Stress Reduction of Electronic Power Switching Elements

Marco Hartung[1], Matthias Viehmann[1], Mathias Nowottnick[2]
[1] Nordhausen University of Applied Sciences, [2] University of Rostock

Keywords

Dynamic Stress Reduction, Service Lifetime and Reliability Extension, Operation Intervention Procedure, Multiparameter Regulator

Introduction

Electronic power switching elements are affected by electrical and thermal stress factors that reduce their reliability and service life. On the one hand, efforts are made to counteract such influences by oversizing circuits or by a progressive specialization of the components employed, see [2]. On the other hand, passive variants are used for the protection of components (cooling surfaces, vibration dampers and protective coatings) which are static in design and unable to adjust when operating conditions change. Active versions, such as power derating systems, record climatic parameters and organize system reactions, primarily in the form of performance reductions. Such reactions can even mean that a component is switched off altogether. Unlike the measures listed above, the identification of life-limiting effects (see [1] and [3]) and the derivation of life-extending measures in electronic assemblies (stress dosage) actively help increase reliability and extend service life. The present article looks at an operation intervention procedure (OIP) implemented in a multiparameter regulator (MPR) that reduces the dynamic stress of the switching element. The multiparameter regulator records the following data of the switching element: voltage load, current change rate, element temperature and other external climate and influencing variables (e.g. ambient temperature or the vibrations occurring in a fan insert as a mechanical stress factor). The following control action variables are used to influence stress: switching frequency, duty cycles and slew rate. The desired functionality of the assembly with its switching element is ensured by a permanent monitoring of the observance of defined functional indicators.

Operation Intervention Procedure and Algorithm

Using the stresses B applied and statistical data as input, the operation intervention procedure (OIP) embedded in the multiparameter regulator (MPR) calculates the control action required to minimize stress. An N_{max} stress amount curve, as shown in Figure 1, provides the basis for this approach.

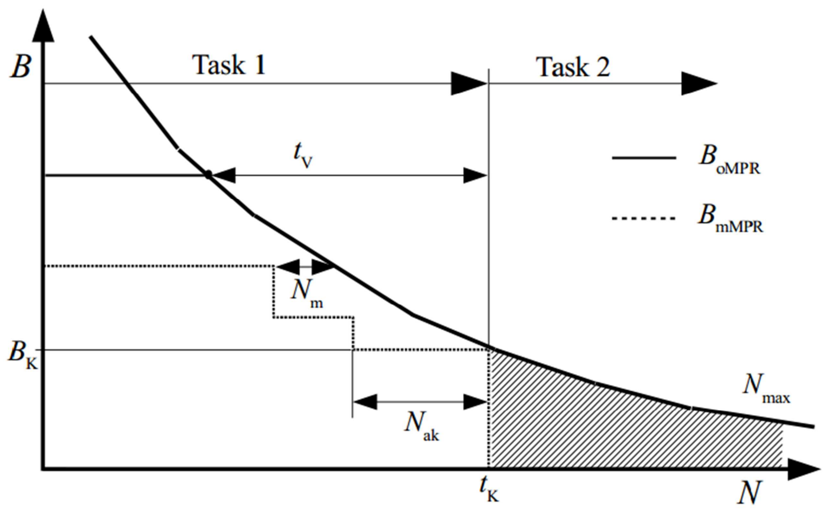


Figure 1: Example of an N_{max} stress amount curve and of other process values

The N_{max} curve describes the amount of stress B that can be tolerated. It shows that minor stresses can be tolerated on a larger scale, while severe stresses can be tolerated in smaller amounts only. Assuming that contacting N_{max} will result in the assembly being destroyed, the stresses applied are thus substantially responsible for the service life of the assembly. To enable assessment, stresses are assigned to different categories. The values contained in Figure 1 are explained in Table 1.

