Chapter 35
Design and Simulation of MPPT-Operated DC-DC Flyback Converter Used for Solar Photovoltaic System

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1 Introduction

One of the major problems faced by the whole world is related to the environment like pollution, global warming, waste disposal, greenhouse gases, CO_2 emissions and many but the reason behind these problems are basic needs of humans. Causes of co_2 emission are natural as well as human sources. Natural sources like decomposition, respiration, ocean release, and the human sources are like production of cement, deforestation, burning of fossil fuels. The demand for electricity has increased the use of fossil fuel like coal, lignite, oil, gas. To fulfil the requirement of electricity, power plants are necessary. In India, almost 60% of the electricity is generated from thermal power plants which use coal as a fuel. There are some other power plants also in which gas and oil are used to burn and generate electricity but it causes Co_2 emission and resultantly, harming our environment. So it is necessary to switch to some other sources to generate electricity which can be environment friendly. The need for human to generate electricity using environment-friendly sources has brought this attention toward natural sources like sun, water, air. Electricity generation using these sources requires a technique which should be the most efficient. For bulk generation as well as for small-scale generation or domestic-level generation, solar energy is the most suitable form of energy. Being particular about solar energy, there are many techniques to extract solar energy but the demand is for the most efficient and economic technique which is the key objective of the paper. In literature, it was found that the Maximum Power Point Tracking Method is the most efficient and economic

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to harness the solar energy using PV Panel. PV modules, MPP Techniques along with net metering can be used at consumer level so that the surplus electrical energy can be fed to the AC Grid. This prototype will require DC-DC converter, DC-AC converter, etc. DC-DC conversion with solar PV power has become very noteworthy for efficient and economical energy production to exploit the maximum solar power possible at every moment, increasing profits and sustainability. The objective of this paper is "design and simulation of MPPT guided an isolated dc-DC Flyback converter used for solar PV system".

There are several methods for exploiting PV solar energy and many existing conventional techniques had incorporated the use of DC-DC converter along with DC-AC converter (inverter) for AC voltage applications. This type of converter topologies has two foremost features as reported in the literature. The first one is where the transformerless inverter is used which has several advantages like abridged size and low cost with high working efficiency. In this topology, the main drawback is that voltage boosting is not achieved as per the need of AC Voltage application or grid applications of voltage range 85−265 V AC. There is another problem of isolation between low voltage circuit (PV side) and high voltage circuit (AC side) and also the problem of grounding in the solar cell side is serious in case of transformerless topologies. The second feature is one where the transformer or coupled inductor system is used and the operating frequency is high. This feature will mitigate the problem of grounding of PV Panel and paved a way of boosting the voltage. Also, the problem of earth parasitic capacitance which will become a source of leakage current is avoided by using an isolation transformer. Since the cost of a line frequency transformer is very high and due to its large volume and weight, the high frequency (say 100 kHz) transformer is preferred [1, 2]. In line with this dissertation work, several authors have worked on Flyback converter with different aspects as follows.

Xiong et al. [3] have implemented the improved maximum or peak power point tracking in a PV system based on Flyback converter. A versatile simulation using MATLAB-based model is constructed for the output voltage behaviours or characteristics of a particular PV system varies nonlinearly with different solar insolation (G W/m^2), panel temperature.

Daniel Calheiros de Lemos [4] has presented MPPT-guided DC-DC Flyback Converter, which fed the solar energy into the grid. The converter used is situated within the family of DC-DC boost/buck power electronic converters. The algorithm presented here is based on Perturb and Observe technique, where it only controls the power generated by the panel, but the algorithm presented controls the power and the current of the panel. It has been found from the literature survey that several assumptions have been made in order to simulate and to realize the performance of DC-DC Flyback converter using different MPPT techniques in the various proposed methods. Many authors have tried to deal with the DC-DC Flyback converters interfacing a load with either Solar PV panel/module/array or rectified DC supply in order to extract the maximum power from the given source. The goal of this paper is to build the software simulation of Flyback converter, being operated by InC MPPT technique, and obtain the performance of converter with varying insolation, temperature and load impedance.

Patil and Kumar [5] have been presented the analysis of open- and closed-loop control of DC-DC Flyback converter. The main objective is to get the voltage mode control in the closed-loop model using a robust PID controller by which the working efficiency is augmented by 9%. The designed models of the open- and closed-loop DC/DC Flyback converter are verified using a MATLAB simulation.

