Health Monitoring of a Power Supply Using Multivariate Regression

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ABSTRACT

Due to the increasing use of electronics in critical aircraft control systems, it has become more and more important in the aerospace industry to understand how the degradation process of electronic devices occurs. Power supplies are devices of special interest since their internal components such as diodes, capacitors, MOSFETs (Metal Oxide Semiconductor Field Effect Transistor) and IGBTs (Insulated Gate Bipolar Transistors) operate under continuous stress conditions and often present elevated failure rates. The aim of this work is to present a methodology for detecting the gradual health degradation of a COTS (Commercial off-the-shelf) power supply. An accelerated aging process for power MOSFETs was conducted. During this experiment, power MOSFETs were subjected to thermal overstress in order to increase die-junction temperature above rated value through large current from drain to source. Multivariate regression analysis was applied to the raw data collected during the tests in order to assess the power supply health status.

1. INTRODUCTION

Health monitoring applications for electronic systems are significantly rarer compared to mechanical components. Some well known reasons are: complex architecture of electronics, interdependency of component functionality, and the lack of monitoring sensors (Kumar, Vichare, Dolev, & Pecht, 2011).

Despite the lower availability of electronic health monitoring applications, some work can be found regarding isolated components such as transistors (Patil, Das, Goebel & Pecht, 2008; Celaya, Saxena, Saha & Goebel, 2011), capacitors (Gu, Azarian & Pecht, 2008; Kulkarni, Biswas & Koutsoukos, 2009) and in some cases, integrated components (Kumar et al., 2011; Zhang, Kwan, Xu, Vichare & Pecht, 2007).

Power supplies play an important role in modern electronic systems and their high failure rate turned these components into great candidates for health monitoring applications. The high level of integration and the lack of sensors turn this component into a challenging problem for PHM applications researchers.

The following work presents a power supply health monitoring application. A real power supply is aged in a testbed to generate degraded data. After that, a health monitoring methodology is proposed using multivariate regression.

This work is described in more details in the following sections. Section 2 presents the system under study. Section 3 presents the degraded data generation procedure. The proposed health monitoring methodology and its results are presented in section 4. In section 5, final conclusions are drawn.

2. SYTEM DESCRIPTION

For the present work a COTS power supply for commercial and military applications was used. The chosen power supply is produced by Century Electronics and is shown in Figure 1.

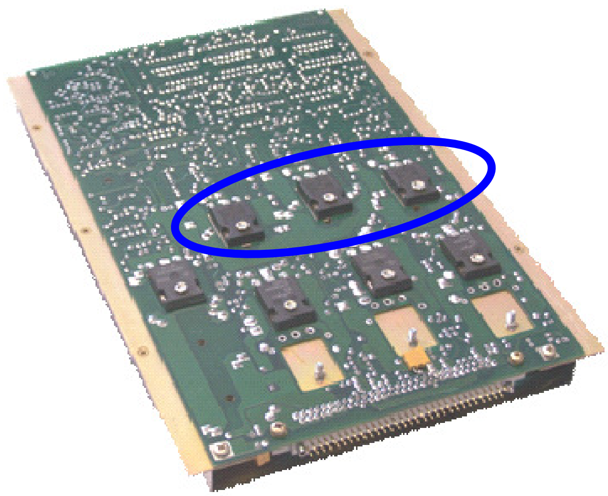

Figure 1. Power supply employed in the present work with indication of the power MOSFETs under consideration.

This is a 200W power supply with three outputs channels. Its input voltage ranges from 15 to 40Vdc with a nominal value of 28Vdc. The electrical specification of each output channel is presented in Table 1.

The chosen power supply was selected for this work due to its electrical and assembly features and typical applications. The power MOSFETs – highlighted in Figure 1 – are located in an accessible position and can be easily disconnected and reconnected. This characteristic is important to the accelerated aging MOSFET procedure used in this work. This procedure will be described in the next section.

