

# Reliability Comparison of MPPT Converter in DCM and CCM Operation

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**Abstract:** The reliability plays an important role in power electronic systems by which the number of system failures, repair costs, guarantee and etc. are estimated. In this paper first, a boost Maximum Power Point Tracker (MPPT) converter is simulated in Discontinuous Conduction Mode (DCM) and Continuous Conduction Mode (CCM) under different output power ratings. For these simulations, all of the inherent parameters of MOSFET and diodes are applied according to the actual types. Then, reliability calculation is done based on MIL-HDBK-217 handbook. Results have shown that the MPPT converter would have better performance from reliability point of view in CCM operating mode.

**Key words:** MPPT, solar cell, photovoltaic, reliability, life time.

## 1. Introduction

In a photovoltaic (PV) system, the PV panel represents the most percentage of the total cost of the system. The energy storage system is second expensive block and other system components such as power electronic inverters and converters contribute only a small percentage of system cost. Due to the high cost of solar cells, it is necessary to operate the PV panel at maximum power point (MPP). The maximum power produced by a solar cell changes with solar radiation and temperature as shown in Figs. 1 and 2 [1].

In order to optimize the ratio between output power and cost of installation, photovoltaic systems are supposed to draw maximum power from the modules continuously, regardless of weather conditions or load voltage. Maximum power point trackers, commonly known as MPPT, are systems that operate PV modules so that maximum power can be achieved in all radiation and temperature conditions. Fig. 3 shows a PV system includes MPPT. The DC/DC conversion

process implies in turn an associated effect of impedance transformation, i.e., the input impedance shows a dependence on a number of parameters such as load resistance, duty cycle, etc. In this sense, converters are similar to transformers. When they are used as impedance adaptors, except that in converters the adaptation parameter is not the turns ratio between the secondary and primary ones, but the duty cycle,  $D$  which can be governed electronically, a fact that corresponds to MPPT. Different topology of DC-DC converters are used as MPPT. Comparisons between different topology of converters for MPPT operation are given in Refs. [2-4]. Buck and Boost are suitable topologies [5]. Boost topology is selected in this paper for investigation. In switch mode converters the main filter inductor can operate in either continues or discontinues conduction mode. Performance comparison of CCM and DCM fly-back converters are given in Ref. [6]. Aspects being compared were component stress, output voltage regulation and transient response due to step load and efficiency.

On the other point of view, recently, reliability is one of the serious requirements of electronic systems. The

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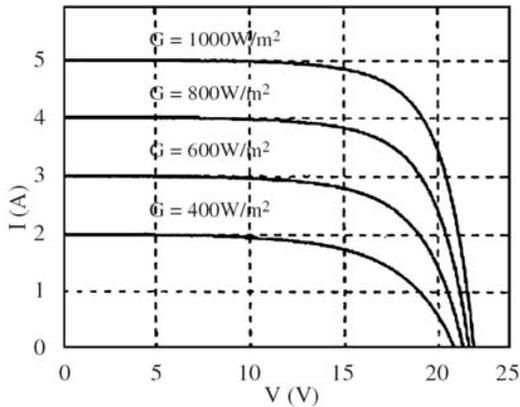


Fig. 1 Produced power in a solar cell versus solar radiation.

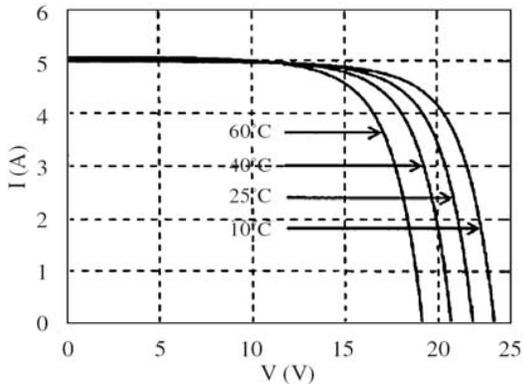


Fig. 2 Produced power in a solar cell versus temperature.

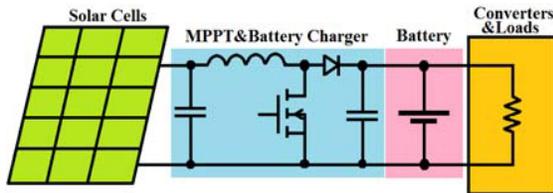


Fig. 3 A PV system including boost MPPT converter.

numbers of system failures, repair cost, guarantee, etc. are estimated by reliability calculations.