Table 1: Stress Amount Curve and Relevant Values (as contained in Figure 1)

Value	**Explanation**
N_{max}	Curve showing the amounts of stress that the element can or must tolerate. It may also be looked upon in a time-related manner.
B_{oMPR}	Stress under operating conditions without MPR
B_{mMPR}	Stress under operating conditions with MPR
B_K	Example of stress with N_{max} contact
t_K	Contact point
N_m	Distance between the stress sustained and N_{max} within a given category
t_v	Service life extension, expressed by the number of additional cycles available when stress is reduced using the OIP, as compared to operation without intervention
N_{ak}	Accumulated stress within a given category

In order to maximize service life, the switching element must be exposed to the lowest possible stress at any given time. Consequently, stress variations brought on by external climatic effects or user-requested performance changes need to be continuously recorded and analyzed. With increasing operating hours, the sum of the stresses sustained so far will get closer and closer to the amount of tolerable stress. In order for the stresses sustained so far to be related to tolerable stresses, the values periodically recorded need to be stored and aggregated with the amounts sustained so far. This means that there are two tasks to be performed: A general reduction of stress – Task 1 (T1) – on the one hand and progressive stress reduction with less intervention – Task 2 (T2) – on the other. Figure 2 shows how Tasks T1 and T2 are embedded in the intervention procedure. Apart from hardware-based control action, the processing of data comprises filtering, averaging and a phase shift to equalize the sequential recording of measured values.

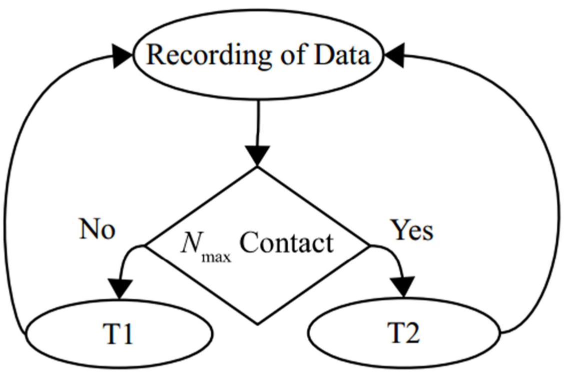


Figure 2: The Embedding of Tasks T1 and T2 in the Intervention Procedure

During the time $t < t_K$, shown in Figure 1 – with a safety margin t_x added later – the algorithm serves to reduce stress and thus to shift contact point t_K. For the purpose of permanent recording, a cyclical workflow between data acquisition and the calculation of intervention needs to be in place. To position the amount of stress sustained so far in the N_{max} curve, all the stresses measured are stored and accumulated as well. With a view to keeping the amount and extent of storage constant during service life, a histogram is created and updated using cyclically measured data. The information obtained from the position in the curve and the current measurement values is utilized to calculate the intervention. There are separate process steps for each stress measured. The procedure to determine the control action data is illustrated in Figure 3.

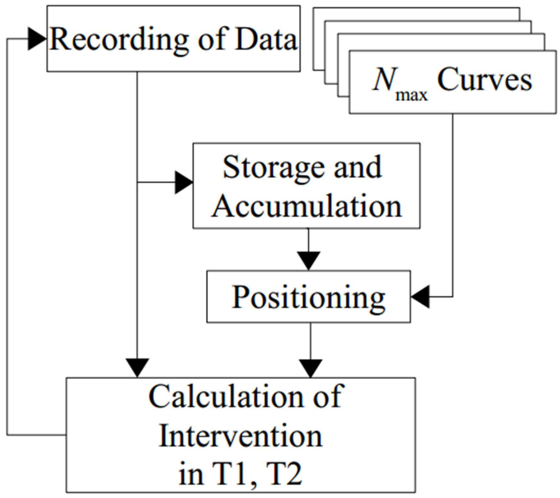


Figure 3: Control Action Calculation Algorithm

It is assumed that the stresses studied and their N_{max} curves will show variations, with stress curves differing significantly from one another during the time of operation. The positioning module monitors the curve approximation process and continuously determines the distance to the relevant N_{max} curves, with N_{max} generated through statistical sampling. In view of the variance associated with that, a safety margin t_x between the stresses already sustained and the maximum tolerable stresses is required for determining a contact point. Real assemblies feature different N_{max} curves, which could be imagined as a family within a given range. The variance of the N_{max} values is specific for each category.

