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Reliability Assessment and Thermal Consideration of a Step-down DC/DC Converter

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ABSTRACT

Reliability consideration is always important among the manufacturers of power modules and converters. Before using of power electronic converters into the related application, it is necessary to predict its reliability over time. In the meanwhile, the power loss and heat generated within the power semiconductors play a key role in the lifespan of the whole system. In this paper, a method for assessing the reliability of a step-down DC-DC converter is employed based on the thermal modeling of power semiconductors. As is evident from the used reliability approach, the junction temperature of power semiconductors – diodes and insulated-gate bipolar transistors (IGBTs) – is the most influential factor on the lifetime of power converters. Therefore, the simultaneous influence of switching frequency and duty cycle is analyzed at the same time as a factor for evaluating reliability. A cut-off of 150°C is considered for the maximum allowable junction temperature for the examined IGBT power module. The results show that a failure can be expected after 46,000 hours of operation of the considered power converter. Additionally, 3D curves are presented to illustrate the influence of duty cycle and switching frequency on the reliability of circuit's components and the overall system. The obtained results confirmed that an increase in switching frequency from 1 kHz to 10 kHz can decrease the circuit's lifetime almost 22%.

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I. INTRODUCTION

In recent years, the use of renewable energy has become more popular because of the negative impacts of fossil fuels and the environmental pollution they cause. Nowadays, various methods and topologies for extracting energy from different renewable sources are being introduced. Solar energy, which can be harnessed using photovoltaic panels, is one of the alternative sources of energy and offers many advantages (such as less negative environmental effects and affordability) in comparison with other sources. As renewable energy sources continue to be used more often, more attention is now being paid to power electronics. A type of converter frequently used for photovoltaic panels in power electronics, as well as in several wind turbine energy conversion systems, is the dc–dc converter. In the last few decades, there have been many dc-dc converter topologies introduced, which have been generally classified based on the ratio of voltage output to input (also known as gain) into three fundamental groups: buck (step-down), boost (step-up), and buck-boost. This paper focuses on the buck converter type, often used in small or low power systems as a simple, remarkably efficient way to reduce the input voltage to a regulated dc voltage [1].

More efficient use of any device has always been a goal of manufacturers. In power electronics, the proper functioning of converters encompasses high output quality, a long lifespan, and less energy consumption. Due to the increase of power electronic converters in different devices, an especially important factor for optimizing converters is power quality, which can be described in terms of its thermal characteristics. Indeed, previous researches have clarified the relationship of

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converter performance and quality in terms of heat loss [2–4]. Furthermore, Usui and Ishiko presented a simple approach for the thermal design of an insulated-gate bipolar transistor (IGBT) module practised only in steady state operation [5].

In recent decades, different approaches for thermal analysis have also been introduced, including the highly accurate method of computational fluid dynamics (CFD), based on how airflow conditions determine heat transfer coefficients [6].

Converter lifespan is another significant factor with a direct relationship to reliability, which represents the probability of failure in a system at a specific time [7]. The reliability of a system depends on various parameters; for this reason, identifying the indicators and calculation of the reliability parameters of the system's parts is required. Usually, two parameters are used to assess the reliability of the system. The first parameter is failure rate explained by failure distribution, and the next parameter is mean time to failure (MTTF) which presents the average operation time before the first failure of a component [8].

In the literature, there are different studies related to the reliability assessment of various circuits and power converters. These circuits include multilevel inverters [9,10], DC-DC converters [11], and AC-AC converters [12]. Khosroshahi et al. [13] evaluated the reliability of two conventional and interleaved DC-DC boost converters based on the MIL-HDBK-217 procedure. They found that the interleaved boost converter performs better in terms of reliability in comparison to the conventional boost converter. Perhaps, the most crucial weakness of this article is using approximate relations for calculating power dissipation in the switch and diode, which are based on their internal resistances.

Rashidi-Rad et al. [14] performed a reliability analysis of modular multilevel converters (MMCs) in the presence of half and full-bridge cells. Their study results illustrated that the modular converters that used half-bridge cells have more reliable performance than other states.

Arifujjaman and Chang [12] compared the reliability of three ac-ac converters namely intermediate boost converter (IBC), intermediate buck-boost converter (IBBC), and back-to-back converter (BBC) with the well-known matrix converter. They concluded that the intermediate boost converter exhibits more reliable than other ones.

