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# Design And Analysis Of Dc-Dc Converter For Photovoltaic (PV) Applications.

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***Abstract:*** *Renewable sources like solar photovoltaic PV, wind turbines plays prominant role in electricity generation. Photovoltaic PV source is one of the biggest source of world energy requirement.For small applications, solar PV generates energy at low voltage and therefore require a high efficiency DC-DC converter to step up the voltage level. To handle this issue, a coupled inductor based high gain, high efficiency dc-dc converter with intermediate capacitor is introduced. Perturb and Observe algorithm is used to track maximum Power Point (MPPT) in photovoltaic array. The converter is analysed considering operation in continuous conduction mode of operation .The converter is designed and simulated in PSIM platform with MPPT.*

***Keywords:*** *Coupled inductor, Maximum power point tracking (MPPT), PV system, Voltage gain, Perturb & Observe (P&O)*

## I. Introduction

The excessive use of fossil fuels such as oil, coal, and gas, results in serious greenhouse effect , environmental pollution and energy shortage. The renewable energy sources like photovoltaic (PV), wind energy were mainly used because of its availability everywhere. Many researchers focus more on the development of photovoltaic technology due to its less operational and maintenance costs for electricity generation . The research of PV based generation is getting increased in both stand-alone application and in grid connected system and hence many research works are being carried out to harvest energy from PV system.

The voltage generated by the PV array is low because of its non linear performance and it is not sufficient for different load application. During irradiance and temperature changing condition the generating power gets varied. To maintain the maximum power from the PV system the MPPT algorithm is necessary for the optimal utilization of the sources . There are many MPPT algorithms like Perturb and Observe (P&O) , Incremental Conductance (INC), Fuzzy Logic Controller(FLC) , Neural Network (NN).

The output power of PV panels varies continuously depending on some environmental factors such as temperature, shading and solar radiation level and load conditions. PV panels have a non linear characteristic since they have different output power at different operating points. And also are operated at low output voltage levels ( 25-50V) . This makes their application to grid connected systems and stand-alone loads difficult because a large voltage boosting is required. Therefore, dc-dc converters are required between PV panels and load to obtain the maximum power from the panels.

Use of conventional dc-dc converters has some disadvantages:

- It causes large peak current results from low input voltage to flow on the input side, which adversely affects the magnetic components and results in high losses.
- The cost of the switches increases with the voltage stress .
- Severe reverse recovery problem at the output diode due to high output voltage .

In view of the above, there is a need to develop a special high gain, high efficiency dc-dc converters to implement MPPT . Several circuit topologies have been proposed in the past for this application. They follow one or more of the following philosophies to achieve high voltage at the converter output.

- Direct voltage step-up using high frequency transformer.
- Use of coupled inductor which utilizes the energy storage capability of the magnetizing inductance .
- Use of interleaved coupled inductor increases the power level, which can reduce the current ripple, minimize the size of passive component and improve the transient response
- Active and passive clamp circuits to recover leakage energy and minimize the voltage stress.
- Use of intermediate energy storage capacitors which act as additional buffers to increase the voltage gain without increasing duty cycle to a high value.

**1.1 Background**

DC-DC converters can be classified as isolated and non-isolated converters. Isolated converters uses a transformer between input and output. Direct voltage step up using high frequency transformer is one of the commonly used converter which provides high gain. Many Isolated current-fed dc-dc converters such as converters with coupled inductors integrated with isolated transformers, coupled inductors integrated with voltage multipliers are such examples [1].However these topologies result in high voltage spikes across the switch (due to leakage inductance) and large ripple in primary side transformer current as the turns ratio in the high frequency transformer increases. The isolated systems are relatively costly, bulky and generally less efficient even though they offer more safety, eliminate issues such as ground leakage current and can provide multiple outputs among other advantages.

In order to reduce system cost and to improve system efficiency, it is suitable to employ the non-isolated DC-DC converters. In non-isolated DC-DC converters, the input source and load are not isolated. The major concerns using non-isolated converters are conduction loss and diode reverse recovery issue. Many techniques were developed to step up the voltage level of the non-isolated structures.The most part of the proposed solutions of non-isolated high voltage gain DC-DC converter are based on the boost topology with an additional technique associated with it.The step-up converter is upgraded by using switched capacitor, coupled inductor ,voltage doubler and diode-capacitor techniques.

