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# A novel Interleaved Boost Converter having low Switching Losses in Photovoltaic Power-Generation System

Sayed Mokhtar Gheasaryan[1], Emad Roshandel[1], Moien Mohamadi[1]
[1]*(Department of Electrical and Computer Engineering, Isfahan University of Technology, Iran)*

***Abstract:*** *In this paper a new interleaved boost converter (IBC) for photovoltaic (PV) power-generation system is proposed. In power-generation systems efficiency and cost are vital criteria which should be taken into consideration .with the proposed converter voltage stress related to one of the switches in IBC decreased noticeably. Furthermore the switching losses is lower than conventional IBC due to softer switching. These advantages lead the photovoltaic system to higher efficiency and lower cost of converter and allow the proposed converter operate in higher switching frequencies. The idea is based on implementation of coupling capacitor in IBC like Zeta and Sepic converters. A 0.5Kw converter is designed and connected to 240W solar cell. The Maximum Power Point Tracking (MPPT) method based on Perturb and Observe (P&O) is used to track efficient power points according to solar irradiation. The Simulation results verify effectiveness of proposed converter.*

***Keywords:*** *Interleaved boost Converter, low Switching Losses, Maximum Power Point Tracking (MPPT), Perturb and Observe, Photovoltaic (PV) Power Generation, Soft-Switching.*

## I. Introduction

Recently solar energy has become Fast growing source of electrical power among renewable energies. Decreasing fossil fuel resources, increasing greenhouse gases, Environmental pollution and high cost of fossil fuels have pushed researchers and engineers toward renewable energies. PV power generation provide clean and low cost energy. PV power generation system nowadays has become favorable power source especially in remote areas where do not have access to power grid. Large amount of research have been done which show PV power generation is a suitable substitute to conventional power plant.

Efficiency of converters plays vital role in PV power generation. DC to DC converter as first stage converter connect PV array to DC link. Because of changing solar irradiation during the day and year, MPPT with accurate algorithm is implemented to DC/DC converter. Combination of MPPT and first stage converter guarantee absorption of maximum power from solar irradiation. DC/DC converter must has high efficiency operation during power conversion [1]. Inter leaved boost converter (IBC) has become favorable in PV systems because of its advantages [2]. In [1] an interleaved soft-switching for PV system has been presented which by adopting resonant soft-switching method has achieved high efficiency. In [2] implementing SiC Schottky diode and a CoolMOS switching device provide lower commutation and higher efficiency. [3] This paper proposes a zero-voltage-transition (ZVT) two-inductor boost converter using a single resonant inductor to meet higher efficiency. In order to use IBC in higher power rating for PV application [4] has presented high-gain soft-switched interleaved boost dc-dc converter. Output voltage of PV panels usually are quite low compared to grid voltage, therefore high gain DC/DC converter in grid connected PV systems are very essential, in [5] by using ZVT-interleaved boost converter with winding-coupled inductors and active-clamp circuits high voltage gain is accessible.

Reducing cost and complexity of converter is a great concern in PV systems. Proposed converter without using any extra circuits and just by applying coupling capacitor lower voltage stress of one of the switches and higher efficiency is obtained. That mean's lower cost and lesser complexity for system. In this paper a novel IBC has been proposed with lower switching losses and lower voltage stress across switches in contrast with conventional IBC. These advantages has been achieved only by using coupling capacitor and an extra diode in contrast with conventional IBC. By using MPPT algorithm presented IBC tracks optimum output voltage for PV array. MPPT method is based on Perturb and observe (P&O). P&O is most widely used algorithm in PV systems because of its simplicity and effectiveness. P&O track maximum power point under variable solar irradiation. In [6, 7] to improve performance of MPPT, adaptive and predictive P&O method has been proposed but it increase complexity of MPPT system. [8] Has presented a fuzzy based P&O method which provide better performance with faster time response, lesser overshoot and more stable operation in comparison with other methods at the expense of more complexity in control system.

Block diagram of the whole system is showed in Fig 1. The first stage converter makes system to absorb maximum power from PV array by tracking efficient output voltage of PV array. It is assumed that DC link's capacitor is big enough to provide fixed output voltage.