Owing to the different N_{max} curves, it is imperative that they be standardized, so that all the stresses can be treated equally. This approach can ensure that it will not always be the curve exhibiting the lowest N_{max} values that will be contacted as a result of its accumulated stress and that the switching element will not be destroyed by the same stress as a consequence. Therefore, the N_{max} curve showing the lowest values determines the characteristic service life.

Condition (1) is checked for validity after the acquisition of each measurement value. If this condition is not fulfilled, the transition from Task 1 to Task 2 will be made. When several stresses having different N_{max} curves are processed, it can be assumed that, for the stresses studied, condition (1) will no longer be fulfilled at different points in time and that the transition to Task 2 will take place at separate points in time.

$$[N_{\mathrm{m}}]_n < [N_{\max}]_n - t_x \tag{1}$$

with N_{m} denoting the amount of values measured so far,
t_x denoting the safety margin between the stresses sustained so far and N_{max}.

From $t > t_K + t_x$ on, failure probability will increase markedly due to the proximity to N_{max}, so that the transition to Task 2 will take place at a defined t_x margin. This results in an extension of the algorithm, where functionality intervention is adjusted in such a way that the available remaining amount of stress – see the hatched area in Figure 1 – below stress contact value B_K will be completely used. For this purpose, all control action possibilities with stress values higher than B_K will be disabled in a look-up table (LuT). This process is called Task 2, see Figure 4. The MPR will remain in Task 2 up to the end of the service life of the switching element.

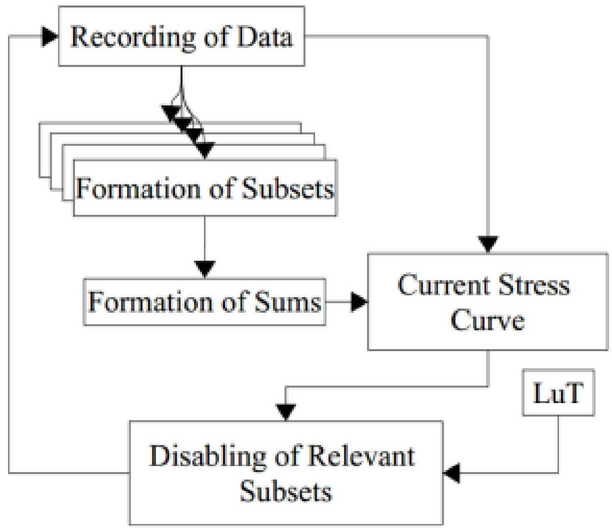
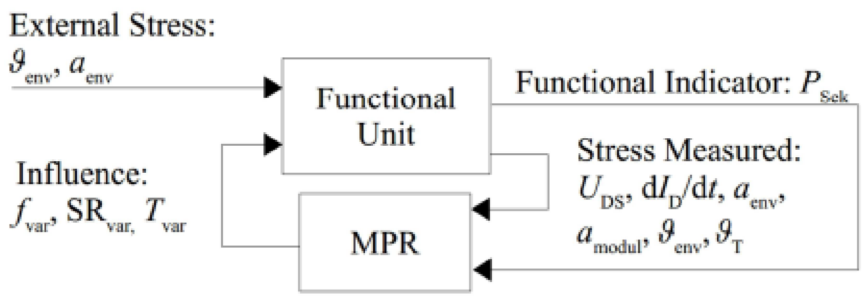