Output Channel	Voltage (Vdc)	Current (A)
1	+5.1	8.0
2	+15.0	5.0
3	-15.0	5.5

Table 1. Output channels electrical specifications

3. Data Generation

Many works using testbed experiments in order to collect data representing the component lifecycle have been published, like (Kappaganthu, Nataraj & Samanta, 2009) and (Saha & Goebel, 2009). In these works, an accelerated aging procedure is conducted to reduce experiment duration.

3.1 Testbed

The testbed used in this work is composed by a power supply, a programmable DC supply, a programmable DC load and a data acquisition system. The testbed basic architecture is illustrated in Figure 2.

Programmable DC Supply

The programmable DC supply is responsible for providing power to the power supply under test according to a predefined profile. As mentioned earlier, the power supply used in the test has an input voltage range from 15 to 40Vdc with a nominal value of 28Vdc. During the experiment, the power supply was submitted to three different input voltage levels: low voltage (16Vdc), nominal voltage (28Vdc) and high voltage (40Vdc). Input voltage levels were defined based on the recommendations obtained from the power supply manufacturer. The input voltage profile is illustrated in Figure 3.

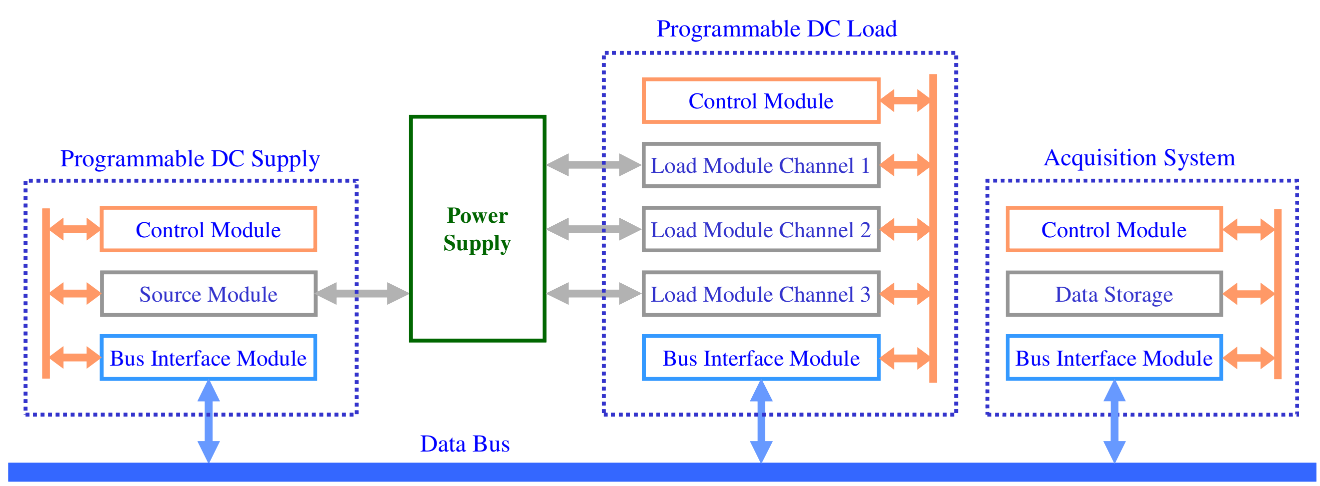

Figure 2. Testbed architecture

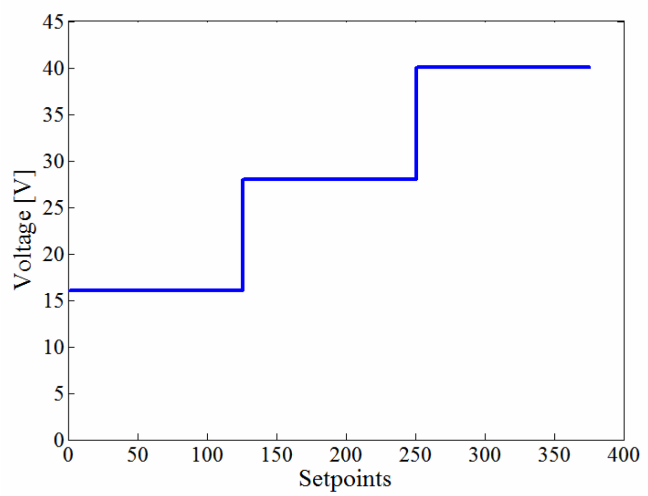

Figure 3. Input voltage profile

Programmable DC Load

The programmable DC load emulates the desired DC resistance loads for each output channel. For each input voltage level considered in the test, a complete load cycling was performed. In the defined load cycling profile, each output current can assume 5 different values equally distant from zero to its nominal value. The load cycling sequence is composed by all possible combinations of output currents. Since there are three output channels and each channel can assume 5 different values, there are 125 possible output current combinations. Figure 4 shows the load cycling sequence.