Most of the non-isolated high voltage gain DC-DC power converters employ coupled inductor which can serve as transformer to enlarge the voltage gain [2]. The coupled inductor based dc-dc converter has advantages over isolated transformer based dc-dc converter in minimizing current stress, using lower rating components and simple winding structure. Modeling procedure of the coupled inductor is described in [3]. For high power converter applications interleaved coupled inductor based boost converters [4-5] have also been proposed . Although it is easy to achieve high voltage gain by employing a coupled inductor, the leakage inductance of the coupled inductor induces high voltage, large switching loss and severe EMI(Electromagnetic interference) problems. The effects of leakage inductance can be eliminated by using an active clamp network shown in [6],[7], which provides an alternate path to recycle leakage energy. By considering disadvantages of active clamp circuit a new topology is proposed which have one additional diode and a small capacitor, the proposed converters operation is similar to that of their active-clamp , but with better performance. Voltage gain of the converter can be increased by connecting a intermediate capacitor [9] in series with the inductor without increasing the duty cycle of the switch.

Keeping in mind the merits and demerits of the various topologies described in above literature, a novel topology has been proposed that achieves high gain high voltage DC-DC converter using a coupled inductor connected in interleaved manner that charges an intermediate buffer capacitor and a passive clamp network to recover the leakage energy. Coupled inductor incorporates 'turns ratio' into the gain expression that leads to high efficiency without increasing the duty ratio.

## II. Overview

Energy conversion efficiency of solar PV is quite low. Therefore, it is essential to use a highly efficient power conversion system to utilize maximum power generated by the PV array. The proposed high gain dc-dc converter configuration is shown in Fig. 1. It consists of one passive clamp network, a coupled inductor ($L_1L_2$) and an intermediate capacitor apart from other components.

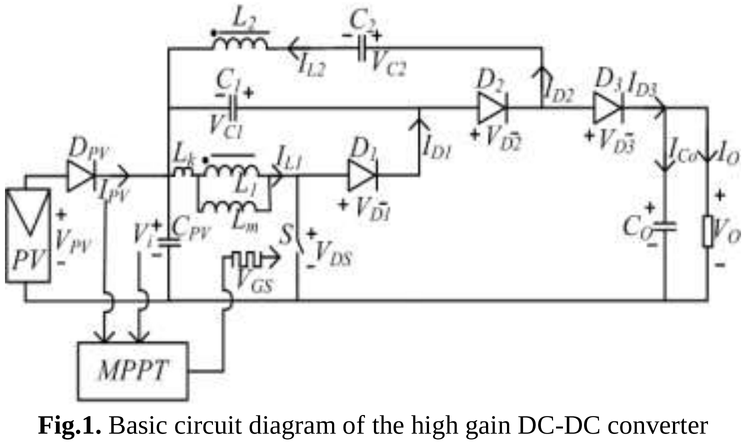


**Fig.1.** Basic circuit diagram of the high gain DC-DC converter

The symbol $V_{PV}$ represents the PV voltage applied to the circuit. S is the main switch of the proposed converter. The coupled inductor's primary and secondary inductors are denoted by $L_1$ and $L_2$. $C_1$ and $D_1$ represent the passive clamp network across $L_1$. The capacitor $C_O$ is the output capacitor while D3 is the output diode. The voltage $V_O$ is the average (DC) output across the load. The intermediate energy storage capacitor, $C_2$ and the feedback diode $D_2$ are connected on the secondary side.

$$n = \frac{V L2}{V L1} \qquad (1)$$

where, $V_{L1}$and $V_{L2}$ represent the voltages across inductor $L_1$ and $L_2$ respectively. The operating modes for continuous conduction mode (CCM) are shown below. Various operating modes are described below:

Mode I [$t_0$-$t_1$]: The switch (S) is turned on at the start of the converter operation.The diodes, $D_1$ and $D_3$ are reverse biased, while $D_2$ is forward biased . The current flows through the switch and both magnetizing inductor $L_m$ and leakage inductor $L_k$ are linearly charged . The intermediate capacitor, $C_2$ is charged through $D_2$ by $L_2$ and capacitor, $C_1$.Current path in this mode is shown in Fig.2.