Prabhakaran and Prasad [6] have designed and analysed an AC-DC and DC-AC isolated Flyback converter without the practice of bridge circuit. The proposed Flyback inverter is driven in continuous conduction (where inductor current is continuous) Modes with low apex current and superior efficiencies. The comparative investigation of the proposed circuit/topology with conventional circuit consists of AC-DC and DC-AC converter is addressed in the simulation of the proposed converter and also implemented using MATLAB Simulink.

2   Basics of Flyback Converter

The Flyback converter is derived from the buck–boost converter with the coupling inductor. The advantage of Flyback converter is that it can provide voltage multiplication by varying the number of turns of the coupled inductor and can provide multiple output DC/DC converters at power levels of 150 W or less. The design parameters of a Flyback converter is discussed in this chapter.

3   Working of Flyback Converter

The Flyback converter is similar to buck–boost converter in design and working. The only difference in construction is of coupling inductor. During ON state, when the MOSFET switch is Turn-ON or closed, the primary winding of the coupled inductor is connected directly to the PV module or source. The current flowing in the primary winding of coupled inductor increases and magnetic flux in the coupled inductor also increases. In this duration, energy is stored in the primary winding of the coupled inductor and the voltage which was induced in the secondary winding of the inductor is inverted. Hence, the diode is in the blocked stage or reversed-biased. During ON state, the capacitor connected at the output side delivers electrical energy to the load.

During OFF state, when the MOSFET switch is Turn-OFF, the current of primary and magnetic flux decreases. The voltage of secondary inductor is positive and the diode comes into conduction state which allows the current to flow to the load circuit. The energy from the secondary coupled inductor is supplied to the capacitor and then supplied to the load and this cycle is continued. The operation of Flyback converter can be continuous conduction mode or discontinuous mode but in this paper, the continuous conduction mode of Flyback converter is chosen so that maximum energy can be harnessed from solar PV module/array (Fig. 1).

3.1 Continuous Conduction Mode of Flyback Converter

A DC-DC converter that provides isolation between the input side and output side is shown in Fig. 2a. In Fig. 2b, it uses the transformer model which includes the magnetizing inductance Lm. To understand the operation of the circuit, a simplified transformer model is considered.

The following additional assumptions for the analysis are made:

- The output capacitor Co is very large and it is providing a constant output voltage Vo.
- The circuit is in steady-state operation which means that all the voltages and currents are cyclic in nature, i.e. they are starting and ending at the same points over one cycle/switching period.
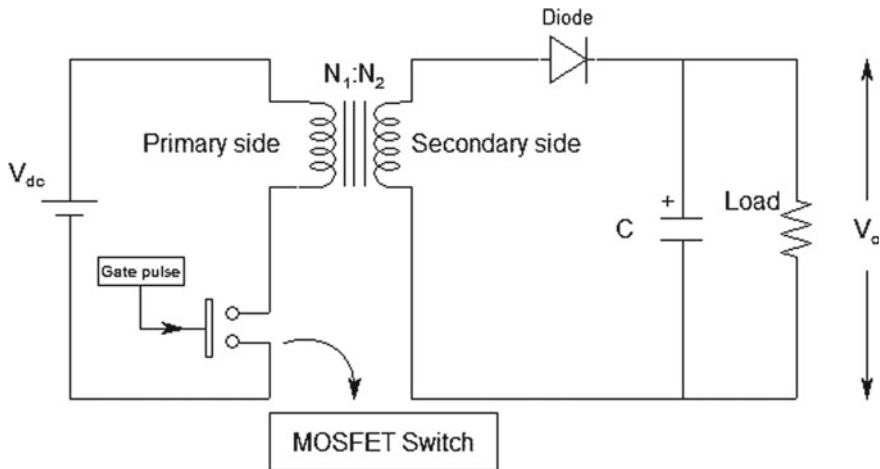

