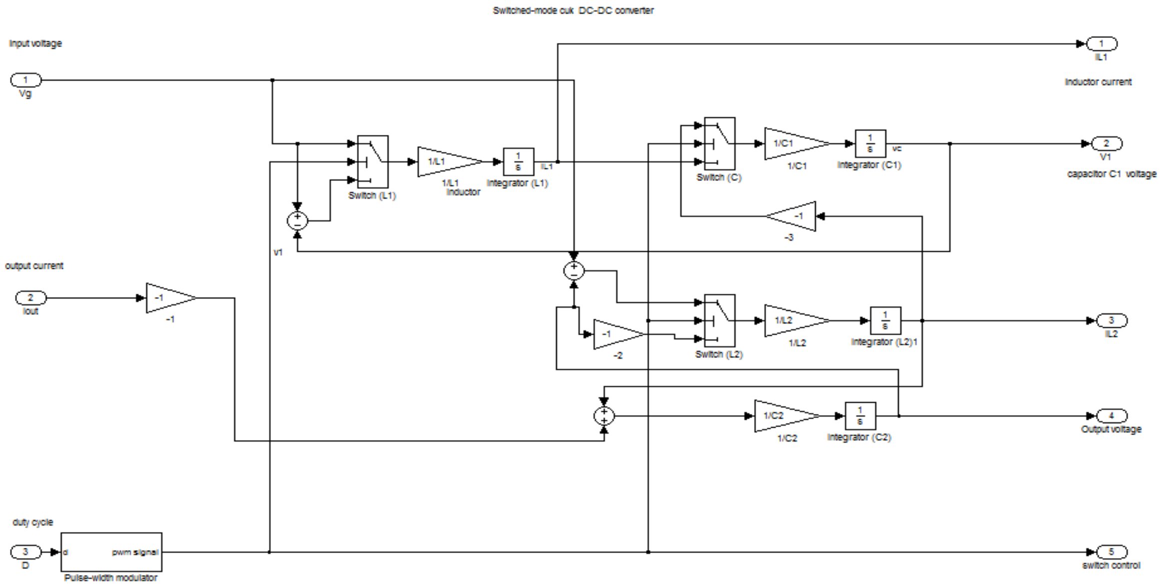
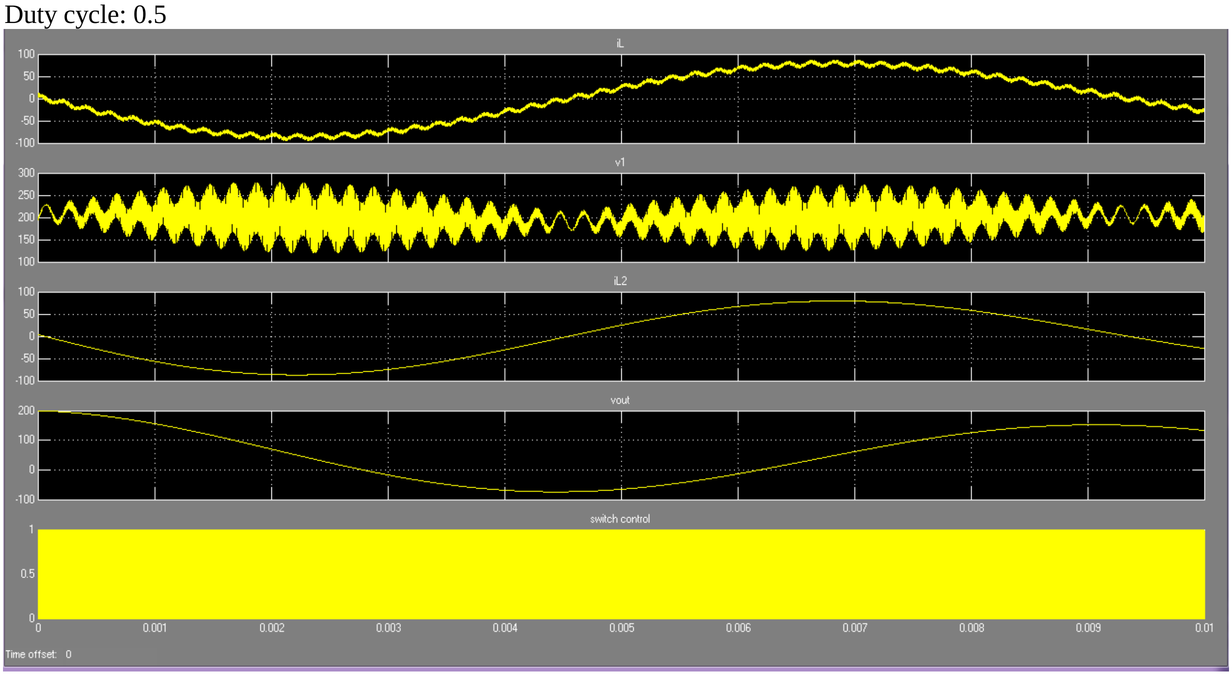