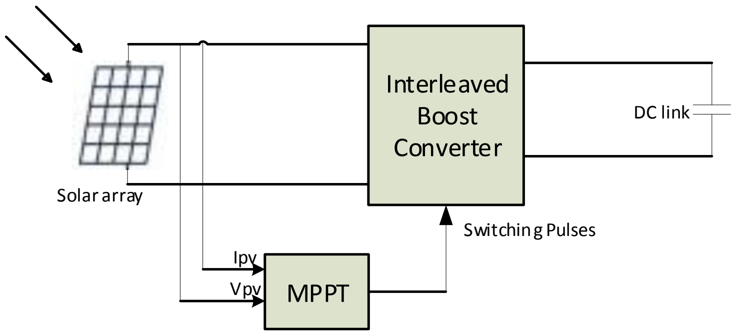



**Fig 1:** Block diagram of PV power generation system.

## II. DC/DC IBC converter

### 1. Conventional IBC

Conventional boost converter connected to PV array is shown in Fig 2 In [7] conventional IBC used as first stage converter. The interleaved boost converter consists of two single-phase boost converters connected in parallel. The two PWM signal difference is 180 degree when each switch is controlled with the interleaving method [1].

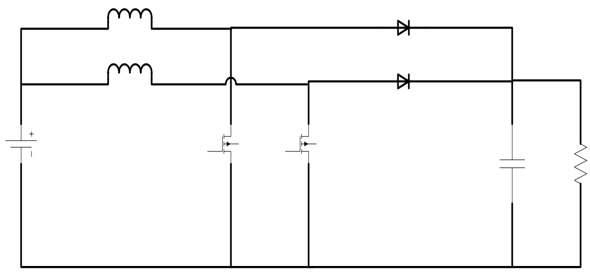


**Fig 2:** conventional IBC circuit.

Operational principle of 0.5 KW prototype IBC is presented in the following and Design guidelines are described step by step.

### 2. Proposed IBC Converter

The proposed topology like conventional IBC has two active switches a coupling capacitor is placed in series with one of the switches which decrease voltage stress across this switches. Series capacitor also provide softer switching condition for the series switch. In the following operation principle of circuit has been described. Proposed converter is shown in Fig 3.

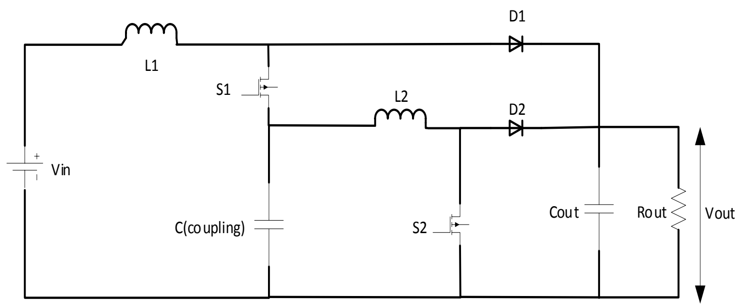
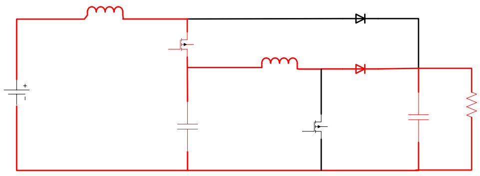
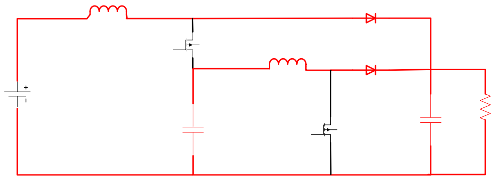


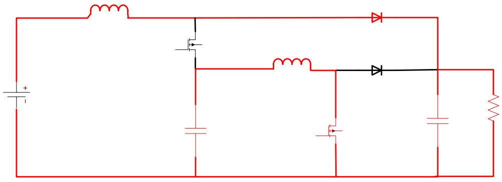

**Fig 3:** proposed IBC circuit.



(a)



(b)



(c)

**Fig 4:** Operational mods of proposed IBC. **(a)** Mode 1. **(b)** Mode 2. **(c)** Mode 3.

**Mode1:** in this mode s1 is on and L1 and Coupling capacitor are charging, the value of coupling capacitor is big enough that the voltage across it is nearly constant. On the other hand L2 supply output current through D2. Which is showed in Fig 4(a).
**Mode 2:** this mode start by turning off S1. L1 is discharging through D1. Coupling act like constant voltage source. Because of coupling capacitor voltage stress across S1 reduce noticeably and provide soft switching condition in other words S1 turned off in Zero voltage. Which is showed in Fig 4(b).
**Mode 3:** in this mode S1 is still off, D2 turned off and S2 turned on. L2 charging through D3 by coupling capacitor. Which is showed in Fig 4(c).