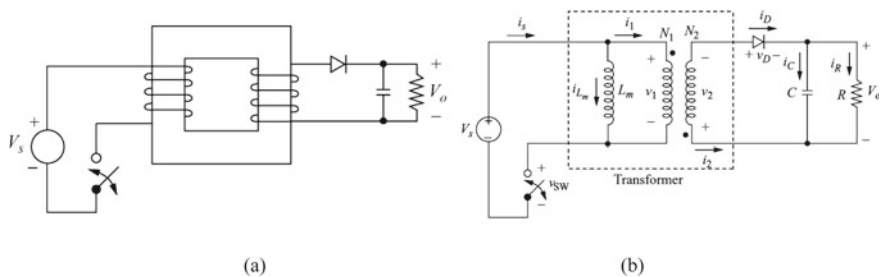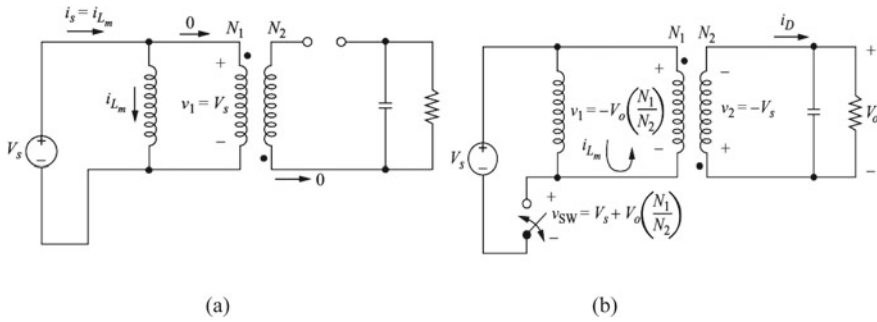**Fig. 1** Circuit diagram of a DC-DC flyback converter

Fig. 2 a Flyback converter. **b** Equivalent circuit using a transformer model that includes the magnetizing inductance

Fig. 3 Flyback Converter circuit during **a** T_{on} **b** T_{off}

- The duty cycle of the switch is D, ON-time period is of DT and OFF-time period is of (1-D)T.
- The semiconductor switch and power diode are ideal, giving a zero conduction loss. The basic operation of the Flyback converter is the same as that of the buck–boost converter.
- When the switch is closed, energy is stored in Lm. When the switch is open, it is transferred to the load. This circuit is analysed for both closed and open switch positions to determine the relationship between input and output.

Various waveforms of Flyback converter are shown in Sect. 3.13. The following relationships are required to design the Flyback converter (Fig. 3):

- Output Voltage (V_o)

$$V_o = V_{pv}\left(\frac{D}{1-D}\right)\frac{N_2}{N_1} \tag{1}$$

- Inductor Current

$$I_{L_m} = \frac{V_o}{R_L}\left(\frac{1}{1-D}\right)\frac{N_2}{N_1} \tag{2}$$

- Minimum Value of Inductance (L_m)

$$L_{m\_min} = \frac{(1-D)^2 R}{2f}\left(\frac{N_1}{N_2}\right)^2 \tag{3}$$

- Value of Output Capacitor

$$C_o = \frac{D}{R_L f . \frac{\Delta V_o}{V_o}} \tag{4}$$

4   Parameter Calculation for Flyback Converter

The following steps are required to determine the parameters of the Flyback converter:

Step 1: With no losses in the Flyback converter, the output voltage across the load resistance of 40Ω will be

$$P_{in} = P_{out} \quad \Rightarrow V_{mpp}\, I_{mpp} = \frac{V_o^2}{R_L}$$

$$50 = \frac{V_o^2}{40} \quad \Rightarrow V_o = 44.7213 \; volt$$

If the turn ratio is $N_1/N_2 = \frac{1}{2}$, then the duty of Flyback converter will be

$$V_o = V_{in}\left(\frac{D}{1-D}\right)\frac{N_2}{N_1} \quad \Rightarrow \quad 44.7213 = 17.7 \times \frac{D}{1-D} \times \frac{2}{1}$$

D = 0.5581 or 55.81%

Step 2: The average inductor current through the inductor L_m is given by

$$I_{Lm} = \frac{V_o^2}{V_{pv}\, D\, R_L} = \frac{44.7213^2}{17.7 \times 0.5581 \times 40} = 5.06155A$$

Step 3: The minimum value of inductance is

$$L_{M\_min} = \frac{(1-D)^2}{2f}R\left(\frac{N_1}{N_2}\right)^2 = \frac{(1-0.5581)^2}{2 \times 50000}40 \times \left(\frac{1}{2}\right)^2 = 19.52\, mH$$