Fig. 7 open loop cuk subsystem Simulink model

Simulation results of different duty cycle are shown below

Duty cycle: 0.5



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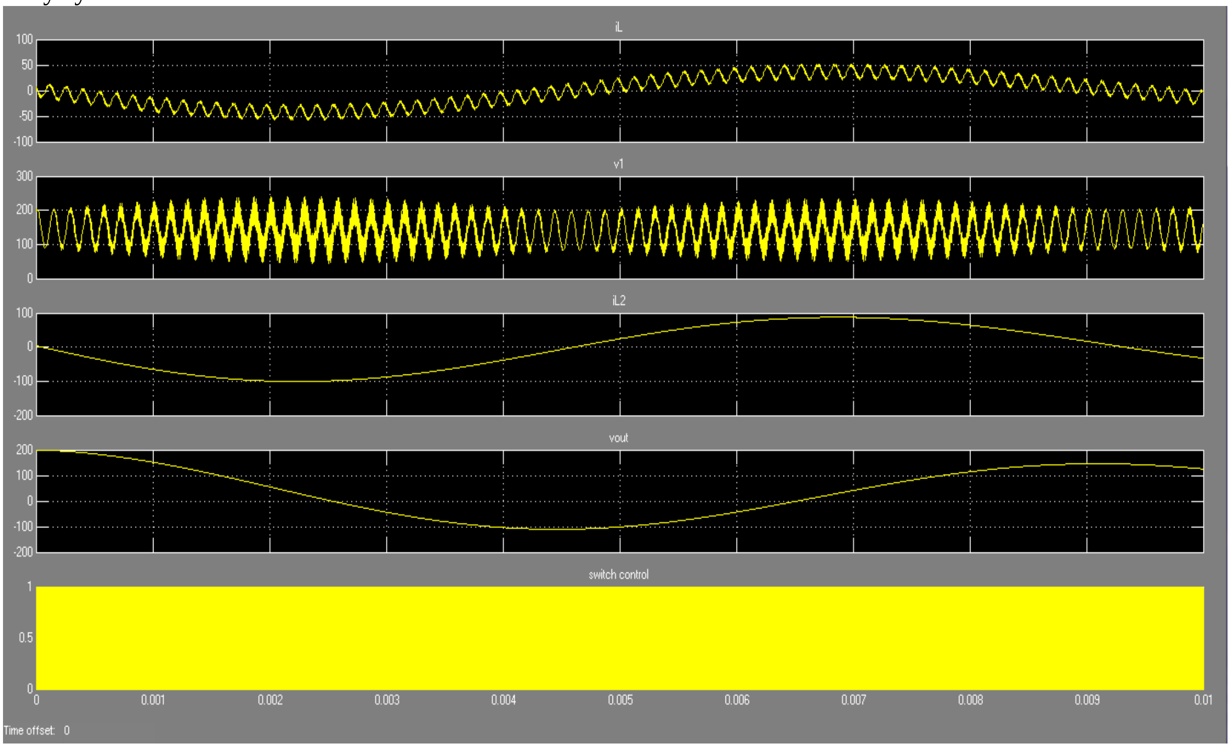
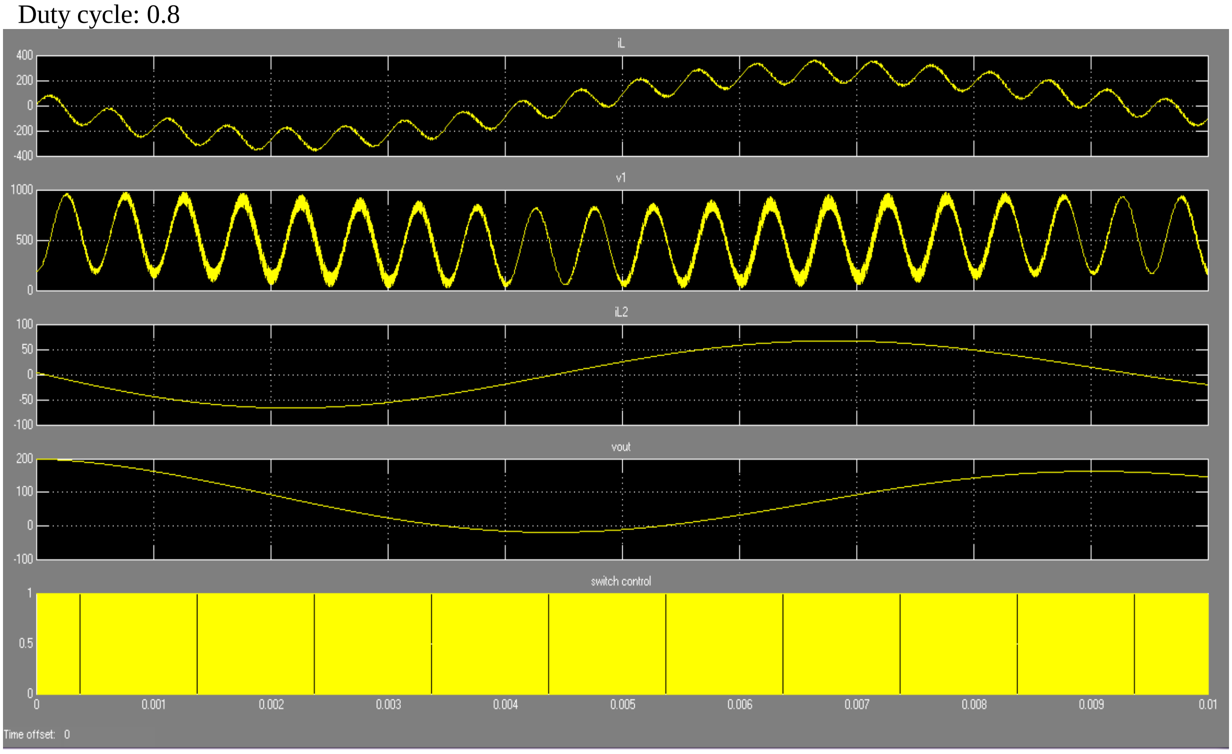
Duty cycle: 0.3



Duty cycle: 0.8



3.2.2 Boost converter:

A boost converter (step-up converter) is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element,

a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

- *Boost Converter Modeling*:

The boost converter of Fig. 9 with a switching period of T and a duty cycle of D is given. Again, assuming continuous conduction mode of operation, the state space equations when the main switch is ON are shown by, [4].

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$$\begin{cases} \frac{di_L}{dt} = \frac{1}{L}(V_{in}) \\ \frac{dv_o}{dt} = \frac{1}{C}(-\frac{v_o}{R}) \end{cases}, \quad 0 < t < dT, \quad Q:ON \qquad (6)$$

and when the switch is OFF

$$\begin{cases} \frac{di_L}{dt} = \frac{1}{L}(V_{in} - v_o) \\ \frac{dv_o}{dt} = \frac{1}{C}(i_L - \frac{v_o}{R}) \end{cases}, \quad dT < t < T, \quad Q:OFF \qquad (7)$$

(7)

Fig. 9 shows These equations in Simulink using multipliers, summing blocks, and gain blocks, and subsequently fed into two integrators to obtain the states $i_L(t)$ and $v_C(t)$, [5-7]