In [15], the reliability of a buck converter was assessed in the presence of N-channel and P-channel MOSFET drivers. That study showed that the considered buck converter has longer lifetime when an N-channel MOSFET is used as switch. However, some portions of the power losses in switch and diode have been neglected; thus, the obtained results may not be accurate enough.

Ranjbar et al. has assessed the reliability of several single/two-stage power factor correction converters (PFCs) [16]. The reliability estimation procedure in that analysis was the MIL-HDBK-217. The outcomes demonstrated that the lifespan of a single-stage converter is about 1.6 times longer than the two-stage converter. In that study, for simplicity of calculations, the case temperature was intended to be a fix value of 35°C. This will lead to an inaccuracy in the results.

A genetic algorithm approach is used to design a boost dc-dc converter based on the both reliability and efficiency constraints [17]. The major objective of this study was to show the effects of capacitor, inductor, diode, power switch, and switching frequency on the reliability of power converters. These indicators are represented as a fitness function; then, the genetic algorithm is responsible to minimize this function to find the optimal condition.

In [18], reliability of two neutral point clamped (NPC) multilevel inverters was assessed. This reliability analysis was performed based on the different voltage levels (three and five). The failure rate value for the three-level inverter is almost a third of the five-level one, and the results showed that a much longer lifespan would be expected for the 3-level NPC inverter.

Another study [19] presented a reliability model for a complex grid-connected photovoltaic energy system; then, they made a sensitivity analysis on the obtained model. Among all the electrical components used within the PV system, the battery charge controller is the most failure-prone component. The reliability assessment was based on the MIL-HDBK-217 standard. In the next stage, a performed Pareto analysis for the electronic components showed that the MOSFET has the highest failure rate, while the inductor has minimum contribution towards system failure.

Juarez et al. [20] estimated the lifetime of a flyback converter for automotive applications based on the MIL-HDBK-217F procedure. This study also confirmed that the MOSFET and diode (semiconductor devices) have the highest failures rates; and they found that reducing switching losses can be a significant factor in increasing the reliability. There are also other studies showing the fact that power semiconductors (IGBT, MOSFET, and diode) are the least reliable components used in the power electronic converters [21,22].

The main purpose of this paper is to estimate the reliability of a buck converter based on the MIL-HDBK-217 standard. To investigate the reliability of semiconductor devices, there is a need for determining the junction temperature in these types of components. In this study, the selected approach is based on information from the manufacturer provided in datasheet. A one-cell Cauer thermal model was utilized in order to demonstrate a precise relationship between the power losses and the junction temperatures in the presence of a heatsink. This approach has an acceptable result as well as suitable speed in calculations. Additionally, this is the first time that the simultaneous impact of switching frequency and

duty cycle on the junction temperature and reliability has been analyzed.

The rest of this paper is structured as follows: Section II describes the buck converter as the case study. The reliability principals employed for the analysis are discussed in Section III. In Section IV, the accurate thermal analysis for the buck converter is discussed. In Section V, the obtained results and reliability evaluation are presented. Finally, conclusions are drawn in Section VI.

II. The Buck Converter

The buck converter circuit shown in Fig. 1 is a highly efficient step-down dc-dc converter which is commonly used in switched-mode power supply circuits (SMPS). Generally, the dc input voltage of the buck converter is derived from the output of a rectifier through a dc-link. In this paper, an IGBT is used as a switch for the converter. Considering the fact that the voltage drop across diode and transistor is dependent on both operating temperature and collector current, this voltage can be accurately determined by the diagrams provided by the manufacturer and there is no need to directly measure this voltage. Thus, the thermal analysis has been performed by identifying this voltage indirectly. The semiconductor's electrical parameters that depend on their operating temperature are known as temperature-dependent parameters (TSPs) [23].

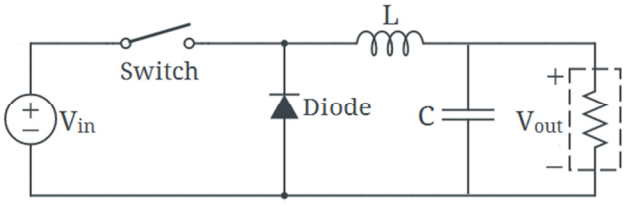


Fig. 1. Topology of a buck DC-DC converter.