Step 4: The output capacitance C_o is given by

$$C_o = \frac{D}{R_L\, f.\frac{\Delta V_o}{V_o}} = \frac{0.5581}{40 \times 50000 \times 0.01} = 27.05\mu F$$

5   Subsystem Configuration of Flyback Converter

Using a Flyback converter, the output voltage can be done step-up or down depending upon the duty ratio of the converter. In this thesis, the proposed Flyback converter is used as an interface between the load with a PV panel of 50 Wp. The controlling parameter of the Flyback converter for a fixed value of load resistance and operating frequency are provided to 'Pulse Generator' block to produce the pulse signal. This pulse signal is given to IGBT gate terminal for its ON/OFF operation. Figures 4
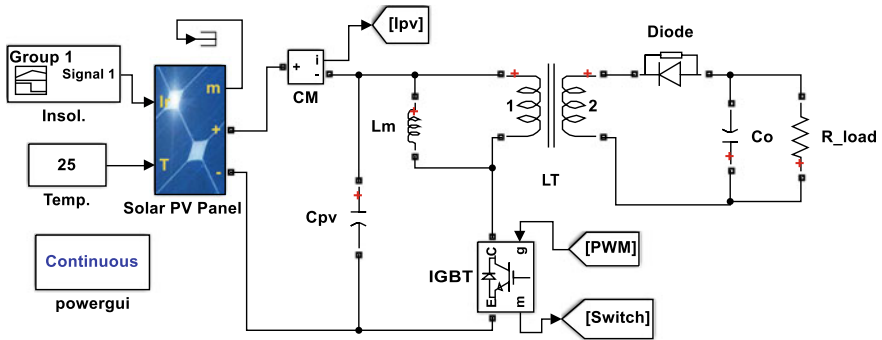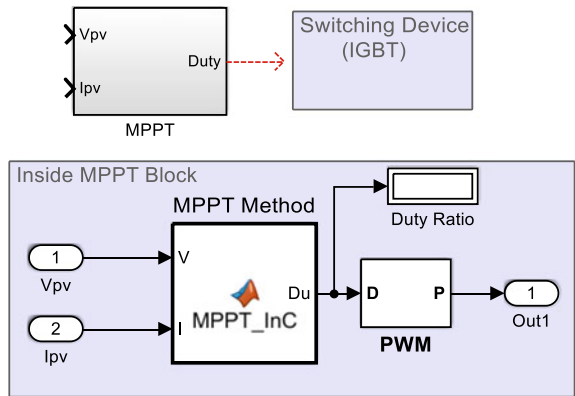
Fig. 4 Simulation circuit

Fig. 5 Maximum power point tracking block

and 5 show the simulation diagram of Flyback converter interfacing the load to SPV panel with MPP technique. The PV module is subjected to variable insolation levels (200 W/m^2 to 1000 W/m^2) and panel temperature is kept constant to observe the effect of insolation on the performance of the PV module.

6   Experimental Results

The experimental setup for the proposed Flyback DC-DC converter is simulated in MATLAB, built and tested for effectiveness under varying load impedance, panel temperature and solar insolation.

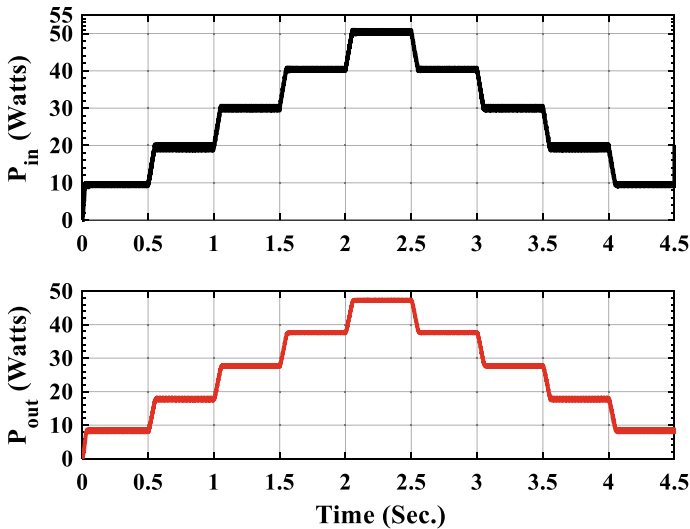## 6.1 Performance of Flyback Converter at Different Insolation Levels

The operating voltage of the PV panel and terminal current is varying with insolation levels. The panel current is increasing with insolation and decreasing with a decrease in insolation as shown in Table 1.