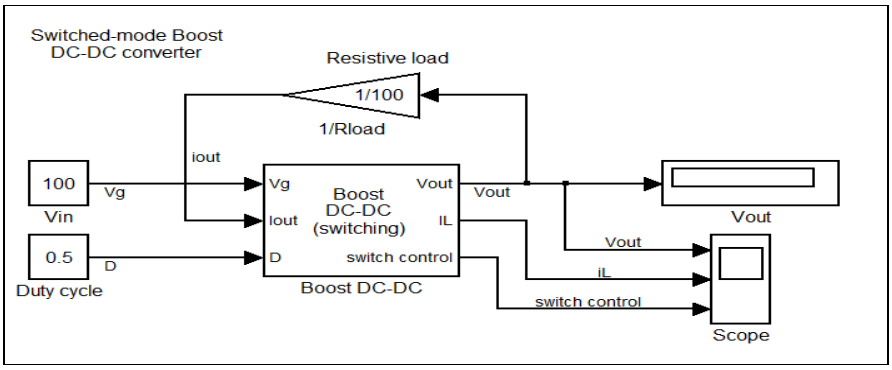


Fig. 8 Switched mode DC-DC converter

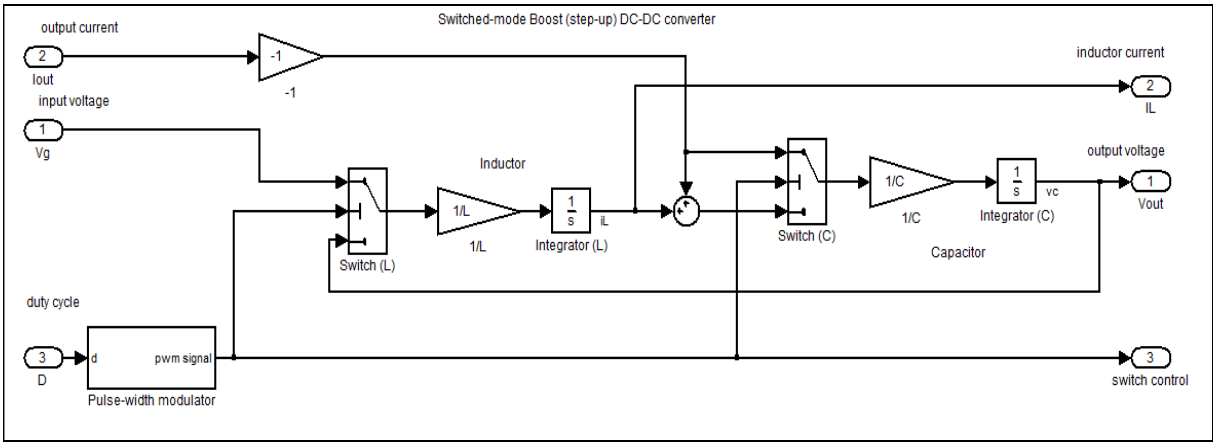
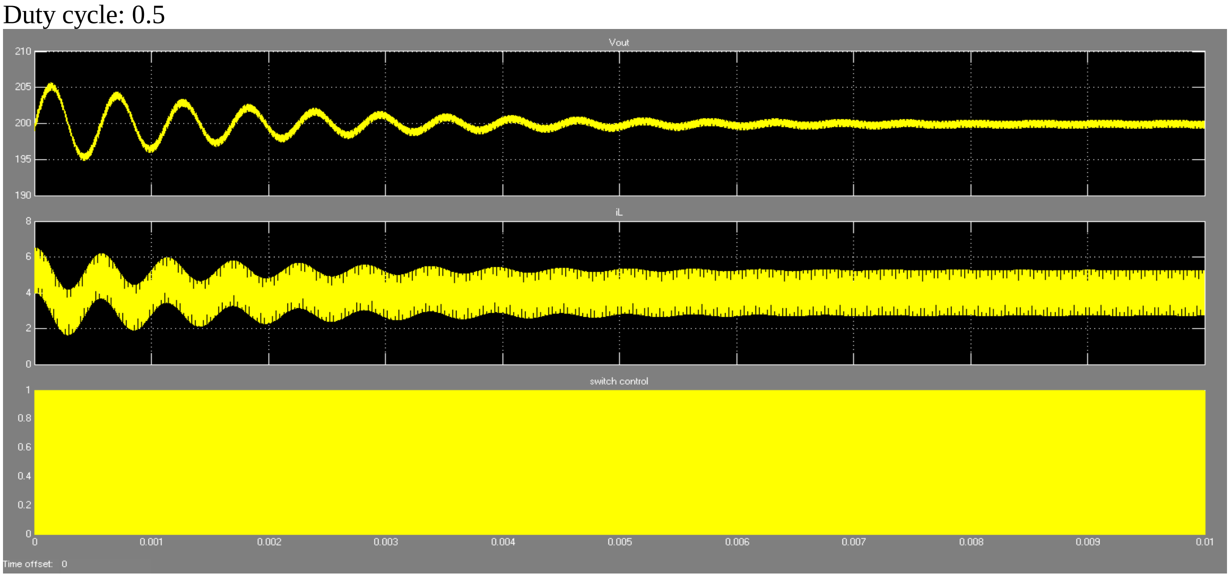


