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A prognostic method for predicting failure of dc/dc converter

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ABSTRACT

The failure of dc/dc converters can directly result in electronic systems working unconventionally or significant downtime. To pre-determine time to failure and generate substantial safety and cost benefits, it is necessary to assess the extent of deviation of dc/dc converters from its expected state of health in real time and predict time to failure in advance. This paper presents a novel prognostic method for predicting the time to failure of dc/dc converters. The process involves identifying precursor parameters, determining prognostic of failure, and determining a criterion for predicting time to failure. The output voltage is used as a precursor parameter and directly monitored when the converter with a given load periodically operates at different temperature stresses. The phenomenon that the differences of output voltages collected at different temperature stresses begin to increase with a large (or small) fluctuation is detected in collected output voltages. This phenomenon is identified as a prognostic of failure. A percentage of the initial difference is used as the criterion for predicting time to failure. A case study is given to illustrate the procedure that how to monitor output voltages, detect prognostic and predict time to failure. The results show the health state could be assessed in real time and the time to failure could be predicted in advance. Furthermore, the deviation of the predicted time to failure from the actual time to failure could meet the demand of a considered acceptable range in engineering practice.

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1. Introduction

Dc/dc converters are widely used in military and commercial applications (e.g. avionics, space, defense, telecommunication and control systems), and are particularly vulnerable to failures in such systems. The failure of dc/dc converters can directly result in the electronic systems working unconventionally, significant downtime or loss of lives. Therefore, to pre-determine maintenance schedules and generate substantial safety and cost benefits, it is necessary to assess the extent of deviation of the dc/dc converter from its expected state of health and predict its remaining useful life (RUL).

Pecht et al. presented an approach to power supply prognostics [1,2]. The process involves identification of precursor parameters, baseline establishment, baseline verification, and testing. The two most critical elements of dc/dc converters are aluminum electrolytic capacitors and semiconductors (e.g. switching transistors, rectifying diodes). Some parameters of these components could be used as the failure precursors and can drift from their nominal values. The process could be monitored and then a reasoning model correlating the change in the parameters with the impending failure could be developed [1,3]. Studies have reported some physics-of-failure (PoF) based and data-driven (DD) prognostic methods for aluminum electrolytic and semiconductor components of dc/dc converters. For example, Saha et al. presented a prognostic routine for power MOSFETs with electrical degradation in threshold voltage [4]. The prognostic routine includes a methodology for accelerated aging by using purely electrical overstress and corresponding identification of a precursor of failure. Santini et al. proposed to model the threshold voltage instability mechanism on a SiC MOSFET by using a non-homogeneous gamma process to perform the estimation of RUL over the course of the aging process [5]. To create a real-time failure prediction of an electrolytic capacitor applied to a power-electronic system, Abdennadher et al. [6] presented an electrolytic-capacitor failure prediction technique to detect the changes in the equivalent series resistance and capacitance C values in real time. In practice, the relative frequency of specific component failures may vary based on converter topology, type of component used, derating factors, operation loading, location in the system and environmental conditions [1,7,8]. Development of a PoF-based model requires detailed knowledge of the physical processes causing degradation and leading to failure of a dc/dc converter, but this knowledge may not always be available. Consequently, it is usually impossible to develop a well PoF-based model representing the multiple physical processes occurring in dc/dc converters.

The DD prognostic methods are dependent on monitored environmental and operational loads and system parameters in real time to determine correlations, establish patterns, and evaluate data trends leading to failure. For example, if a shift in the output voltage of a dc/dc converter might suggest impending failure, ideally, a reasoning

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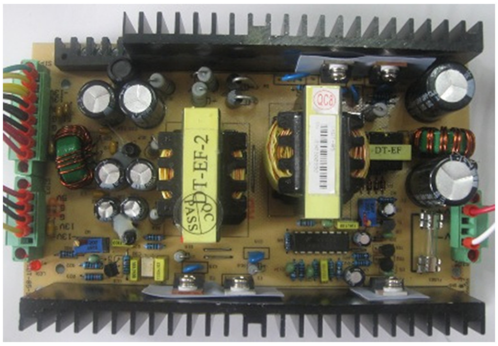

Fig. 1. A picture of the dc/dc converter.

model (e.g. time-series trending [9], parametric curve-fit [10])could be developed to correlate the change in the output voltage with the impending failure according to the present prognostic techniques to predict the RUL. One of the advantages of DD prognostic methods is that they can be used as black-box models as they learn the behavior of the system based on monitored data to statistically and probabilistically derive decisions, estimates, and predictions about the health and reliability of electronic systems, and hence do not require system-specific knowledge [1]. However, for dc/dc converters with varying usage profiles, an unexpected change in the usage profile could result in a different (or anomal) change in the output voltage. If the reasoning model is not characterized to factor in the uncertainty in life-cycle usage and environmental profiles, it may provide false prediction results [11,12]. Furthermore, for a system level electronic product with multiple failure mechanisms, a reasoning model which could be applied to one product might be not suitable for the other ones, and it is usually very difficult to determine the healthy baseline which could represent all the possible variations of the healthy operating states [8,13,14]. Therefore, the present prognostic methods for estimating RUL of dc/dc converters usually not work well in field [7,11]. The main problems exposed in field are false indications of anomalies (false alarms) and failure to detect anomalous behavior of the system (missed alarms).