Approximate waves form of converter are shown in Fig 5. It is assumed that all devices and passive elements are ideal, the parasitic components of all switching devices and elements are ignored and the initial value of each operation mode is equal to zero [1].

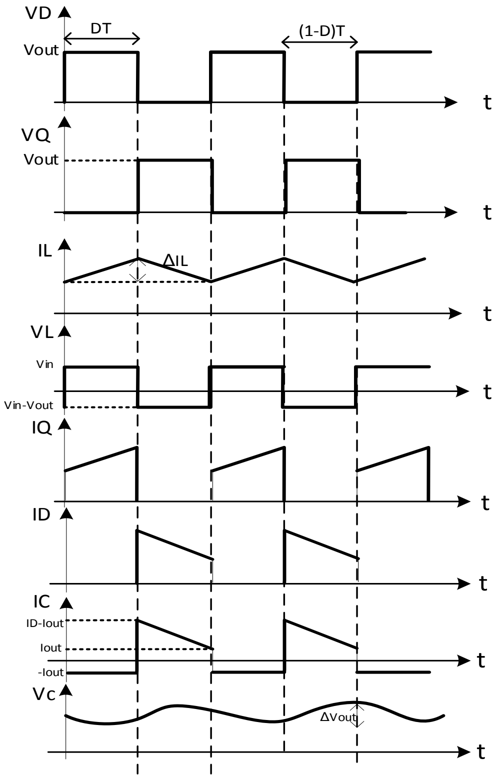



**Fig 5:** Wave form of boost converter.

As it is shown in Fig 5 that IBC operate in Continues Conduct Mode (CCM) because current of inductor never became zero. Both diode and switch has stress voltage equal to output voltage so in step up converters voltage stress across power elements is a real challenge. $\Delta I_L$ Is current ripple of inductor must satisfy (1) to ensure operation of converter in CCM mode. In (1) $I_{o(min)}$ is minimum amount of output current.

$$\Delta I_L = 2I_{o(min)} \tag{1}$$

According to Volt-Second Balance of inductor A1=A2. It is noteworthy that proposed IBC operate like two separate boost converters, thus its design equations are same as boost converter. It is assumed that inductance current change linearly according to the time, and voltage is clamped across inductance for one period which switch is turned on or off. Volt-Second Balance equation of inductor can be written as a following:

$$\int_0^T V_L\,dt = 0 \rightarrow \int_0^{DT} V_L\,dt = -\int_{DT}^{T} V_L\,dt \tag{2}$$

$$V_{in}DT = (V_{out} - V_{in})(1-D)\mathrm{T} \tag{3}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \tag{4}$$

$$V_{in} \times I_{in} = V_{out} \times I_{out} \tag{5}$$

$$(1-D)V_{out}I_{in} = V_{out}I_{out} \rightarrow \frac{I_{out}}{I_{in}} = 1-D \tag{6}$$

Which $T$ and $D$ are period of switching and duty cycle respectively. On the assumption of loss less operation input power is equal to output power. To determine inductance, V-I equation of inductor is written for turn off mode.

$$V_L = L\frac{di}{dt} \rightarrow V_{in} = L\frac{\Delta I_L}{DT} \tag{7}$$

$$L = \frac{V_{in}DT}{f\Delta I_L} \tag{8}$$

Which $L$ , $\Delta I_L$ and $f$ are inductor, current ripple of inductors and switching frequencies respectively. Maximum L occur in D=0.5.

Output capacitor must supply output current and output voltage must be low enough. Forasmuch as output voltage frequency has doubled, Frequency of capacitor is twice the input frequency. And it reduces value of capacitance. In the proposed converter output capacitor always is charging by both or one of the two inductors as act of over design that for small amount of time both D1 and D2 are turned off.

$$\Delta V_c = \frac{1}{C_{out}}\int_0^{DT} i_c\,dt = \frac{1}{C_{out}}\int_0^{DT} I_{out}\,dt = \frac{I_{out}DT}{C_{out}} \tag{9}$$

$$C = \frac{\overline{I_{out}} \times \overline{D}}{2f\Delta V_c} \tag{10}$$

Which $\overline{I_{out}}$ , $\overline{D}$ and $\Delta V_c$ are maximum output current, maximum duty cycle and ripple of output voltage. The coupling Capacitor must provide low ripple voltage and supply inductor current. By assuming that voltage of coupling capacitor is approximately constant. By assuming that both inductors have a constant current, coupling capacitor is determined as following:

$$\mathrm{C_{coupling}} = \frac{(\mathrm{I_{L1}} - \mathrm{I_{L2}})(\mathrm{DT})}{f\,\Delta \mathrm{V_C}} \tag{11}$$