Influence of electrolytic capacitors on SMPS's reliability is given in Ref. [7]. Reliability modification of power electronic converter are discussed for full cell utilities in Ref. [8] and for photovoltaic applications in Refs. [9-12]. It is discussed also for wind turbine applications in Ref. [13]. The effect of leakage inductance on reliability of switch mode power supplies is presented in Ref. [14]. Reliability issue is discussed for pulsed power resonant conversion in Ref. [15] and for automotive power electronics in Ref. [16]. The design for reliability of

power electronics modules is given in Ref. [17] and using a single integrated power module (IPM) instead of paralleling power electronic devices from reliability point of view is given in Ref. [18]. Finally, the reliability of transformers is discussed in Ref. [19].

In this paper, a boost converter is considered as the MPPT part of a photovoltaic system. Then the simulation and reliability calculation of boost converter in DCM and CCM modes operating in three different power ratings is done. Reliability calculation is based on MIL-HDBK217 handbook and in part counting method [20].

### 2. Definition of Reliability

Probability of proper function of a system after a time interval is referred to as its reliability, which is dependent on the type and quality of the parts and materials used in the device, tension each part endures, the ambient conditions in which the device is working, etc. The failure rate in most of electronic systems is constant and is represented by  $\lambda$ ; the reliability is expressed by:

$$R(t) = e^{-\lambda t} \tag{1}$$

The mathematical mean of  $R(t)$  occurs at:

$$t = \frac{1}{\lambda} \tag{2}$$

Which is the amount of time that should elapse until the first failure occurs. This is called the mean time to failure (MTTF). The mean time to repair (MTTR) of the system is negligible compared to MTTF, so the mean time between failures (MTBF) of a system is expressed as:

$$MTBF = MTTR + MTTF = \frac{1}{\lambda} \tag{3}$$

The total rate of the system failure is the sum of the failure rates of all parts of the system:

$$\lambda_{system} = \sum_{n=1}^N \lambda_{part} \tag{4}$$

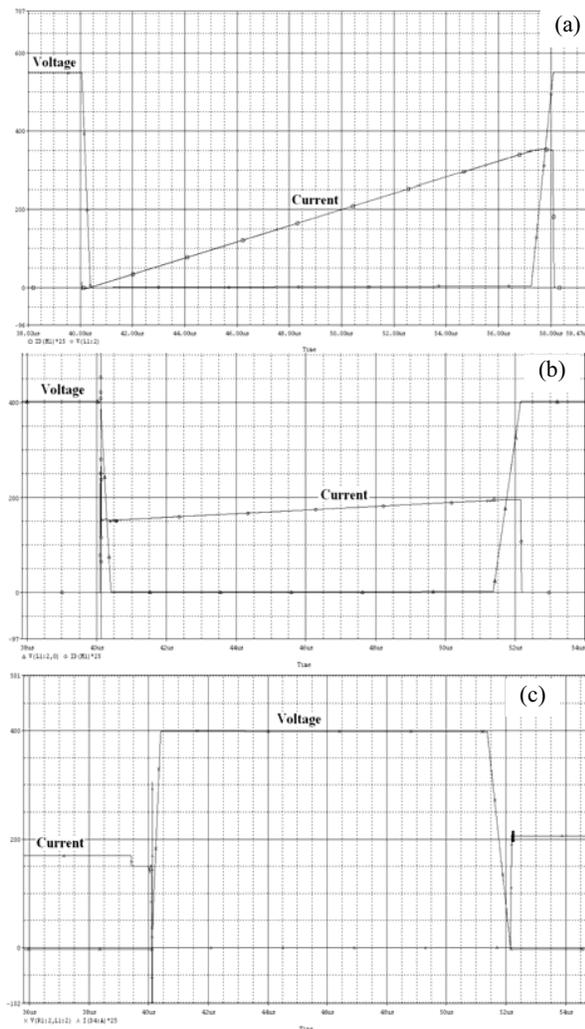
Hence, the reliability of the system will be the product of all the system components' reliabilities [6]:

$$R_{system} = \prod R_{part} \tag{5}$$



**Table 2 Simulation results for different output powers in DCM and CCM operating modes.**

Output power	300 W		600 W		1000 W	
Operating mode	CCM	DCM	CCM	DCM	CCM	DCM
$P_{dynamic}$ (MOSFET) (W)	7.5	15	15	25.5	25	45.5
$P_{dynamic}$ (MOSFET) (W)	0.486	1.26	1.94	3.75	3.9	9.5
$P_{dynamic}$ (MOSFET) (W)	0.75	0.75	1.25	1.25	2.35	1.8
$P_{dynamic}$ (MOSFET) (W)	3	3.25	6	6.25	10	10.5
$P_{dynamic}$ (MOSFET) (W)	3.26	4.1	6	7.25	8.4	12.6
$P_{dynamic}$ (MOSFET) (W)	93.2	90.6	93.8	92	94.1	91.5