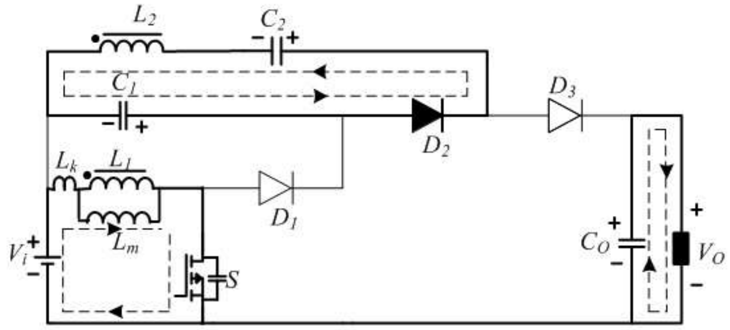


**Fig.2.** Equivalent circuit of Mode I

Mode II [$t_1$-$t_2$]:The switch S is turned off at $t_1$ .The parasitic capacitance of the switch S is charged by the magnetizing current flowing through the inductor $L_1$approximately linear way. The diode $D_2$ remains forward biased and current continues to flow through this. Current path in this mode is shown in Fig.3.

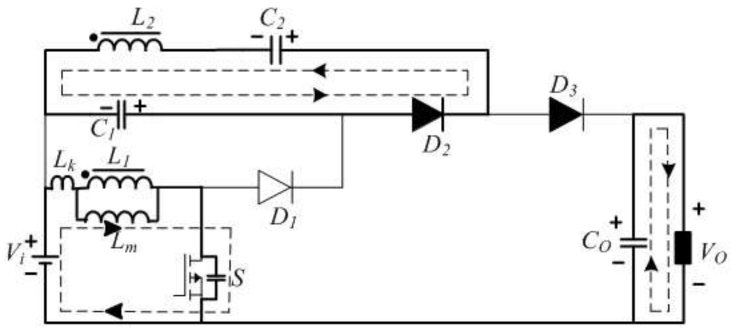


**Fig.3.** Equivalent circuit of Mode II

Mode III [$t_2$-$t_3$]: In this mode, diodes $D_1$ and $D_3$ become forward biased. $D_2$ is reverse biased . The leakage energy stored in the primary side of the coupled inductor ($L_1$) begins to charge the clamp capacitor ($C_1$) through $D_1$. Also,the energy from the input side to the output side is transfered through diode $D_3$ as shown in Fig.4.

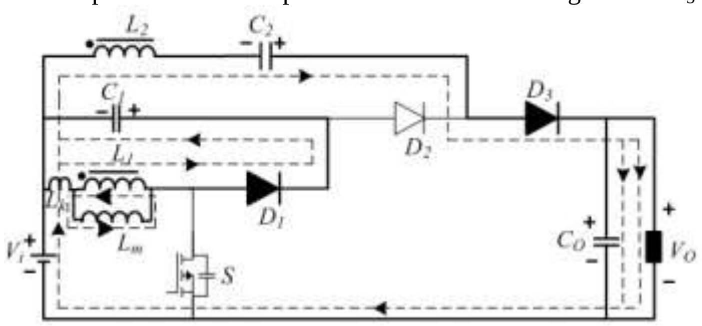


**Fig.4.** Equivalent circuit of Mode III

Mode IV [$t_3$-$t_4$]: This mode begins after the completion of recovery of the leakage energy from inductor $L_1$. The diode $D_1$ now becomes reverse biased while diode $D_3$ remains forward biased in this mode. The current flows from the input side to the output side to supply the load as shown in Fig.5.

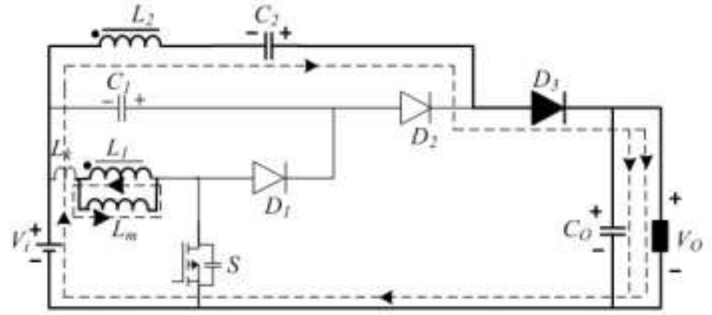


**Fig.5.** Equivalent circuit of Mode IV

Mode V [t4-t0]: This mode begins by turning on switch S.The leakage inductor energizes quickly using the full magnetizing current while the parasitic capacitance across the switch discharges in this mode. The two diodes D1 and D2 are in reverse biased condition. The current flow path in this mode is shown in Fig. 6. This mode ends when diode D3 becomes reverse biased and current flow through inductor, L2 changes direction.