## III. Control system and MPPT

Solar irradiation constantly is changing and there is numerous factors such as temperature, shadow effect and bird dropping and so on which affect generated power. So control system in a PV power generation system plays very important rule. Fast and accurate control is needed to increase efficiency of the whole system. One of the solar system applications is supplying power in remote areas. Due to this robust control system must be applied to system. In the proposed IBC there is two active switches which must be switched with 180 degree phase difference. Block diagram of control system for first stage converter is shown in Fig 6.

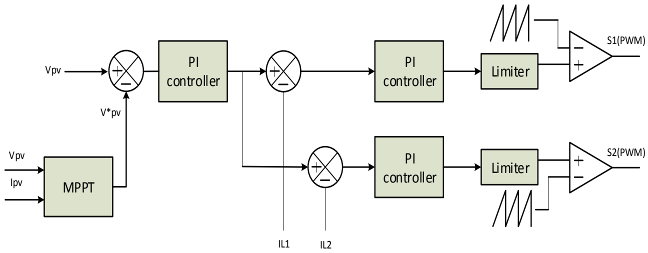



**Fig 6:** Block diagram of control system.

In order to produce 180 degree phase shift between two switches, two Sawtooth wave with 180 degree shifted phase used to generate switch pulses. PI of voltage generate reference current from voltage error. In order to limit value current PIs, saturation blocks are used. Value of PIs is determined by trial and error. MPPT box inputs are voltage and current of solar array. First by multiplying current and voltage instantaneous power (P (t)) is calculated then by subtracting P (t) from P (t-t0) rate of change of power characterized. It is not possible to determine MPP only by the sign of power changes. In each step of calculation voltage changes are computed too. According to flowchart of P&O in Fig 6 step of voltage is adjusted. This strategy called hill climbing. As it is depicted in Fig 7 MPP is tracked based on P-V curve and control system try to reach higher point, why it is called hill climbing strategy. It is noteworthy that P&O is most commonly used method in PV power generation systems [7].

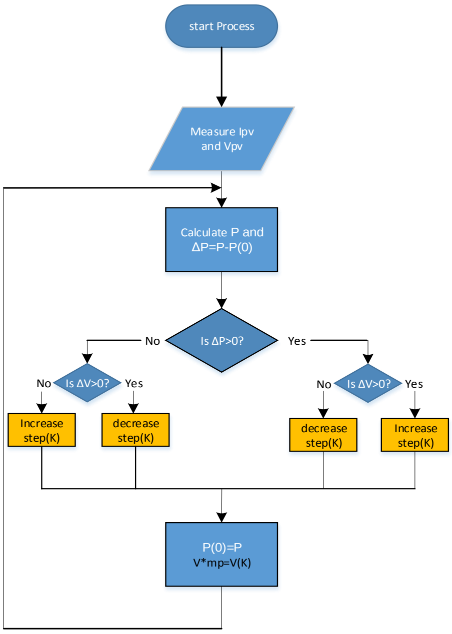



**Fig 7:** Flowchart of MPPT method.

Simple P&O method may causes system oscillation around MPP, in order to overcome this problem, variable steps can be used for voltage [6]. In this study 240W panel from [9] is used. P-V and I-V curves are shown in Fig 7 for various solar irradiation. For each irradiation MPP is given by manufacture which are achieved via practical tests.

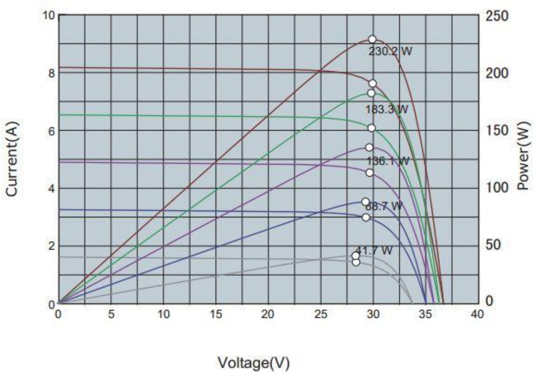



**Fig 8:** P-V curves for solar array.

## IV. Simulation and Analyze

To Operational principle of 0.5KW prototype IBC and its control system for PV power generation system has been presented. Design guidelines has been described step by step. It is assumed that solar irradiation changes from 500W/m^2 to 1000W/m^2 In order to verify theoretical results simulation outputs is shown as following. Specification table which summarize system parameters are given in Table 1 and Table 2.