The input and output power of the Flyback converter with varying insolations is depicted in Fig. 6.

The efficiency of the Flyback converter with insolation is shown in Fig. 6. At standard condition (G = 1000 W/m^2 and Panel Temperature = 25 °C), the efficiency of converter is around 93%. From the efficiency curve, it can be stated that the conversion efficiency of the DC/DC Flyback converter is increasing with increasing solar insolation and temperature remains constant. But in real world, the temperature of the PV panel is also increasing with insolation and this effect is highlighted in the next session.

Table 1 Photovoltaic panel current with different insolations at constant temperature

Insolation (G)W/m^2	Current (I_{pv}) A
200	0.5527
400	1.127
600	1.687
800	2.276
1000	2.849

Fig. 6 Input and output power of Flyback converter with varying solar insolation

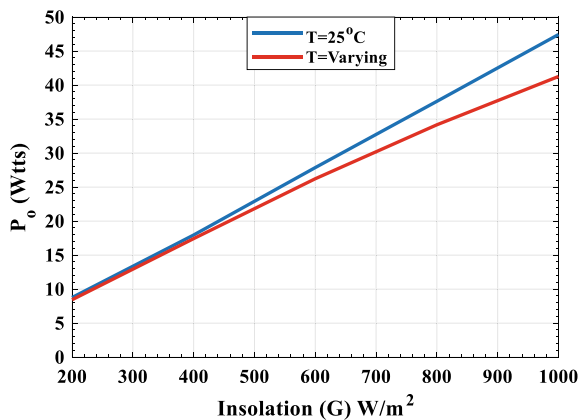## 6.2 Performance of Flyback Converter at Different Temperature Levels

When the PV panel is subjected to both different insolations and temperatures, the output power is slightly lowered compared to the previous one (when the temperature is constant) as shown in Table 2.

The compared power of Flyback converter is shown in Fig. 7. From Fig. 7, one can say that as insolation is increasing the temperature of the PV module is increasing and this will cause of alleviation of the corresponding output power of the PV module. And also, with increased insolation, the photogenerated current is increased. With increased panel current the switching losses and the conduction losses are increased.

Table 2 Output power of flyback converter with different insolation levels and different temperature levels

Insolation (G) (W/m^2)	Panel temperature (°C)	Output power (P$_o$) Watts
200	25	8.441
400	30	17.43
600	40	26.23
800	50	34.16
1000	60	41.26

Fig. 7 Output power for different temperatures and different insolations

6.3 Performance of Flyback Converter with Varying Load Conditions

The load resistance, in this paper, was varied from 20Ω to 50Ω and the output power is slightly decreasing as shown in Fig. 8.

The MPPT technique is trying to extract the maximum power from the PV module for any value of load resistance. Here, the load resistance is increasing and to match this increased load resistance with characteristics impedance of solar PV panel, the duty should be increased. If the switching device is Turn-ON for a lonng time then PV panel can't be able to feed the maximum available power to the load. The comparative analysis of the Flyback converter with varying insolation is depicted in Table 3.
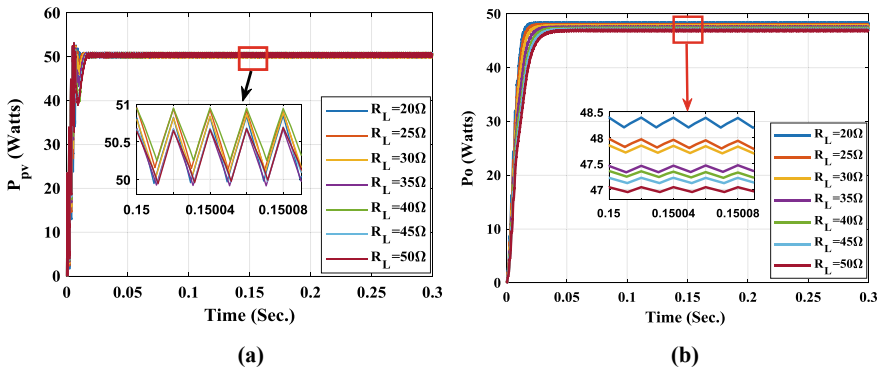