When the buck converter operates in continuous conduction mode (CCM), its current will never fall to zero during the cycle. Assuming the steady state operation for this converter, it can concluded that the energy stored in each of circuit components at the end of a cycle is equal to energy stored at the beginning of the cycle. Therefore, the input and output voltages in the buck converter have a direct relationship with the duty cycle of the pulses, which can be shown as follows:

$$V_{out} = DV_{in} \quad (1)$$

where V_{out}, V_{in}, and D are the output voltage, the input voltage, and the converter duty cycle, respectively. With regard to the value of $0<D<1$, as a consequence, the output voltage is always lower than the input voltage. The basic characteristics of the converter are summarized in Table I.

TABLE I
Rated Parameters for The Desired Buck Converter

Characteristic	Value
Rated output active power P_o	12 kW
Input voltage V_{in}	300 V DC
Output voltage V_{out}	125 V DC ± 1.2%
Switching frequency f_s	10 kHz
Inductor L	3 mH
Capacitor C	1 µF

A buck converter with parameters based on Table I is simulated in MATLAB/Simulink. An open-loop controller is also used for the simulation. Furthermore, a value of 42% is considered as the duty cycle in this study. The results of the simulation are shown in Fig. 2.

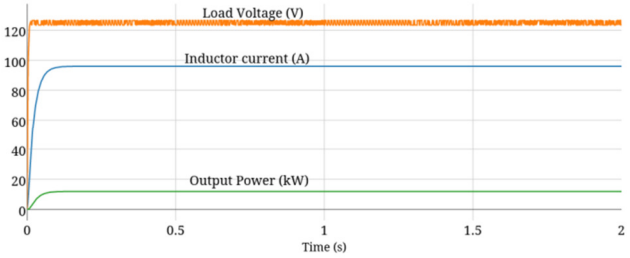


Fig. 2. The simulation results of basic characteristics of the converter.

III. The Reliability Principle

Reliability means the ability of an item to perform a specific function under given conditions over a specific time period, which is expressed as a probability or failure frequency [24]. The importance of reliability in space and in the arms industry is more prominent than that of other industries because in these significant instruments, detecting or replacing a failed part is very difficult. Different methods have been introduced to improve the reliability of a system. One of these methods involves adding redundancy to parts of the converters, thereby increasing the global reliability of a system. Reliability is improved by adding more parts for redundancy, but cost is a deterrent to increasing the number of redundancy circuits [25].

One of the factors influencing reliability is failure rate. Failure rate can be expressed as the probability of failure per unit time occurring in the interval $[t,t+\Delta t]$, and there is no failure before time t. Usually, Δt is a very small value, and is close to zero [26].

If a failure rate is presented with λ, the probability distribution function for failure can be expressed as a relationship in terms of failure rate, and can be obtained using the exponential distribution. Equ. (2) presents the distribution function:

$$f(t,\lambda) = \lambda e^{-\lambda t} \quad (2)$$

Also, the reliability function can be expressed as follows [8]:

$$R(t,\lambda) = e^{-\lambda t} \tag{3}$$

where in the above equations, λ is the component's failure rate. Another influential factor of reliability is mean time to failure (MTTF). The MTTF is the average length of time before the first failure of a component or device occurs after it starts to work, after which the device is no longer able to continue with its normal operation. The MTTF is expressed by the integral of reliability as follows:

$$MTTF = \int_0^{+\infty} R(t)dt \tag{4}$$

A simple equation for the expression of MTTF is derived by substituting Equ. (3) with Equ. (4):

$$MTTF = \frac{1}{\lambda} \tag{5}$$

In the last decades, various procedures have been introduced to estimate the reliability of different organizations. Some of the most popular procedures – such as RAC's PRISM [27], Telcordia SR-332 [28], SAE's PREL [29], CNET's reliability prediction method [30], Siemens SN29500 standard [31] and British Telecom's HRD-4 [32] – are described and discussed according to the organization's strategies. A comprehensive comparison has been made among these procedures in a prior study [33]. Today, the MIL-HDBK-217F handbook is used as a suitable reference for estimating reliability particularly in military applications. This paper also employed a calculation method based on the MIL-HDBK-217F procedure [34].