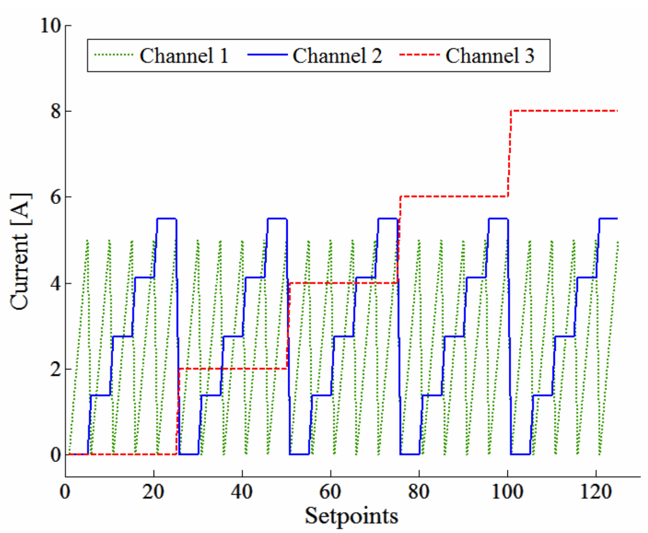

Figure 4. Load cycling sequence

Data Acquisition System

The testbed comprises a data acquisition system that is responsible for recording the relevant signals during test execution. The variables recorded during the tests that will be used in the proposed health monitoring method are listed below. All variables were recorded with a sample rate of 1 Hz.

- Input voltage
- Input current.
- Output Voltage of each output channel.
- Output Current of each output channel.

3.2 MOSFETs Accelerated Aging Procedure

ALT (Accelerated Life Testing) and HALT (Highly Accelerated Life Testing) methodologies are frequently used to assess the reliability of products. These methodologies also play an important role in the development of PHM (Prognostics and Health Monitoring) solutions for electronics components and systems. The typical expected lifetime for electronic devices is in the order of thousands of hours. In such situations, it is not feasible to wait for devices to fail under normal operation in order to collect a dataset that is representative of the component lifetime (Celaya, Saxena, Wysocki, Saha & Goebel, 2010).

In this work, the power supply accelerated degradation process was obtained by the accelerated aging procedure of its power MOSFETs. There are four main semiconductor failure mechanisms that contribute to aging tendencies of MOSFET devices. These mechanisms are listed below (Kalgren, Baybutt, Ginart, Minnella, Roemer & Dabney, 2007):

- Thermal cycling
- Electro-migration
- Hot carrier injection effects
- Time-dependent dielectric breakdown

The accelerated aging process used in this work was based on the hot carrier injection effects principle. A more detailed description of each MOSFET main failure mechanism is provided by Kalgren et al. (2007).

3.3 Test Sequence

The power supply test campaign is composed by two main phases: Healthy Testing and Degraded Testing.