Fig. 9 Open loop model of boost converter

Duty cycle: 0.5



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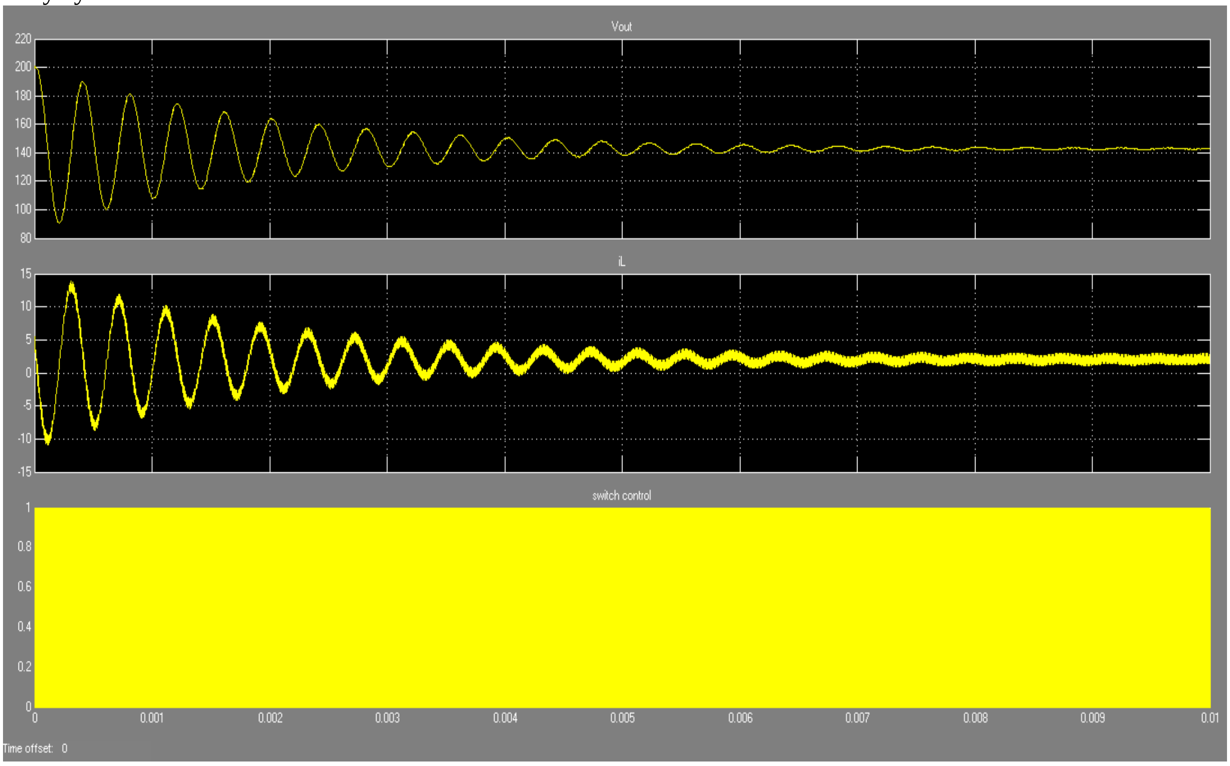
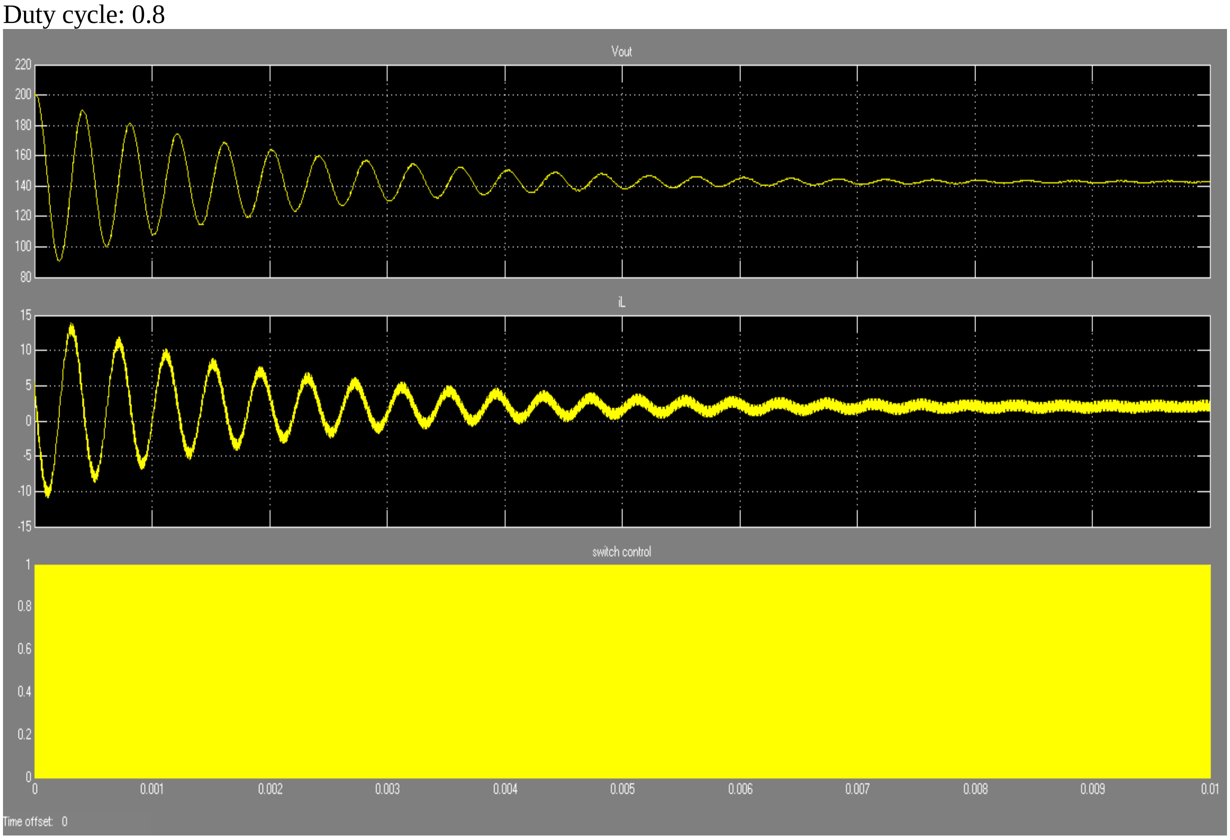
Duty cycle: 0.3



Duty cycle: 0.8



3.2.3 Buck-Boost Converter Modelling

A DC-DC buck-boost converter is shown. The switching period is T and the duty cycle is D. Assuming continuous conduction mode of operation, when the switch is ON, the state space equations are given by, [4]

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(V_{in}) \\ \dfrac{dv_o}{dt} = \dfrac{1}{C}(-\dfrac{v_o}{R}) \end{cases} , \quad 0 < t < dT , \quad Q:ON \tag{8}$$

and when the switch is OFF

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$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(v_o) \\ \dfrac{dv_o}{dt} = \dfrac{1}{C}(-i_L - \dfrac{v_o}{R}) \end{cases}, \quad dT < t < T, \quad Q:OFF \qquad (9)$$