Two methods are discussed in the handbook: parts stress and parts count. In the parts count method, less information is required, such as number of parts, quality level and environmental conditions [35].

According to the series structure of the buck converter, the failure rate can be calculated using the summation of all failure rates of the circuit components, as shown in Equ. (6) [36]:

$$\lambda_{System} = \sum \lambda_{Components} \tag{6}$$

where $\lambda_{Components}$ is the failure rate of each circuit component.

By increasing complexity of the studied system, the overall system should be divided into subsystems so that the reliability evaluation becomes simpler and more concise [36].

A. *The Reliability of Components*

The buck converter consists of various components, including switch, diode, inductor and controller. In related studies on the reliability of electronic components (switches, diodes, capacitors and inductors), specific relationships for determining the failure rate for each component are expressed as follows [25,34,35]:

$$\lambda_p(Capacitor) = \lambda_b \pi_{CV} \pi_Q \pi_E \tag{7}$$

$$\lambda_p(Inductor - Transformer) = \lambda_b \pi_C \pi_Q \pi_E \tag{8}$$

$$\lambda_p(Switch) = \lambda_b \pi_T \pi_A \pi_Q \pi_E \tag{9}$$

$$\lambda_p(Diode) = \lambda_b \pi_T \pi_C \pi_S \pi_Q \pi_E \tag{10}$$

In Equs. (7)–(10), λ_b is the base failure rate, which is different and constant for each component. The base failure rates for the switch and the diode are 0.012 and 0.064 *failure/10^{6}h*, respectively. Additionally, π_i is a factor related to each component, and should be determined accurately.

The inductor base failure rate can be expressed as follows:

$$\lambda_b = 0.000335 \times \exp\left(\frac{T_{HS} + 273}{329}\right)^{15.6} \tag{11}$$

where T_{HS} is the hot-spot temperature in degree Celsius, which can be determined using Equ. (12):

$$T_{HS} = T_A + 1.1 \times \Delta T \tag{12}$$

In Equ. (12), T_A expresses the device ambient operating temperature in degree Celsius. Also, ΔT is the average temperature rise above the ambient [34,35]. The inductor failure rate is much lower than other circuit components, so it can be even omitted from the reliability analysis.

The capacitor failure rate can be described by the following equation:

$$\lambda_b = 0.00254\left[\left(\frac{S}{0.5}\right)^3 + 1\right] \times \exp\left(5.09 \times \left(\frac{T_A + 273}{378}\right)^5\right) \tag{13}$$

where S is the ratio of operating voltage to nominal voltage.

The factors π_Q and π_E represent quality and environmental, respectively. The quality and environmental factor values can be assumed to be equal to one, although the effects of these two factors are eliminated [25]. The controller failure rate can be considered to be a constant value of 0.88 *failure/10^{6}h* [35]. Another factor is the application factor, π_A, and is based on different rated powers. The parameter π_T is the temperature factor that, for the switch and diode, can be expressed as follows [35]:

$$\pi_{T(S)} = \exp\left(-1925 \times \left(\frac{1}{T_j + 273} - \frac{1}{298}\right)\right) \tag{14}$$

$$\pi_{T(D)} = \exp\left(-1925 \times \left(\frac{1}{T_j + 273} - \frac{1}{293}\right)\right) \tag{15}$$

where T_j is the junction temperature.

One of the major concerns regarding reliable power electronics is the operating temperature. Thus, it seems that the precise determination of the junction temperature results in a more accurate assessment of the reliability. There are five different approaches introduced by Reliability Analysis

Center (RAC) to predict the junction temperature for semiconductor devices. In this study, Method IV was used. This method is utilized when a heatsink is mounted on the device, and the exact value of the case temperature is also available [37].

According to the used approach, the junction temperature can be calculated from Equ. (16):

$$T_j = T_C + \theta_{jc} \times P_{loss} \quad (16)$$

In Equ. (16), T_C is the case temperature, θ_{jc} is the thermal resistance of the diode or switch, and P_{loss} is the total power losses of switch or diode.

In fact, Equ. (16) can be exhibited by a scheme of the one-cell Cauer thermal network. Fig. 3 shows this power losses to thermal translation.