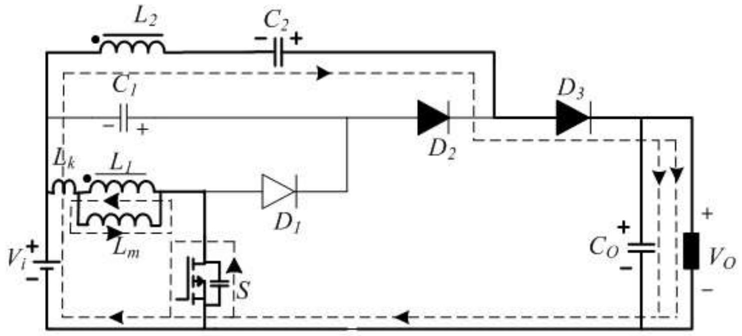


**Fig.6.** Equivalent circuit of Mode V

Typical waveforms of the circuit are shown in Fig. 3.7.

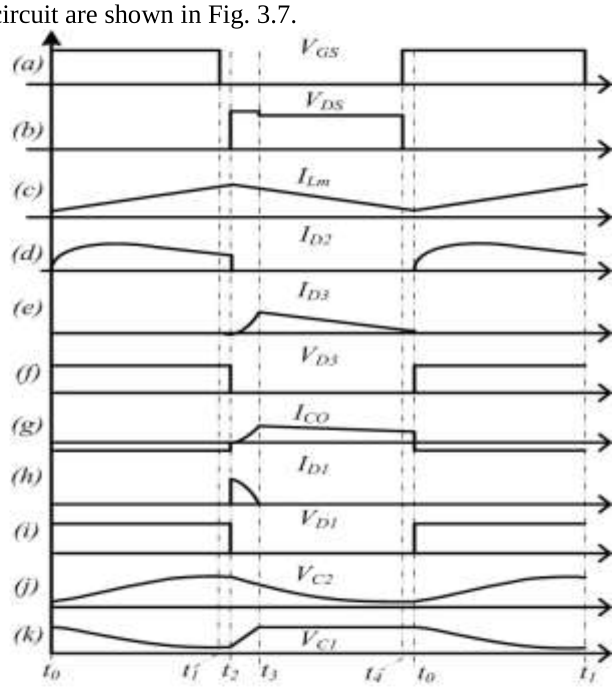


**Fig.7.**Typical waveforms during CCM operation where (a) shows gate pulse $V_{GS}$,(b)shows voltage across the switch $V_{DS}$, (c) shows magnetizing inductance current $I_{Lm}$ ,(d) shows current through diode $D_2$ ,(e)

shows current through diode $D_3$,(f) shows voltage across diode $D_3$,(g) shows output capacitance current $I_{C0}$,(h) shows current through diode $D_1$,(i) shows voltage across diode $D_1$,(j) shows voltage across capacitor $C_2$ and (k) shows voltage across capacitor $C_{1.}$

## III. Design

For the given input, output specifications, a suitable turns ratio is selected and the nominal duty cycle can then be calculated using $\frac{V0}{Vi} = \frac{1+n}{1-d}$ where $V_0$ is output voltage Vi is input voltage d is duty ratio, n is turns ratio which is given by n = $\frac{VL2}{VL1}$

- Assume ΔVc1 = Δ Vc2 =1% of V0 = 1.5 V (2)
  d=66.7%
- The value of the magnetizing inductance (Lm)
  $L_m = \frac{Vi\, d}{2\Delta\, Im\, fs} = 50\times 10^{-6}$ H (3)
- The minimum value of the clamp capacitor $C_1$
  $C_1 = \frac{Im\, dlk}{\Delta V\, C1\, fs} = 1\times 10^{-6}$F (4)
- The minimum value of the intermediate capacitor C2 is
  $C_2 = \frac{Im\, d}{n\, \Delta V\, C2\, fs} = 47\times 10^{-6}$F (5)
- The minimum value of the output capacitor Co is
  $C_0 = \frac{Io\, d}{\Delta V0\, fs} = 180\times 10^{-6}$F (6)

## IV. Maximum Power Point Tracking (MPPT)

The photovoltaic system should operate at the voltage where the global maximum of the P-V characteristic is present. The point at which product V and I is maximum in VI characteristics of a solar cell is defined as maximum power point (MPP). This point in the P-V characteristic is called the Maximum Power Point (MPP). The MPP changes when the irradiation and temperature changes or when the solar panel is partially shaded. MPP is unique and it is located at the knee of PV characteristics. MPPT system is actually an electronic device interface between the PV array and the load. They are used to track peak power by operating PV panel at peak voltage.