Healthy Testing

A healthy test was performed in order to characterize the baseline response of the power supply. During the healthy testing, no MOSFET aging procedure had been conducted. All MOSFETs had nominal operational condition.

The main goal of running a healthy test is to collect datasets prior to any seeded fault insertion. These will be the datasets upon which all seeded fault datasets can be compared with to determine the performance effects of environmental conditions and MOSFET degradation.

Degraded Testing

After performing a series of healthy tests, a healthy MOSFET was replaced by a degraded one. It was decided to insert only one degraded MOSFET within the power supply. The output channel 2 MOSFET was chosen to be replaced since channel 2 is the one with the highest nominal output power.

The purpose of performing a seeded fault testing is to collect datasets after a degraded MOSFET has been inserted within the power supply. System level effects caused by the insertion of a degraded component can be investigated and a comparison between a healthy power supply and a degraded one can be made.

4. HEALTH MONITORING METHODOLOGY

The insertion of a degraded MOSFET in a channel is supposed to increase its internal resistance. The main idea behind the proposed method is to estimate the internal resistance for each channel and check for variations as the MOSFET is degraded.

For the proposed method, it is assumed that only currents and voltages for each channel are available. With this information, it is possible to equate input and output power for each channel, as described in Eq. (1):

$$V_{IN} \cdot I_{IN} = V_{OUT} \cdot I_{OUT} + T_L \qquad (1)$$

where V_{IN} is the input voltage, I_{IN} is the input current, V_{OUT} is the output voltage, I_{OUT} is the output current and T_L are the total losses involved in the circuit.

T_L can be expanded, resulting in the expression shown in Eq. (2):

$$P_{IN} - P_{OUT} = R_1 \cdot I_1^2 + R_2 \cdot I_2^2 + R_3 \cdot I_3^2 + L \qquad (2)$$

where P_{IN} is the input power, P_{OUT} is the output power, R1, R_2 and R_3 are the equivalent internal resistances for each output channel, I_1, I_2 and I_3 are the output currents for each output channel and L is an independent loss. Equation (2) may be rewritten in a vector form, resulting in:

$$\left[P_{IN} - P_{OUT}\right] = \left[R_1 \quad R_2 \quad R_3 \quad L\right] \cdot \begin{bmatrix} I_1^2 \\ I_2^2 \\ I_3^2 \\ 1 \end{bmatrix} \qquad (3)$$

Internal resistances can then be estimated using least squares regression according to Eq. (4).

$$\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ L \end{bmatrix}^T = \left(\begin{bmatrix} I_1^2 \\ I_2^2 \\ I_3^2 \\ 1 \end{bmatrix}^T \cdot \begin{bmatrix} I_1^2 \\ I_2^2 \\ I_3^2 \\ 1 \end{bmatrix} \right)^{-1} \cdot \begin{bmatrix} I_1^2 \\ I_2^2 \\ I_3^2 \\ 1 \end{bmatrix}^T \cdot (P_{IN} - P_{OUT}) \qquad (4)$$

4.1 Results

The internal resistance of each output channel as well as the independent losses estimated according to Eq. (4) is presented in Figure 5. An estimation of the internal resistance of each channel as well as the independent loss is made for each test run. During a test run, the power supply is submitted to a complete input voltage cycling (as shown in Figure 3) and load cycling (as shown in Figure 4).