**Fig. 4 Voltage and current overlap waveforms of: (a) MOSFET in 1000 W output power and CCM operating mode; (b) MOSFET in 1000 W output power and DCM operating mode; (c) Output diode in 1000 W output power and CCM operating mode.**

**Table 3 Results of reliability calculations for different output powers in CCM/DCM operating modes.**

Output power	300 W		600 W		1000 W	
Operating mode	CCM	DCM	CCM	DCM	CCM	DCM
$\lambda_p$ (MOSFET) (failure/ $10^6$ hours)	7.04	11.24	9.08	14.18	8.48	14.32
$\lambda_p$ (output diode) (failure/ $10^6$ hours)	0.26	0.26	0.3	0.3	0.35	0.35
$\lambda_p$ (input bridge) (failure/ $10^6$ hours)	0.25	0.27	0.29	0.29	0.29	0.35
$\lambda_p$ (output capacitor) (failure/ $10^6$ hours)	2.52	2.96	2.88	2.97	3.08	3.25
$\lambda_p$ (input inductor) (failure/ $10^6$ hours)	0.37	0.37	0.38	0.38	0.39	0.39
MTBF (hours)	95785	66225	77399	55187	79428	53590

$$P = V_{avg} \times I_{avg} \times t_{ol} \times f_s \tag{6}$$

Where  $V_{avg}$  and  $I_{avg}$  are the average voltage across the switch and the average current follows through the switch during turn-on/turn-off overlap times respectively.  $t_{ol}$  is the turn-on/turn off overlap duration and  $f_s$  is the switching frequency of the circuit. Using Eq. (6) and considering Fig. 4, the peak of turn-on/turn-off losses of MOSFET during overlap time is calculated for 1000 W output power in DCM and CCM operating modes as below:

In CCM operating mode:

$$P_{loss(Turn-off)} = \frac{400}{2} \times \frac{190}{25} \times \frac{794}{40000} = 30.17 W$$

$$P_{loss(Turn-on)} = \frac{400}{2} \times \frac{150}{25} \times \frac{311}{40000} = 9.33 W$$

In DCM operating mode:

$$P_{loss(Turn-off)} = \frac{400}{2} \times \frac{350}{25} \times \frac{780}{40000} = 54.6 W$$

The values calculated above for the turn-on/turn-off losses are the peak of these losses (at 5 msec) that should be integrated in duration of the input voltage frequency (50 Hz). This integration is done by the ORCAD software and the average dynamic losses during one cycle of input voltage (50 Hz) are brought in Table 2.

Now, the failure rate of each part can be calculated as below:

- Calculation of failure rate ( $\lambda_p$ ) for MOSFET

(APT8043BFL):

$$V_n = 80V, \theta_{jc} = 0.31^\circ C/w, P_{loss} = 28.9W$$

$$T_c = T_a + \theta_{ca} \times P_{loss} = 27 + 1 \times 28.9 = 55.9^\circ C$$

$$T_j = T_c + \theta_{jc} \times P_{loss} = 55.9 + 0.31 \times 28.9 = 64.86^\circ C$$

$$\pi_T = \exp\left(-1925 \times \left(\frac{1}{T_j + 273} - \frac{1}{298}\right)\right) = 2.14$$

$$\lambda_b = 0.012, \pi_E = 6, P_{out} = 310W \Rightarrow \pi_A = 10,$$

$$\pi_Q = 5.5$$

$$\lambda_p = \lambda_b \times \pi_Q \times \pi_A \times \pi_E \times \pi_T$$

$$= 0.012 \times 5.5 \times 10 \times 6 \times 2.14 = 8.48 \quad (\text{failure}/10^6 h)$$