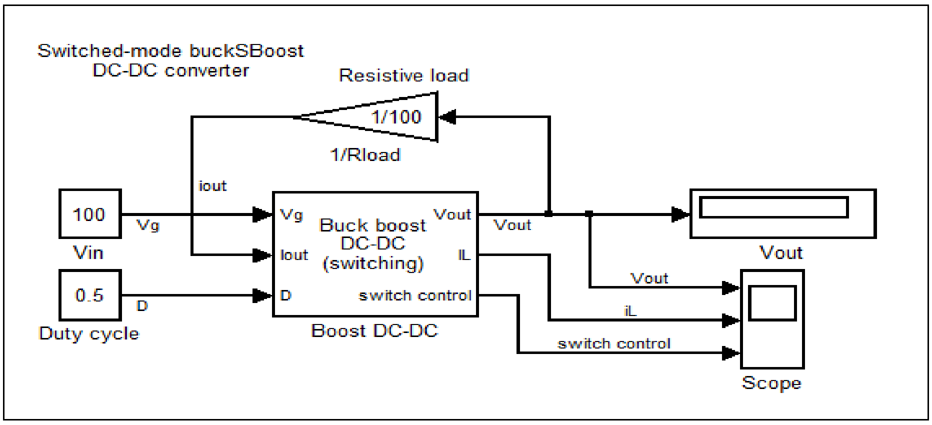


Fig. 10 Switched mode buck boost DC-DC converter

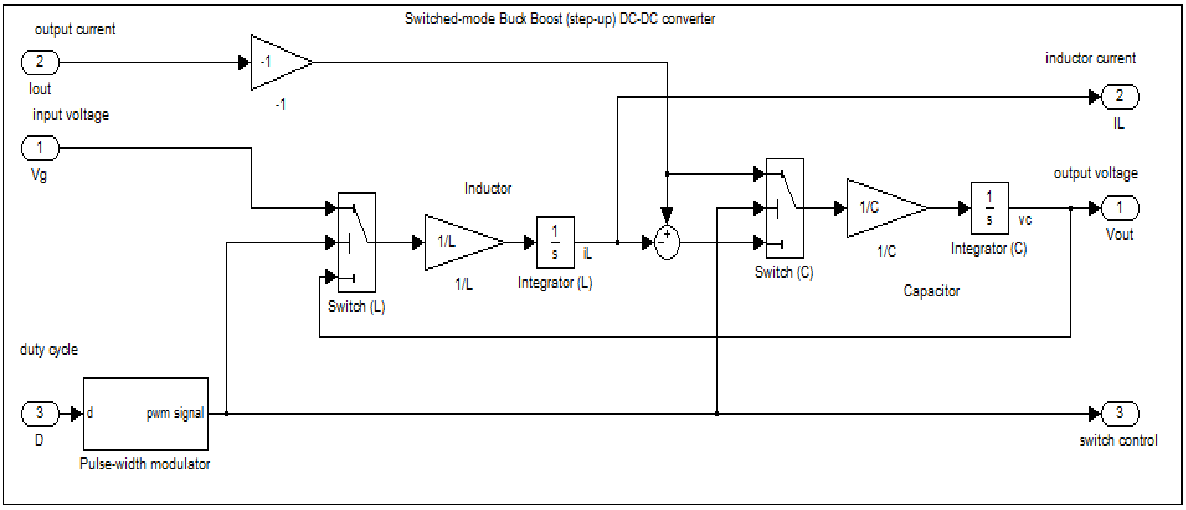
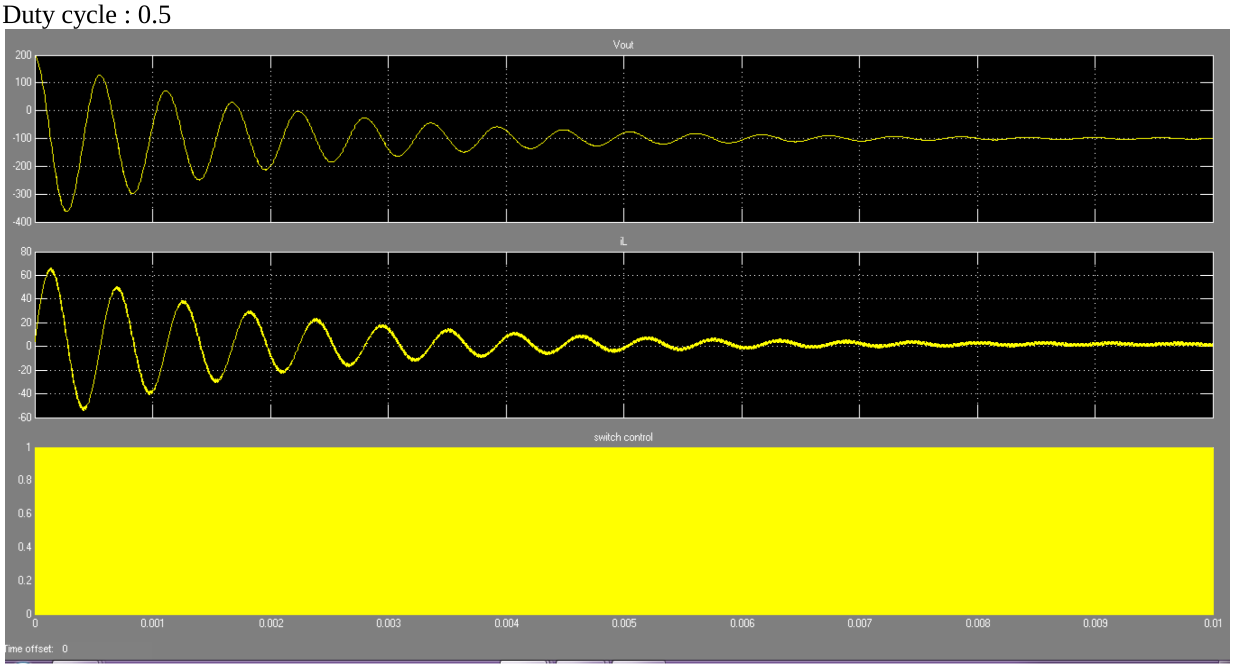


Fig. 11 Buck boost open loop model.