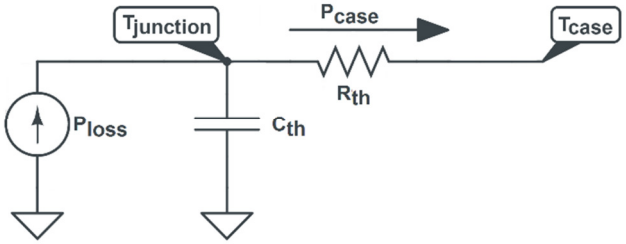


Fig. 3. One-cell Cauer thermal network model.

In Fig. 3, R_{th} and C_{th} are the thermal resistance and capacitance from junction-to-case, respectively, and these indicators should be selected from the datasheet of the used IGBT module. Also, by similarity of thermal modeling and electrical modeling, the junction temperature can be found easily from the total power losses.

As mentioned earlier, the determination of semiconductors' failure rate depends on their power losses. The power losses in semiconductor devices can be categorized into two main groups of switching and conduction losses. Switching energy losses over a single period of switching can be divided into two parts: turn-on energy (E_{on}) and turn-off energy (E_{off}). For an IGBT chip, the switching power losses can be determined by multiplying switching frequency (f_s) by the summation of these two energies. However, the values of energy losses as a temperature-sensitive parameter (TSP) depend on the junction temperature (T_j), collector current (I_c), and the supply voltage (V_{CC}) as follows [38]:

$$P_{switching} = f_s(E_{on}(V_{CC}, I_c, T_j) + E_{off}(V_{CC}, I_c, T_j)) \quad (17)$$

The conduction losses would be calculated by multiplying collector-emitter voltage (V_{CE}) by the collector current as follows:

$$P_{conduction} = V_{CE}(I_c, T_j) \times I_c \quad (18)$$

In order to obtain the relationships between the aforementioned parameters, the given curves in the datasheet must be digitized and extracted. The utilized approach in this paper is based on calculating both conduction and switching losses for the diode and switch using lookup tables. Detailed explanation of this process is given in [39].

In the following equation, π_S is the stress factor for diodes:

$$\pi_S = V_S^{2.43} \quad (19)$$

where V_S is the ratio of operating voltage to nominal voltage.

The factor π_C explains the contact construction. Considering it is metallurgically bonded, the contact construction leads to the value of 1 for π_C [35]. In the capacitor failure rate, π_{CV} is the capacitor factor which can be calculated as follows:

$$\pi_{CV} = 0.34 \times C^{0.12} \quad (20)$$

where C is the capacitance in microfarad.

IV. Thermal Analysis of Buck Converter

In order to determine the thermal analysis of the converter, a 600V/150A FUJI IGBT module is selected. The features of this module include high speed switching, voltage drive, and low inductance [40]. From the datasheet, the values of the thermal resistance and capacitance for the Cauer network are 0.25 K/W and 0.18 J/K, respectively.

Fig. 4 shows the IGBT on-state characteristics in 25°C and 125°C, based on collector current versus collector-emitter voltage.

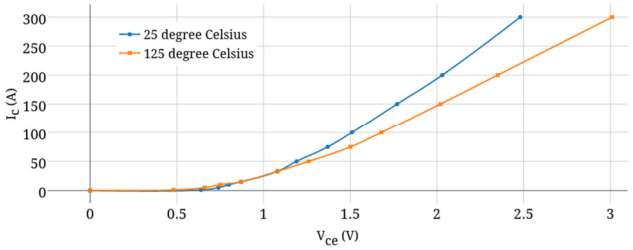


Fig. 4. IGBT's collector current in terms of collector-emitter voltage [40].

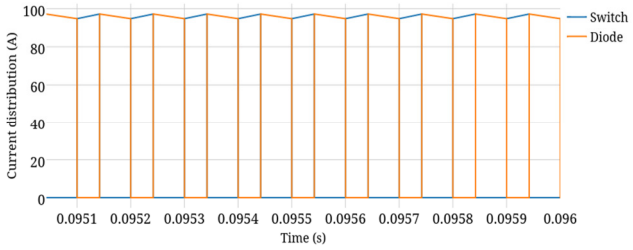


Fig. 5. Current distributions of the switch and diode.

The rated current distributions for the switch and diode are shown is Fig. 5, which this figure clearly demonstrates the summation of switch and diode currents can produce the inductor current (when the switch is on, the diode is off). Conversely, when the diode is on, the switch is off. The inductor current will be a triangular waveform when its voltage analogue is pulsating in a rectangular form.