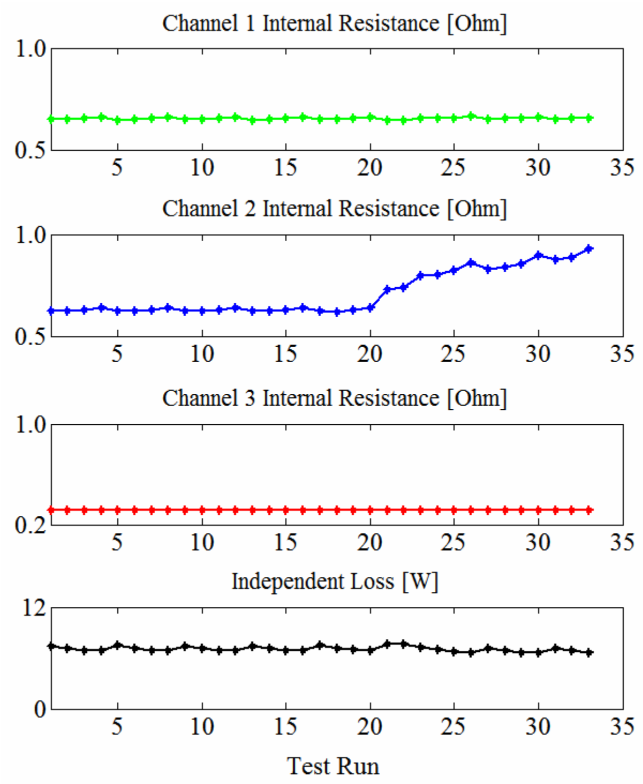

Figure 5. Estimation results

It can be noticed that the estimated internal resistance values of all three output channels are stable during the healthy stage of power supply lifetime. But when a degraded component is inserted into the power supply (approximately at the 20th test run) an increase in the estimated value of the output channel 2 internal resistance can be observed. It is important to remember that the fault was inserted only in the output channel 2 MOSFET. No changes were made in other two MOSFETs.

The multivariate regression analysis showed that the power supply was operating in a faulty condition and correctly identified that the degraded component corresponded to channel 2.

The last point of each curve showed in Figure 5 was calculated using the last dataset collected before the actual failure of the power supply.

5. Conclusions

This paper presented a methodology for detecting the gradual health degradation of a COTS power supply using multivariate regression.

The proposed method was capable of distinguishing a healthy power supply from a degraded one. Also, the results obtained showed that it is possible to monitor the health condition of electronic devices using a low bandwidth signal.

Many of the efforts to monitor the health condition of electronic devices use high bandwidth signals. The reason for that is that electronic devices failure modes, once present, tends to lead the device to a failure condition in a shorter period of time, when compared to other types of failure modes such as hydraulic or mechanical. However, the cost of recording and transmitting signals using high sample rates in aerospace industry is very high. This fact confirms the potential advantages of the proposed methodology.

Acknowledgment

The authors acknowledge the support of FINEP (Financiadora de Estudos e Projetos - Brazil), CNPq (research fellowship) and FAPESP (grant 2011/17610-0).

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BIOGRAPHIES

Leonardo Ramos Rodrigues holds a bachelor's degree in Electrical Engineering from Universidade Federal do Espírito Santo (UFES, 2003), Brazil, and a Master Degree in Aeronautical Engineering from Instituto Tecnológico de Aeronáutica (ITA, 2008), São José dos Campos, São Paulo, Brazil. He is currently pursuing his doctorate in Aeronautical Engineering at ITA. He is with EMBRAER S.A., São José dos Campos, São Paulo, Brazil, since 2006. He works as a Development Engineer in an R&T group at EMBRAER performing research on PHM technology for application to aeronautical systems. His current research interests are the application of health monitoring techniques for electronic components and the usage of PHM information for inventory optimization.

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Roberto Kawakami Harrop Galvão is an Associate Professor of Systems and Control at the Electronic Engineering Department of ITA. He holds a bachelor's degree in Electronic Engineering (Summa cum Laude, 1995) from Instituto Tecnológico de Aeronáutica (ITA), Brazil. He also obtained the master's (1997) and doctorate (1999) degrees in Systems and Control from the same institution. Since 1998 he has been with the Electronic Engineering Department of ITA as a full-time academic. Dr. Galvão is a Senior Member of the IEEE and an Associate Member of the Brazilian Academy of Sciences. He has published more than 200 papers in peer-reviewed journals and conference proceedings. His main areas of interest are fault diagnosis and prognosis, wavelet theory and applications, and model predictive control.