- Calculation of failure rate for output diode (DSIE12):

$$V_n = 1200V, \theta_{jc} = 1.6^\circ C/w, P_{loss} = 12.4W$$

$$T_c = T_a + \theta_{ca} \times P_{loss} = 27 + 1 \times 12.4 = 39.4^\circ C$$

$$T_j = T_c + \theta_{jc} \times P_{loss} = 39.4 + 1.6 \times 12.4 = 59.25^\circ C$$

$$\pi_T = \exp\left(-1925 \times \left(\frac{1}{T_j + 273} - \frac{1}{293}\right)\right) = 2.17$$

$$\lambda_b = 0.069, \pi_E = 6, \pi_Q = 5.5, \pi_C = 1$$

$$V_S = \frac{400}{1200} = 0.33 \Rightarrow \pi_S = V_S^{2.43} = 0.07$$

$$\lambda_p = \lambda_b \times \pi_E \times \pi_Q \times \pi_C \times \pi_S \times \pi_T$$

$$= 0.069 \times 6 \times 5.5 \times 1 \times 0.07 \times 2.17 = 0.35 (\text{failure}/10^6 h)$$

- Calculation of failure rate for input bridge:

$$V_n = 1200V, \theta_{jc} = 1.6^\circ C/w, P_{loss} = 8.4W$$

$$T_c = T_a + \theta_{ca} \times P_{loss} = 27 + 1 \times 8.4 = 35.4^\circ C$$

$$T_j = T_c + \theta_{jc} \times P_{loss} = 35.4 + 1.6 \times 8.4 = 48.84^\circ C$$

$$\pi_T = \exp\left(-1925 \times \left(\frac{1}{T_j + 273} - \frac{1}{293}\right)\right) = 1.8$$

$$\lambda_b = 0.069, \pi_E = 6, \pi_Q = 5.5, \pi_C = 1$$

$$V_S = \frac{400}{1200} = 0.33 \Rightarrow \pi_S = V_S^{2.43} = 0.07$$

$$\lambda_p = \lambda_b \times \pi_E \times \pi_Q \times \pi_C \times \pi_S \times \pi_T$$

$$= 0.069 \times 6 \times 5.5 \times 1 \times 0.07 \times 1.8 = 0.29 (\text{failure}/10^6 h)$$

- Calculation of failure rate for inductor:

$$T_{HS} = T_a + 1.1 \times \Delta T = 27 + 1.1 \times 1.5 = 28.65^\circ C$$

$$\lambda_b = 0.0016 \times \exp\left(\frac{T_{HS} + 273}{329}\right)^{15.6} = 2.2 \times 10^{-3}$$

$$\pi_Q = 30, \pi_E = 6$$

$$\lambda_p = \lambda_b \times \pi_E \times \pi_Q = 2.2 \times 10^{-3} \times 6 \times 30 = 0.39 (\text{failure}/10^6 h)$$

- Calculation of failure rate ( $\lambda_p$ ) for capacitor:

$$\pi_{cv} = 0.34 \times C^{0.18} = 0.34 \times (680)^{0.18} = 1.1$$

$$S = \frac{400}{450} = 0.89, T_A = 27^\circ C$$

$$\lambda_b = 0.00254 \left[ \left( \frac{S}{0.5} \right)^3 + 1 \right] \exp \left[ 5.09 \times \left( \frac{T_A + 273}{358} \right)^5 \right]$$

$$\lambda_b = 0.14, \pi_Q = 10, \pi_E = 2, \pi_{cr} = 1.1$$

$$\lambda_p = \lambda_b \times \pi_Q \times \pi_E \times \pi_{cr}$$

$$= 0.14 \times 10 \times 2 \times 1.1 = 3.08 \quad (\text{failure}/10^6 h)$$

Failure rate of control circuit is calculated in Ref. [4] and is:

$$\lambda_{P(\text{control circuit})} = 0.8858 \quad (\text{failure}/10^6 h)$$

## 5. Discussion of Results

Considering Table 3, the following points can be concluded:

-The boost converter has higher reliability in CCM operating mode than in DCM operating mode.

-According to results, it can be seen that in all of output power ratings and both of DCM/CCM operating modes, switches has the highest failure rate in the converter structure. So, enough attention must be paid to them.

-Switches have higher failure rate in DCM mode than CCM modes. Since, in DCM mode, the peak and rms values of current is higher that results in higher current stress on switches in this mode. So, failure rate is higher in DCM mode.

## 6. Conclusion

In this paper, a boost MPPT converter is simulated under three output power ratings and CCM/DCM operating modes. Then, reliability calculation of the converter is done based on MIL-HDBK-217 and in part counting method. Results have shown that switches have the highest failure rate in the converter structure in both CCM/DCM operating modes and different output powers. Since the peak and rms values of current is higher in DCM mode, then the switch sustains higher current stress in DCM mode, resulting in higher failure rate in this operating mode. So, the converter has better performance in CCM operating mode.

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