Duty cycle : 0.5



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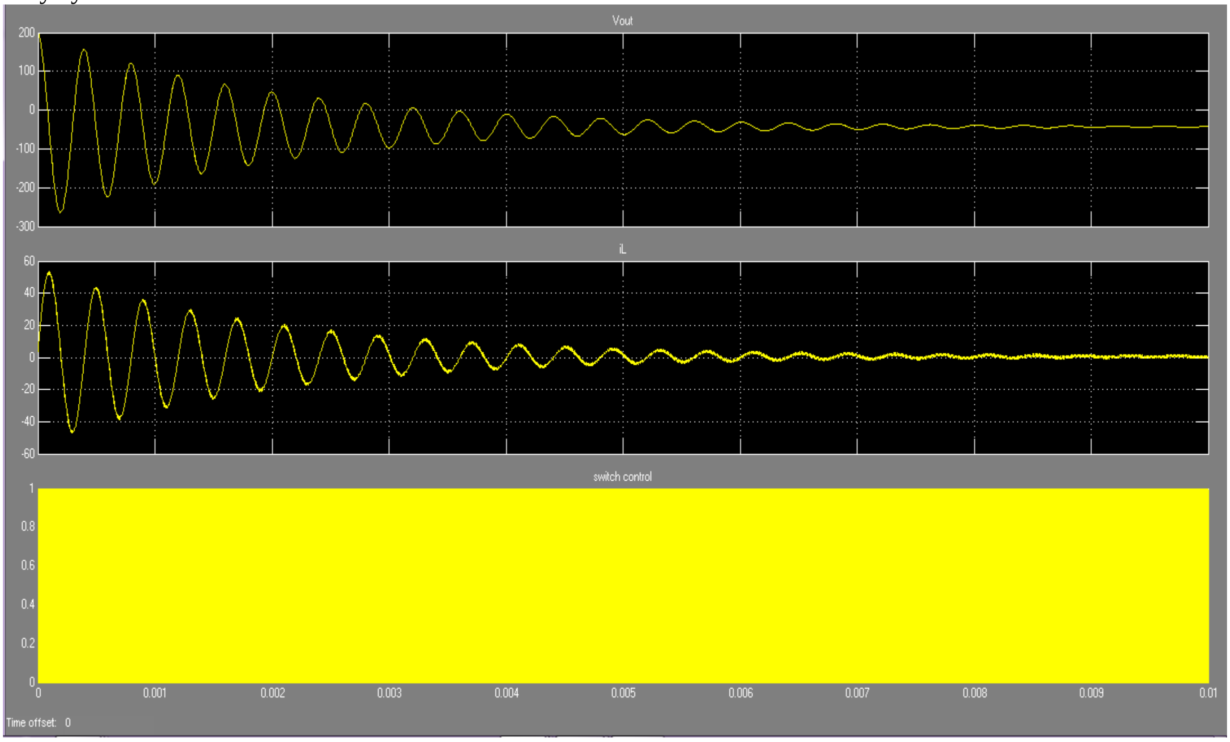
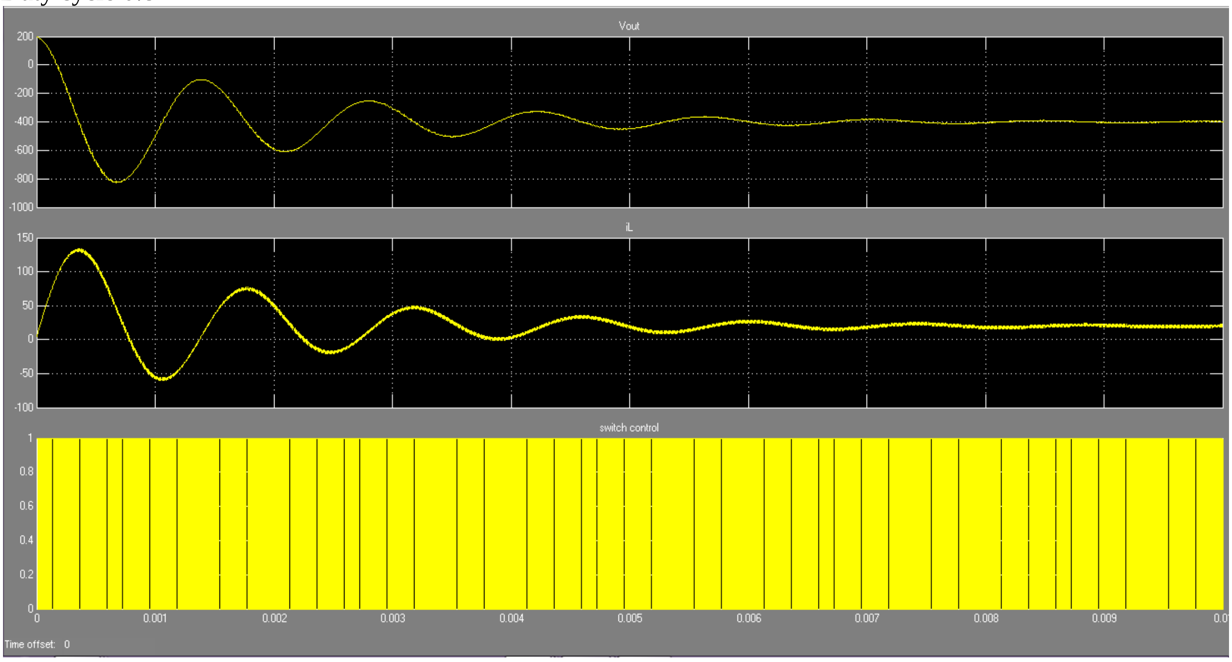
Duty cycle:0.3



Duty cycle 0.8



3.3 MAXIMUM POWER POINT TRACKING:

Maximum Power Point Tracking (MPPT) is an electronic system that operates that allows the Photovoltaic (PV) modules to produce all the power they are capable of. It is not a mechanical tracking system that "physically moves" the modules to make them point more directly at the sun. ***Perturb & observe (p&o) method*** is depicted in Fig.13 below.

Perturb & Observe (P&O) is the simplest method. In this we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing on both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm.