The most important factor in evaluating the converter

reliability is the junction temperature, which is directly related to power losses of the switch and diode. Thus, the calculation of the junction temperature is a sure way to assess reliability. Various elements can influence the junction temperature and its value will change with variations in component's power losses; increasing the switching frequency can lead to more power losses in the switch and diode. Another important factor for power losses in the buck converter is the modulation index or duty cycle. By setting a different duty cycle for the converter, the gain of the output voltage will change; and by considering a constant output power, the value of output current would be varied. An analysis is undertaken to show the effects of the switching frequency and the duty cycle on the junction temperature and the heat sink temperature. Fig. 6(a-c) represents the parameters influencing the junction temperatures.

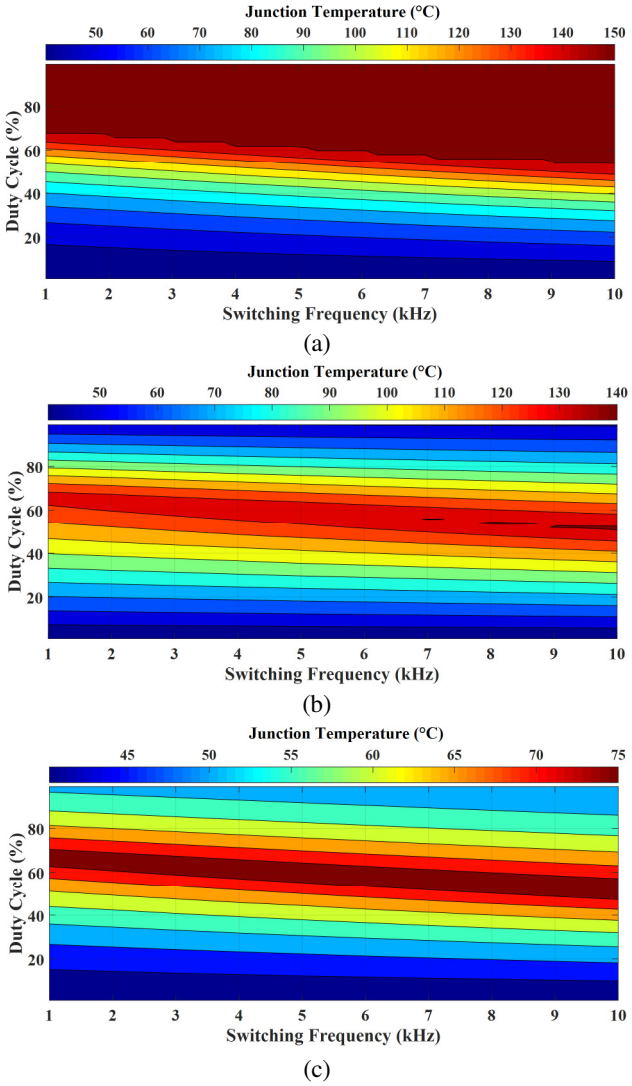


Fig. 6. Effects of duty cycle and switching frequency on (a) the switch junction temperature, (b) the diode junction temperature, (c) the heat sink temperature.

It is evident from Fig. 6 that a lower duty cycle corresponds to a better performance in terms of temperature because of the decrease in the output voltage level. Therefore, it is possible to change the duty cycle to its desired value by changing the basic characteristics of the converter. Increasing switching frequency from 1 to 10 kHz has a negligible impact on the temperature, but switching frequencies higher than 10-kHz will increase the temperature dramatically. The over-temperature is limited to 150°C, so the converter ceases to operate beyond this temperature. For duty cycles higher than 51%, the junction temperature of the switch rises beyond the over-temperature. This shows the weakness of heatsink for cooling the module under thermal pressure. Using a more efficient heatsink will result in a decrease in the junction temperature and the extension of authorized period for increasing the duty cycle. The calculated power losses for the switch and diode (based on the rated parameters) are 145.02 W and 89.69 W, respectively. Also, the results illustrate that the switch junction temperature for a duty cycle of 42% and f_s=10 kHz is 117.29°C. The junction temperature of the diode is 122.27°C, and it has a higher value than the switch's temperature. This shows that greater thermal resistance can produce higher junction temperatures. Typically, the heat sink temperature is much lower than that at the junction of other components, and in reliability designs, a temperature of 40°C is considered a stable value for the temperature of the heat sink [41]. However, the structure and design of the heat sink can affect its operating temperature. The simulation results showed that the heat sink temperature measured with the parameters rated was 69.32°C.