**Table 1:** Converter specification

| | |
|---|---|
| Nominal Power | 0.5 KW |
| Switching Frequency | 25 KH |
| L1 | 30 µH |
| L2 | 20 µH |
| C(coupling) | 150 µF |
| Cout | 100 µF |
| ΔVout | ±2 V |
| ΔVc(coupling) | ±1 V |
| Vout(Vdc link) | 50 V |

**Table 2:** Solar cell specification [9]

| | |
|---|---|
| Peak Power | 240 W |
| Maximum Power Voltage(Vmp) | 29.96V |
| Maximum Power current(Vmp) | 8.02A |
| Open Circuit Voltage(Voc) | 37.17V |
| Short Circuit Current(Isc) | 8.58A |
| Number of cells | 60 cells in series |
| Module Efficiency | 14.75% |

In Fig 9 stress voltage across S1 is compared with S2 and it is clear that voltage stress across S1 decreased significantly. In Fig 10 soft-switching related to S1 compared with S2 is depicted. Voltage across S1 is increasing slowly in turning off interval. In Fig 11 output voltage of solar array (Vpv) and reference voltage generated by MPPT method (V*pv) is shown. As it is obvious MPPT method track MPP effectively.

In Figure 12 and 13, two transient point of Fig 11 has magnified to show the proper dynamic of system. Output power of PV panel is shown Fig 14. The solar irradiation of PV panel is shown in Fig 15.

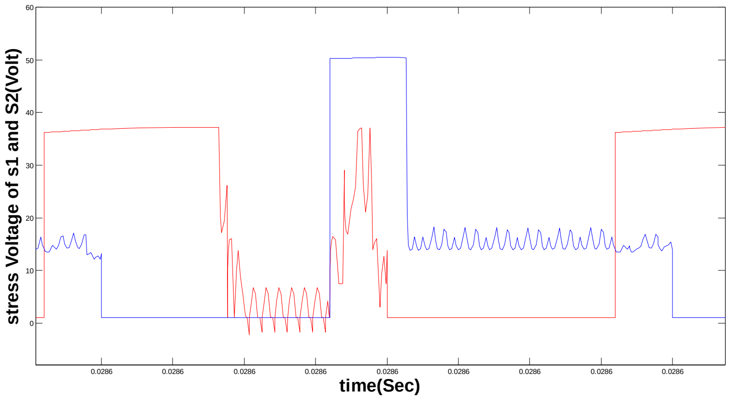
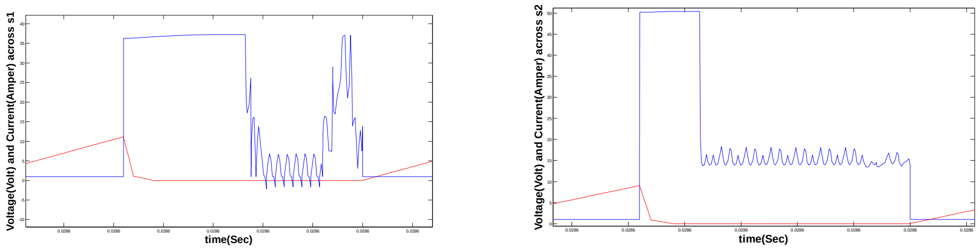