The purpose of this paper is to develop a novel prognostic method for predicting failure of dc/dc converters in advance. The output voltages were monitored to aid in determining the health state of the dc/dc converter in real time and then present a reasoning algorithm to correlate the change in the output voltages with the impending failure. This paper is organized as follows. Section 2 describes the procedures for monitoring the output voltages. Section 3 focuses on developing a reasoning algorithm to correlate the change in the output voltages with the impending failure. The conclusion is given in the last section.

2. Procedures for monitoring output voltage

2.1. Dc/dc converter description

Fig. 1 shows a picture of a dc/dc converter used for CNC controller. The anormal fluctuations of output voltage will causes faults of the CNC controller, and thus can cause the CNC machine tool downtime. The main hardware components include MOSFETs, power rectifiers, voltage regulators, isolating transformers, pulse width modulation controller chip and filter electrolytic capacitors. Under normal conditions, the dc/dc converter has a variable input ranging from 18 V to 30 V DC, and the DC output voltages and output ripple noise are required to remain within the regulation ranges (see Table 1). For the dc/dc converter's temperature limits, the upper specification limit is 60 °C, the upper design limit is 75 °C, the upper operating limit is close to 90 °C, and the lower design limit −20 °C.

Table 1
DC output voltage regulation.

Output	Min (V)	Nom (V)	Max (V)	Max ripple noise (mV)	Max current (A)	Nominal working (V)
+5 V DC	+4.5	+5.1	+6.0	50	6.0	5.1–5.5
+13 V DC	+12.0	+13.0	+14.0	130	3.0	12.5–3.5
−13 V DC	−12.0	−13.0	−14.0	130	2.0	−12.5–−13.5

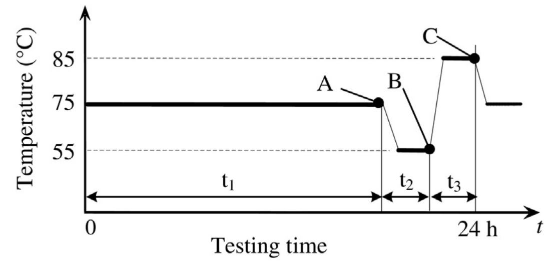

Fig. 2. Temperature stress loading profile.

2.2. Procedures

The high-temperature environment can noticeably accelerate the dc/dc converter failure and hence is applied to shorten test time [1,15,16]. Nine samples were periodicity subjected to a temperature stress loading profile shown in Fig. 2. According to design and use requirements, the three temperature stress levels are 55 °C, 75 °C and 85 °C, respectively. The stress 55 °C is used to verify whether the sample could be operating under normal use. The test period *p* for each stresses loading profile is 24 h. The corresponding test time t_1, t_2 and t_3 are 21.5 h (1290 min), 1 h (60 min), and 1.5 h (90 min). Each sample was tested at stress 75 °C for t_1, and then the stress was decreased to 55 °C with ramp rate 1 °C/min. Next, the samples were tested at stress 85 °C and then the stress was decreased to 75 °C with ramp rate 1 °C/min. The testing was continually running as described above.

The +5 V DC output voltage was monitored with full load to shorten test time and the sampling rate is 20 Hz. A failure occurs when a sample fails to meet the criteria: samples must output voltage exactly to specifications shown in Table 1. The ±13 V DC output voltages were not monitored with 50% load (which is the same as the actual load) because there are no failures in field use. As shown in Fig. 2, when a test period was conducted the testing at 55 °C and 85 °C removed a few portion of the life comparing with the whole lifetime of all the samples. Therefore, the changes in output voltages measured at testing time A (about 3 min before $\tau_{i,1}$), B(about 3 min before $\tau_{i,2}$) and C(about 3 min before $\tau_{i,3}$) could demonstrate the changes in performance with increasing temperature stress from 55 °C to 85 °C under a given time (e.g. A, B, C). The output voltages measure at time A could demonstrate the actual degradation state at 75 °C.

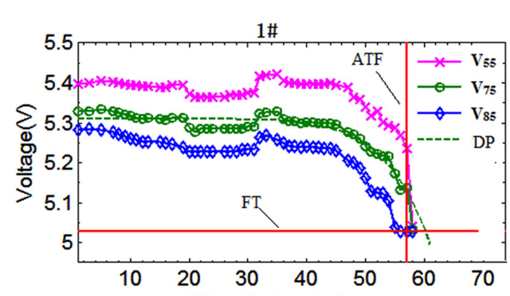

Fig. 3. Changes in output voltage of 1# sample.

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