V. The Reliability Evaluation of Buck Converter

In the first stage, the basic characteristics provided in Table I are considered for the reliability assessment. Estimated failure rates for each component under identical conditions are shown in Tables II-V. Due to the rated active power of the converter, a value of 10 is considered to be the application factor. Values of π_Q and π_E were set for the components according to [35].

TABLE II
The Estimated Failure Rate for The Switch.

P_{Loss} (W)	T_j (°C)	π_T	π_A	π_E	π_Q	λ_b	λ_P (*failure/10^{6}h*)
145.02	117.29	4.60	10	6	5.5	0.012	18.216

TABLE III
The Estimated Failure Rate for The Diode

P_{Loss} (W)	T_j (°C)	π_T	π_C	π_S	π_E	π_Q	λ_b	λ_P (*failure/10^{6}h*)
89.69	122.3	5.47	1	0.19	6	5.5	0.064	2.195

TABLE IV
THE ESTIMATED FAILURE RATE FOR THE CAPACITOR.

Value	T_A (°C)	π_{CV}	π_E	π_Q	λ_b	λ_P (*failure/10^{6}h*)
1 µF	40	0.34	2	10	0.029	0.197

TABLE V
THE ESTIMATED FAILURE RATE FOR THE INDUCTOR

T_A (°C)	T_{HS} (°C)	π_C	π_E	π_Q	λ_b	λ_P (*failure/10^{6}h*)
40	69.32	1	4	20	6.22×10^{-4}	0.049

A value of 0.88 was considered to be the failure rate of the controller, similar to [35], and the failure rate of the converter can be estimated by summing all of the failure rates. The failure rate of the entire system was calculated at 21.537 (*failure/10^{6}h*). By reversing the failure rate, MTTF can be calculated as follows:

$$MTTF = \frac{1}{\lambda_{System}} = 46{,}432\ hours \tag{21}$$

By following the above procedure for different switching frequencies and duty cycles, the MTTF for various conditions can be extracted as three-dimension graphs. Fig. 7 shows the mean time to failure values for the IGBT in terms of duty cycle and switching frequency. As is evident from Fig. 7, while the applied switching frequency is 1 kHz, the duty cycles more than 65% will lead to a MTTF less than 40,000 hours. If the switching frequency of 10 kHz is applied to the switch, the duty cycle interval will be narrowed; and in this case for the duty cycle more than 50%, the switch lifespan will be less than the same MTTF. Although very low duty cycles are not possible in practice, lifetime increases dramatically as the duty cycle drops, and the maximum MTTF would be equal to 184,053 hours.

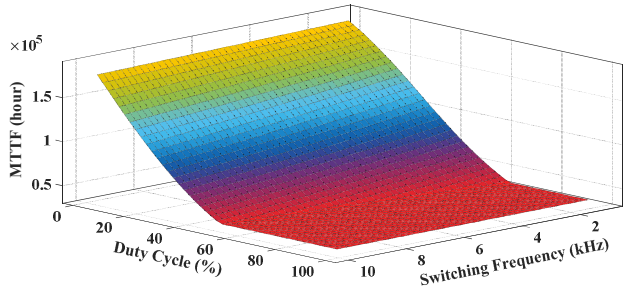


Fig. 7. Effects of duty cycle and switching frequency on the switch's MTTF.

Fig. 8 depicts the influence of both duty cycle and switching frequency on the diode's MTTF. In addition to the temperature factor, the stress factor also affects the reliability of the diode, which its value varies by changing the duty cycle. Thus, the trend of its graph would be different from the switch curve. Based on the calculations, the minimum lifetime for a diode occurs in a state where the duty cycle is about 50-65%. As expected, the best conditions for a diode are for situations where the duty cycle is less than 20%.