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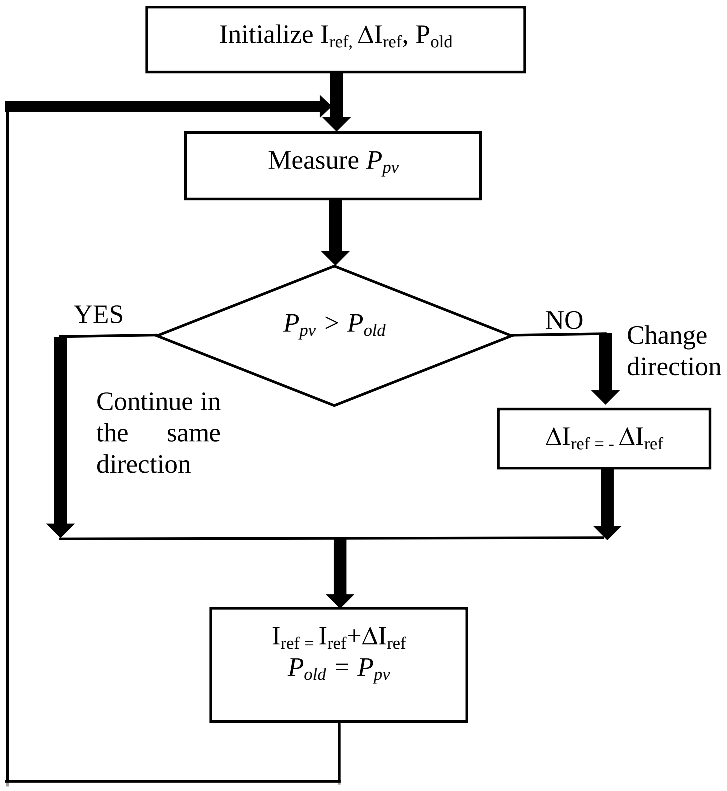

Fig. 12 Flowchart showing p&o method

IV. COMPARISON OF THE RESULTS OF DIFFERENT CONVERTERS

The results obtained are summarized as below

1) The grid connected PV system operated using only boost converter setting boost Iref to operate PV array at MPP gives Ipv= Iref= 4.95A
2) Energy balance is obtained by setting different values of I_{RMSref} and after analysing the waveforms, the right I_{RMSref} = 3.94A is set.

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Comparisons of voltage output of different converters are recorded in table I.

Table I: Output voltage of different converters against different duty cycle.

Converter type	Duty cycle	Output voltage (V)
CUK	0.3	125.1
	0.5	133.2
	0.8	145.4
BOOST	0.3	143.3
	0.5	200.4
	0.8	500
BUCK BOOST	0.3	-41.41
	0.5	-99.63
	0.8	-397.7

Thus it is observed that boost converter gives the highest voltage at different duty cycles.

V. COMPLETE MODEL OF TWO STAGE CONVERTER SYSTEM

Fig. 14 below shows the complete model of a Photovoltaic system that uses boost converter and inverter.

The following results were found on simulating the grid connected PV system.
Boost efficiency = 0.9643,
DC-AC conversion efficiency = 0.9586

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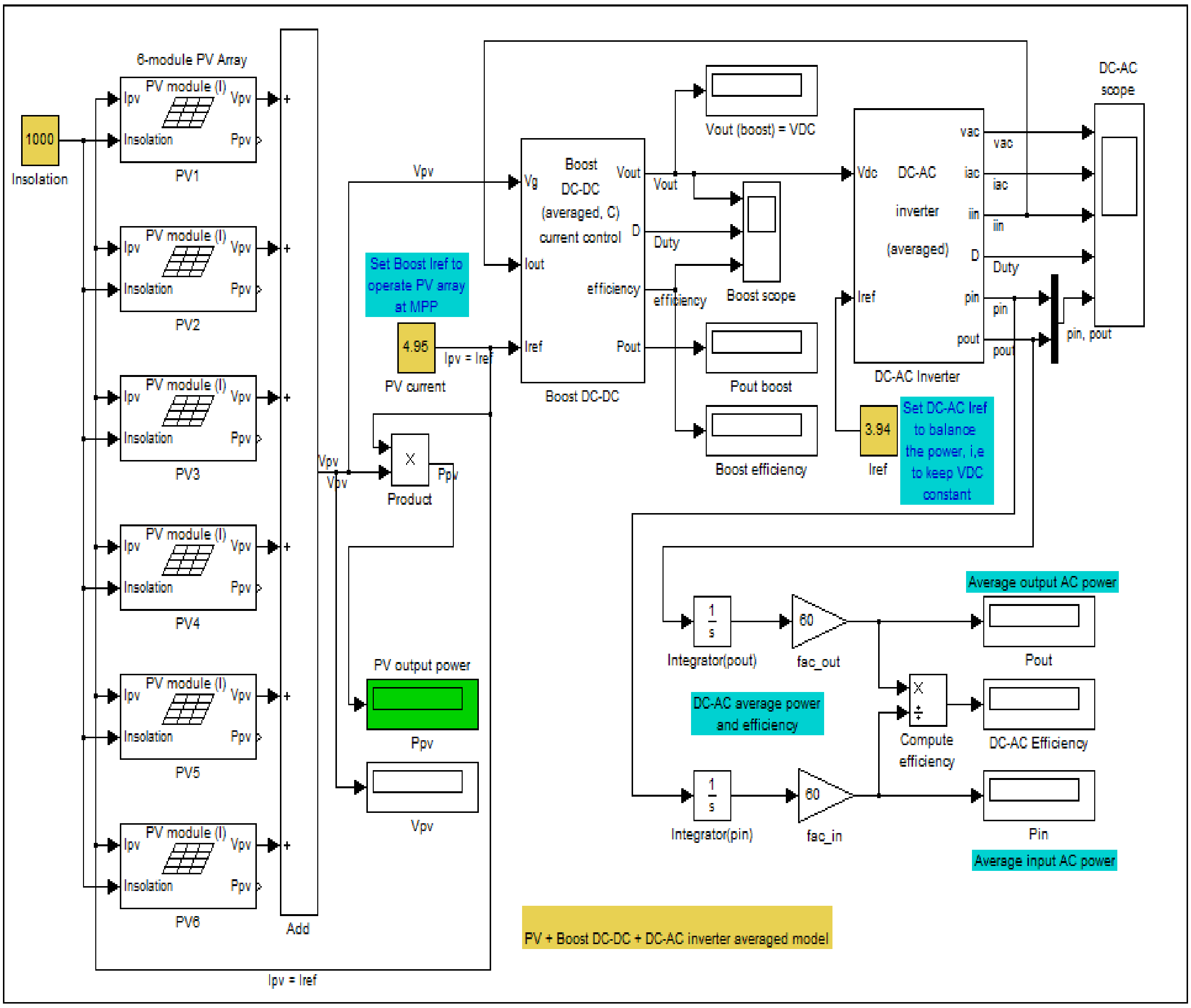

Fig. 13 PV system using boost converter and inverter.