The MPPT consists of two main parts, a micro-controller part to track the MPP and a converter to convert the generated voltage to a desired level suitable for the load. An algorithm runs on the microcontroller to track the MPP. There are a lot of different algorithms to track the MPP such as

- Hill Climbing Method
- Incremental Conductance Method
- P & O Method

Here we are employing P&O MPPT method for maximum power extraction. In this P & O method is commonly used in all sort of applications due to several advantages. Simple structure, easy implementation and less required parameters for tracking down MPP are some of the advantages of P & O method. Even though, it has some drawbacks such as power tracked by the P and O method will oscillate and perturb up and down near the maximum power point and the changes in weather conditions are not specified. The algorithm followed to track MPP using P and O is shown in fig.8. The Perturb & Observe (P & O) algorithm perturbs the duty cycle which controls the power converter, in this way it takes steps over the P-V characteristic to track the MPP. This perturbation causes a new operating point with a different output power. To achieve maximum power point of PV modules, the condition (dP/dV = 0) is to be attained in P-V characteristics. The load of the PV system is adjusted in order to change the terminal voltage and output power of the PV modules. In P & O, the variations of the output voltage and power before and after the sampling instant are observed. The present power is compared to be the reference for increasing or decreasing the load in the next perturbation. If the perturbation causes an increased output power of PV modules than that before the variation, the perturbation direction is positive. Otherwise, if the output power of PV modules is less than that before variation, it indicates that the varying direction should be reversed.

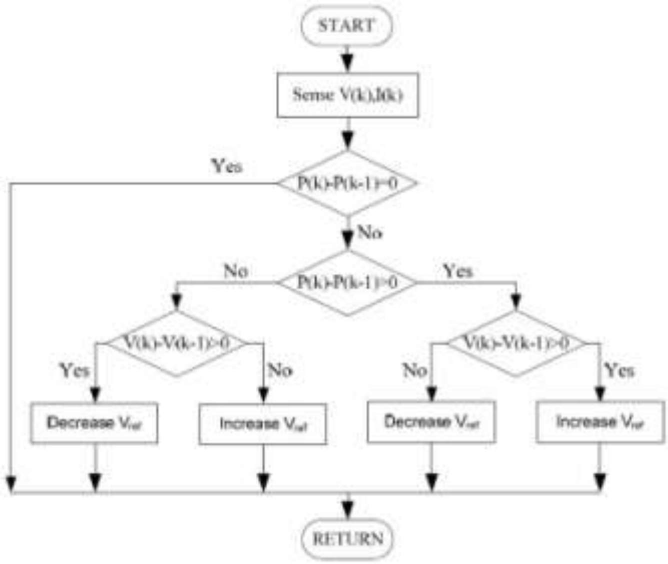


**Fig.8.** P&O Algorithm

## V. Simulation

The PSIM simulation of PV based high gain DC-DC step-up converter for a resistive load is done as per the parameters used are tabulated in table 1.The simulation of DC-DC boost converter with resistive load is done.

| | |
|---|---|
| Rated Power | 100W |
| Input DC Voltage | 10 – 20 V |
| Output Voltage | 150 – 200 V |
| $C_0$ | 2.96μF |
| $C_1$ | 49.92 μF |
| $C_2$ | 27.7 μF |
| $L_m$ | 333.5 μF |
| $L_k$ | .3335 μF |
| Turns ratio of the coupled Inductor (n) | 4 |
| Switching Frequency ($f_s$) | 50kHz |