**Fig 9:** Stress voltage across S1 (in Red) S2 (in Blue)




**(a)** **(b)**

**Fig 10**: Voltage and Current of switches. **(a)** S1 (in Red). **(b)** S2 (in Blue)

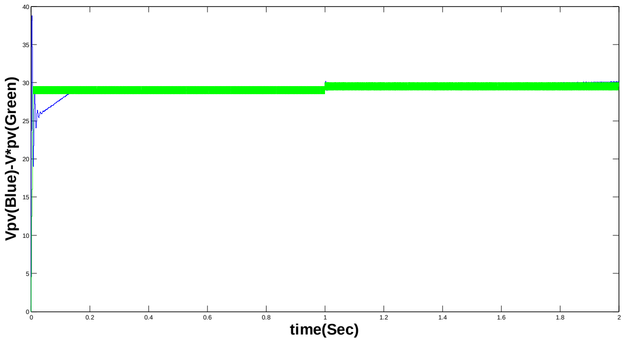



**Fig 11:** Output voltage of PV panel (in green) and voltage reference generated by MPPT (in blue).

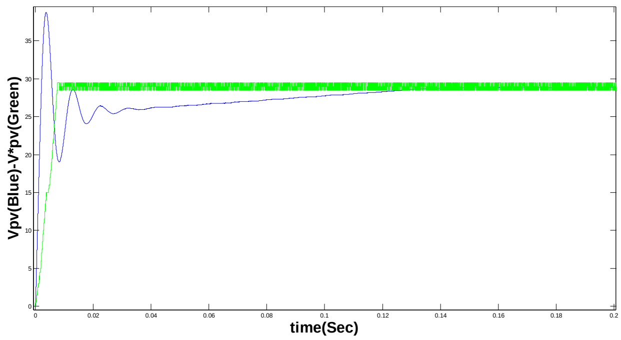



**Fig 12:** Transient operation of system in t=0. Output voltage of PV panel (in red) and voltage reference generated by MPPT (in green).

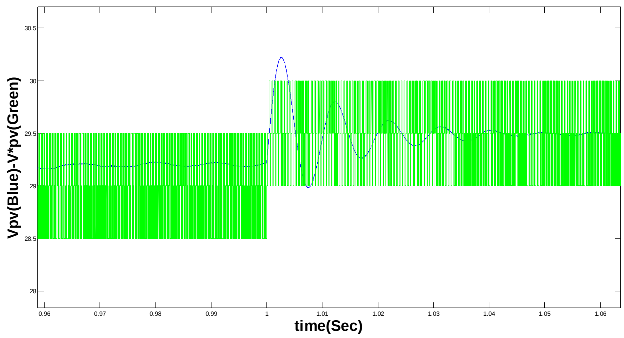



**Fig 13:** Transient operation of system in t=1. Output voltage of PV panel (in red) and voltage reference generated by MPPT (in green).

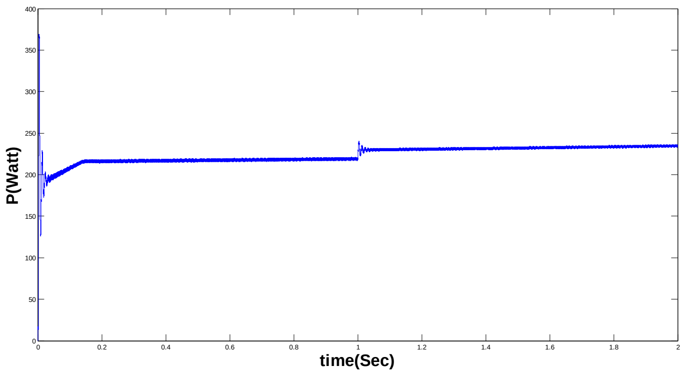



**Fig 14:** Output power of PV panel.

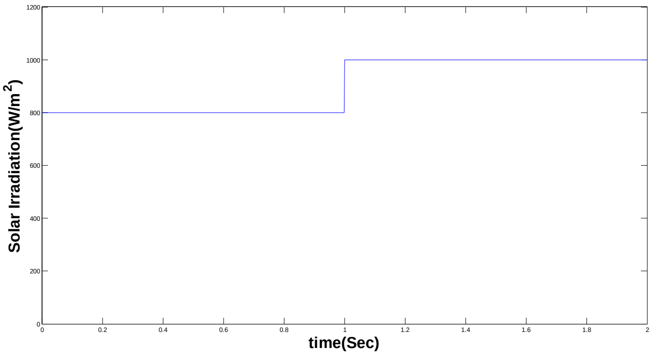



**Fig 15:** Input solar irradiation of PV panel.

## V. Conclusion

In this paper a novel interleaved boost converter for PV power generation system was proposed. In order to achieve maximum power from variable solar irradiation MPPT and PI based control system was used.

Implementation of coupling capacitor in converter provides lower voltage stress across one of the switches and soften its switching operation. It will lead converter toward higher efficiency and lower cost. Effective MPPT based on Perturb and Observe method was presented that guarantees fast response and accurate MPP tracking. To verify theoretical results a 0.5Kw converter was designed and connected to 240W panel. The simulation results show effectiveness of system in absorbing maximum power from solar irradiation.

Simulation results shows that voltage stress of one of the switches is reduced noticeably and converter has softer switching operation in comparison with conventional IBC. This is a favorable thing in PV power generation systems. By using simple and robust MPPT method, reliability of the system has increased and it can be used in remote areas which are far from power grid.

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