The output waveforms are shown below:

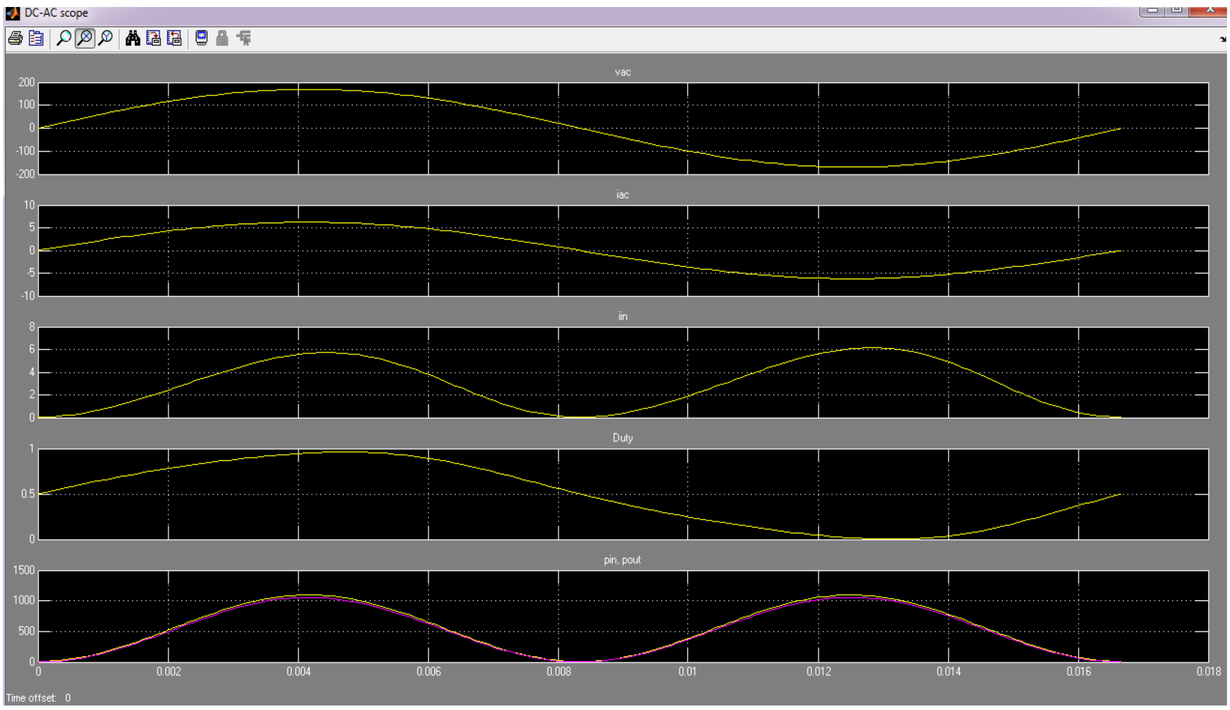

Fig. 14 DC to AC scope results of v_{ac} ,i_{ac} ,i_{in} ,duty,p_{in} ,p_{out}

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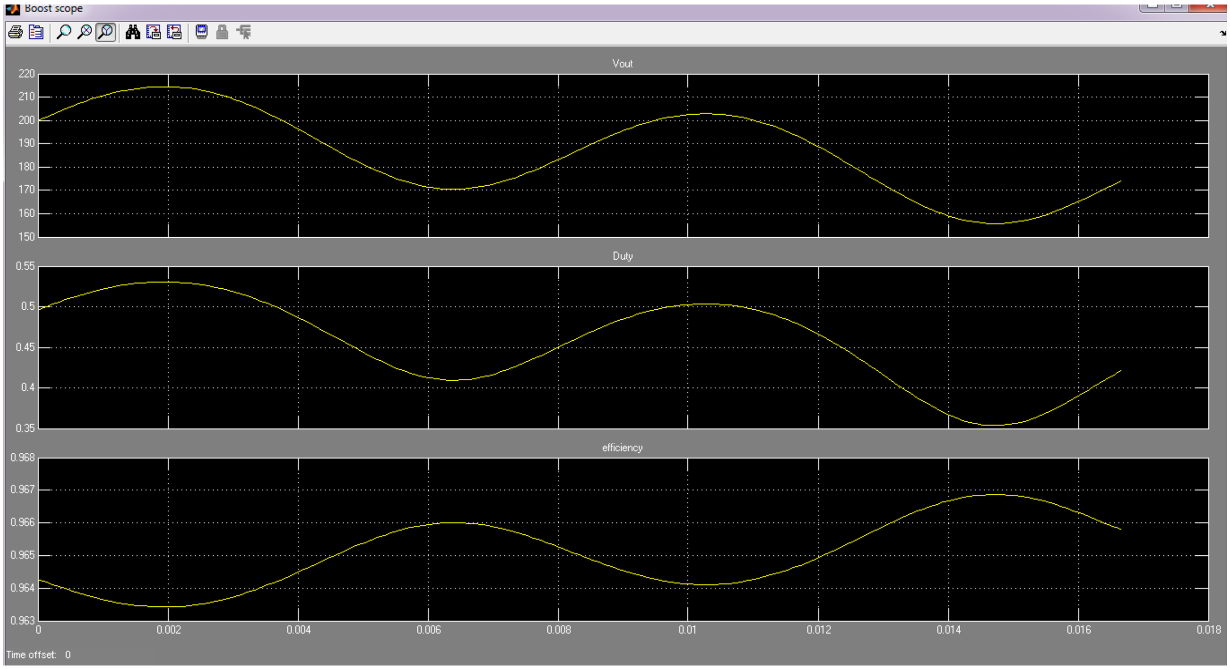

Fig. 15 Boost DC to DC scope results v_{out} ,duty, efficiency.

VI. CONCLUSION

The paper presents the comparative analysis of three dc-dc converter and the result of the analysis is used to decide the dc-dc converter to be used in grid connected PV system. From the comparative analysis boost dc-dc converter is chosen because of its simplicity and high efficiency. The overall performance of the system is quite satisfactory with the overall efficiency close 100 %. The efficiency is less than 100 % because in the design of the system we have included the loss current due to switching. In future work we have considered to including the analysis of total harmonic distortion and reduction in input current ripples.

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