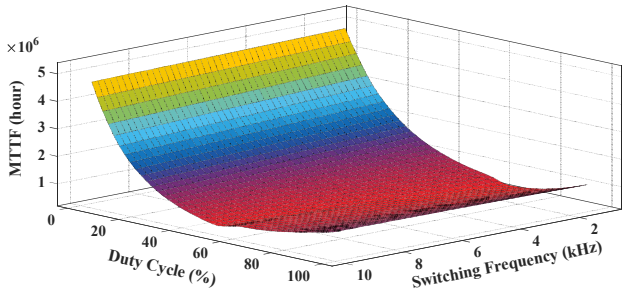


Fig. 8. Effects of duty cycle and switching frequency on the diode's MTTF.

By considering all the components used within the converter, the total MTTF can be shown in Fig. 9. It is clear that the resulting diagram is more similar to the lifetime of the switch, because the component that has a lower lifespan would create more impact on the overall system's reliability. According to Fig. 9, design parameters (e.g., duty cycle and switching frequency) have a decisive effect on the lifespan; therefore, it is recommended to consider this reliability analysis before design of all power electronic converters.

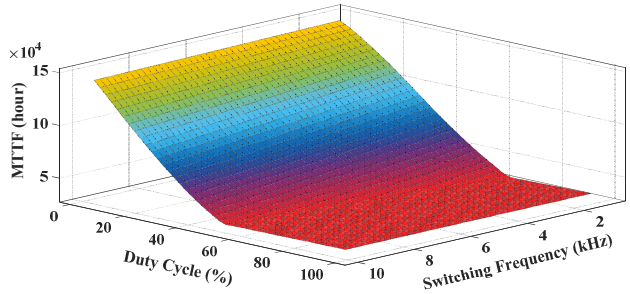


Fig. 9. Effects of duty cycle and switching frequency on the MTTF of the whole system.

To clarify the effect of switching frequency more precisely, the overall MTTF is shown in Fig. 10 for two different duty cycles (25, and 50%).

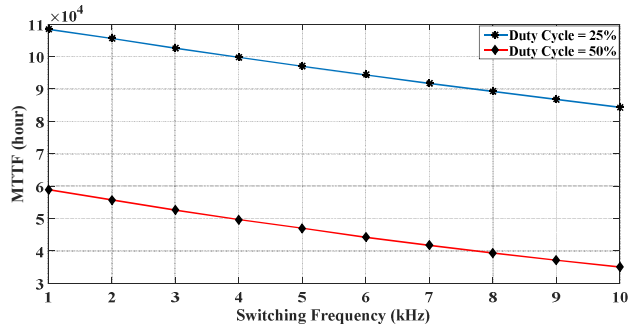


Fig. 10. Effects of switching frequency on the MTTF of the whole system for two duty cycles.

It is obvious that two both line graphs follow an approximately linear downward trend by increasing switching frequency; however, the duty cycle of 25% shows a better performance compared to the higher duty cycle (50%). When the duty cycle is 25%, the MTTF is equal to almost 108,500, and 84,350 hours for the switching frequencies of 1 and 10 kHz, respectively. With an increase of 1 kHz in switching frequency, the MTTF value is reduced about 2500 to 3000 hours. In the second case (duty cycle = 50%), when the switching frequency changes from 1 to 10 kHz, the MTTF experiences a decrease from 58,970 to 35,080 hours; and the converter is more vulnerable to failure. In the second case, an increase in switching frequency by 1 kHz can reduce the MTTF value by a step in the range of 2200-3200 hours.

VI. Conclusion

A new approach to reliability assessment based on thermal analysis of the switch and diode was presented. The thermal analysis of a buck converter with the basic characteristics shown in Table I was conducted by calculating the temperature at the switch and diode junction. The total failure rate of the converter was expressed by summing the failure rate of the components using the parts count method. The procedure employed for the reliability analysis was that given in the MIL-HDBK-217F handbook. The results of the simulation using MATLAB/Simulink showed that the buck converter analyzed will operate reliably for 5.3 years, which is an acceptable performance. Additionally, the reliability assessment was performed by considering the effect of both duty cycle and switching frequency. The obtained 3D graphs showed that an increase in switching frequency from 1 kHz to 10 kHz can reduce the lifespan approximately 22%.

The reliability evaluation based on physics-of-failure (PoF) procedures can be considered as the future work. According to the PoF approaches, the failure rate is not constant during the time and is determined by the means of probability distribution functions (e.g., Weibull). Moreover, more complex methods such as modified Coffin-Manson can be used to make a comparison between different states.

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