### 5.1 Simulation Diagrams

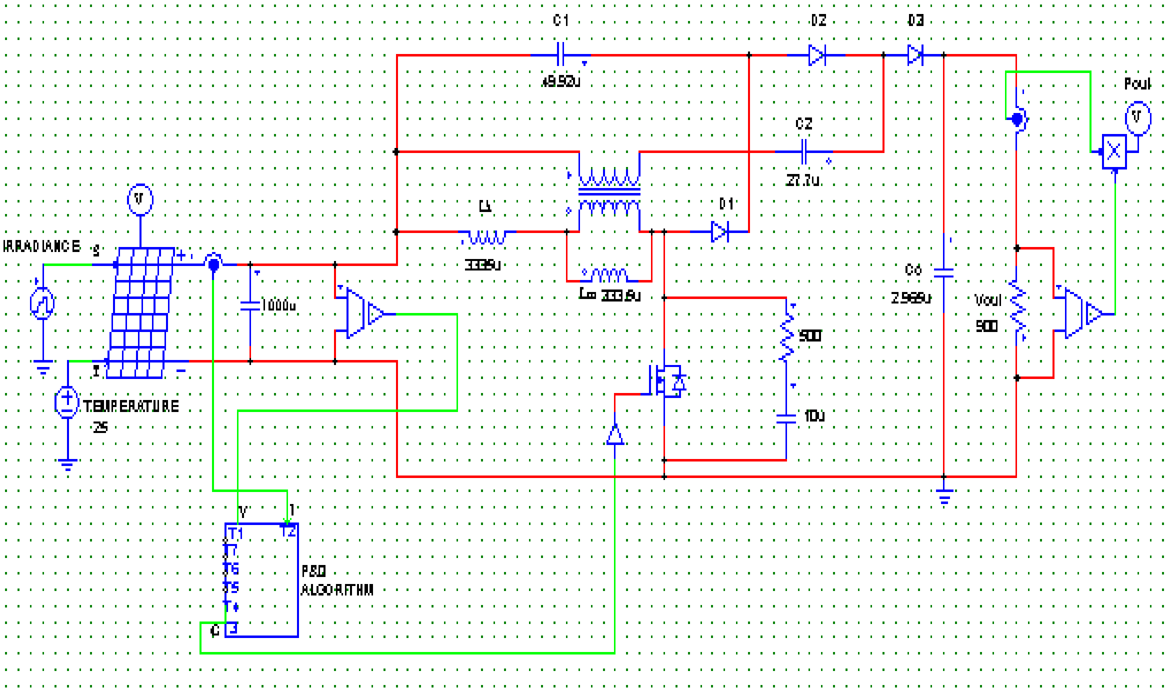


**Fig.9.** Simulation of proposed topology employing P&O MPPT Algorithm

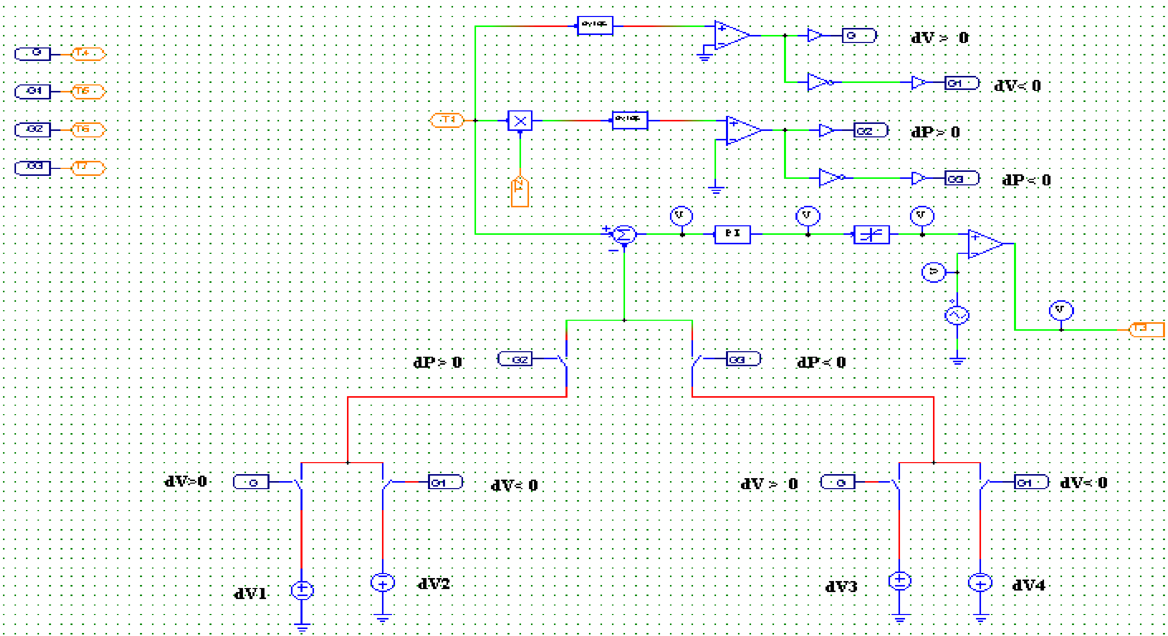


**Fig.10.** P&O MPPT Algorithm

### 1.2 Simulation Results

| Temperature( °C) | Irradiance ($W/m^2$) | Power Pmax(W) | Voltage ($V_0$) |
|---|---|---|---|
| 25 | 1000 | 60.5 | 233.34 |
| 25 | 800 | 47.5 | 206.76 |
| 25 | 600 | 35.5 | 178.79 |

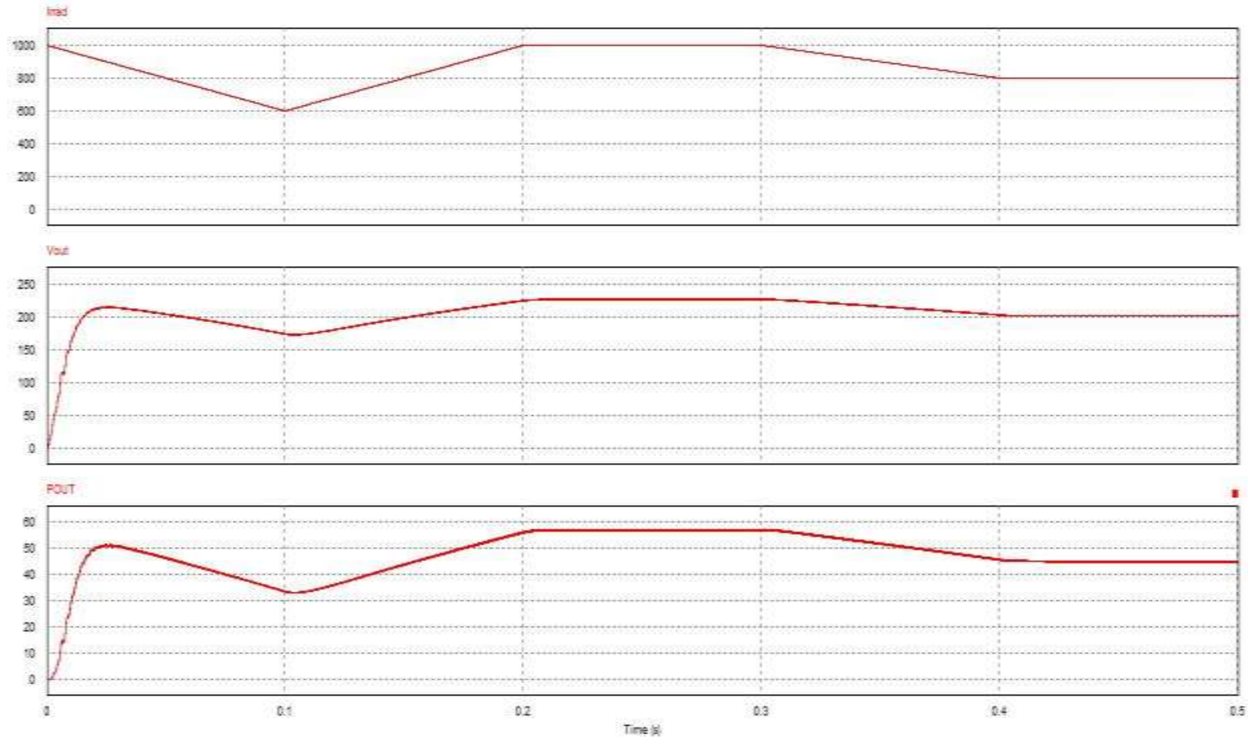


**Fig.11.**shows the waveform of output voltatge $V_{out}$ and output power $P_{out}$ for varying irradiance.

## VI. Conclusion

The design and simulation of High gain DC-DC converter with coupled inductor for photovoltaic application with resistive load is done. Satisfactory results are obtained. To operate the converter in maximum power point P&O algorithm is employed. The MPPT results for varying solar irradiation at standard temperature 25 $^{c}$ C is obtained.

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