Fig. 8 **a** Input power and **b** output power of Flyback converter for varying loads

Table 3 Performance of flyback converter with variable loads at standard conditions

R_L	V_{pv}	I_{pv}	P_{pv}	V_o	I_o	P_o	η	Duty
20	17.4057	2.8527	49.5854	30.5296	1.5265	47.0289	94.84%	0.4669
25	17.4348	2.8522	49.6668	34.0519	1.3621	46.8063	94.24%	0.4933
30	17.5034	2.8443	49.7361	37.3515	1.2451	46.8081	94.11%	0.5142
35	17.4766	2.8498	49.7566	40.216	1.1490	46.5322	93.52%	0.5326
40	17.5276	2.8405	49.7322	42.8496	1.0712	46.239	92.98%	0.5473
45	17.4783	2.8483	49.7269	45.3022	1.0067	45.9609	92.43%	0.5615
50	17.5384	2.8376	49.7046	47.5855	0.9517	45.6603	91.86%	0.5726

6.4 Performance of Flyback Converter Under Dynamic Weather Conditions

The output power of the Flyback converter is also increasing by increasing the solar insolation. The output power is a combined effect of temperature and solar insolation because the photogenerated current is directly proportional to the insolation but terminal voltage falls logarithmically with an increase in panel temperature. The power of Flyback converter is obtained for different insolations at different temperatures as shown in Fig. 9.

The comparative efficiency of Flyback converter with varying insolation and temperature is depicted in Fig. 9b. The efficiency of the Flyback converter is high for lower temperature for the same insolation level. The efficiency of the Flyback converter with variable load is depicted in Fig. 10.
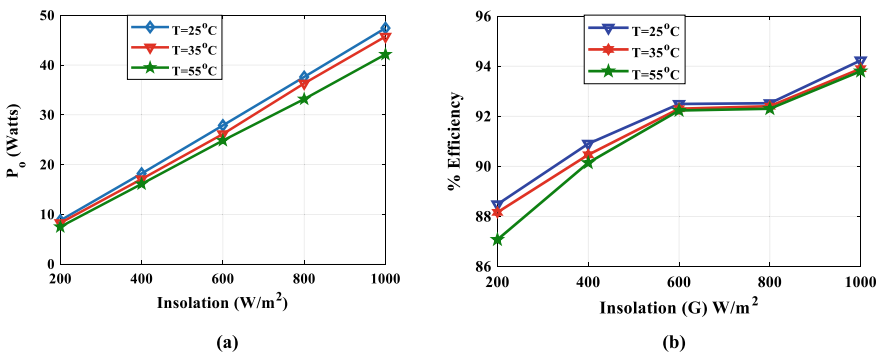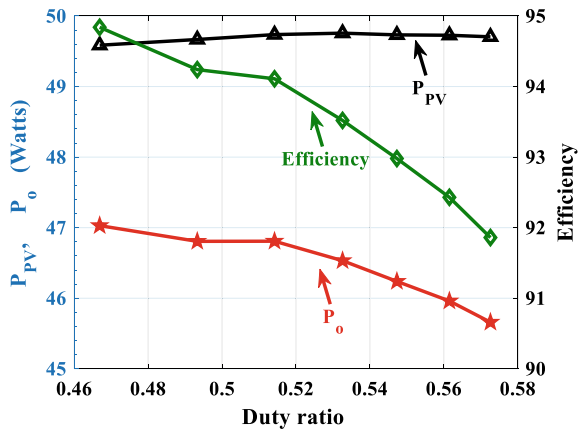

Fig. 9 a Output Power with varying insolations at constant temperature. **b** Output Power with varying insolations at varying temperatures

Fig. 10 Efficiency and power of Flyback converter versus duty ratio

7   Conclusions

The proposed Flyback DC-DC converter is realized using MATLAB for different temperature levels, insolation levels and for varying insolation levels. Following main points are the conclusion for this paper.

(1) With increasing temperature level of solar PV panel, the efficiency of the system falls down.
(2) With increasing insolation, the efficiency of DC-DC converter is increasing when the temperature remains constant but in practice it is not possible. Therefore, the efficiency of the converter will slightly fall with increasing insolation level.
(3) With increasing load impedance, the duty of converter is increased and this results in large conduction loss in switch and hence efficiency will decrease.

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