Figure 4: Algorithm of Task 2

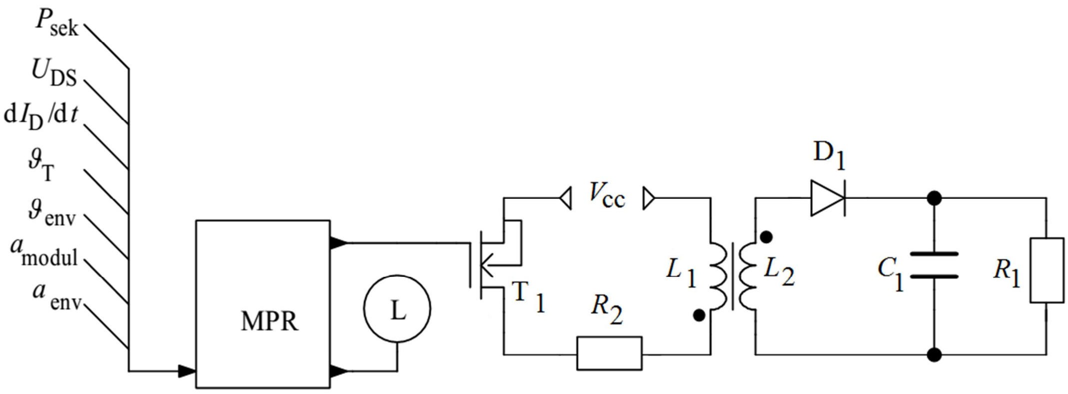
Figure 5 relates the environment to the functional unit. The multiparameter regulator is fed with data about internal and external stress variables affecting the functional unit, which enables it to deduce measures to influence the operational behavior of the functional unit.



U_{DS}	Drain-Source Voltage
dI_D/dt	Gradient Drain Current
a_{env}	Mechanical External Acceleration
a_{modul}	Module-Related Acceleration
ϑ_{env}	External Temperature
ϑ_T	Transistor Temperature
f_{var}	Variable Frequency
SR_{var}	Variable Slew Rate
T_{var}	Variable Duty Cycle
P_{sek}	Secondary Power, Defined Functional Indicator

Figure 5: Multiparameter Regulator (MPR)

Using a demonstrator, see Figure 6, the operation intervention procedure and the multiparameter regulator have been studied in an exemplary manner on an electronic inductance switching element. Without MPR intervention, failure in all assemblies ranges between $1.006 \cdot 10^7$ and $1.008 \cdot 10^7$ cycles. Through the action of the multiparameter regulator, failure is shifted to the $1.02 \cdot 10^7$ to $1.06 \cdot 10^7$ cycle ranges.



L Air Exhauster

Figure 6: Demonstrator exemplified by an FET Switch

Abstract

Electronic power switching elements are affected by electrical and thermal stress factors that reduce their reliability and service life. On the one hand, efforts are made to counteract such influences by oversizing circuits or by a progressive specialization of the components employed. On the other hand, passive variants are used for the protection of components (cooling surfaces, vibration dampers and protective coatings) which are static in design and unable to adjust when operating conditions change. Active versions, such as power derating systems, record climatic parameters and organize system reactions, primarily in the form of performance reductions. Such reactions can even mean that a component is switched off altogether. Unlike the measures listed above, the identification of life-limiting effects and the derivation of life-extending measures in electronic assemblies (stress dosage) actively help increase reliability and extend service life. The present article looks at an operation intervention procedure implemented in a multiparameter regulator that reduces the dynamic stress of the switching element. The multiparameter regulator records the following data of the switching element: voltage load, current change rate, element temperature and other external climate and influencing variables. The following control action variables are used to influence stress: switching frequency, duty cycles and slew rate. The desired functionality of the assembly with its switching element is ensured by a permanent monitoring of the observance of defined functional indicators. With the operation intervention procedure for dynamic stress reduction, the service life of electronic power switching elements can be extended. Based on the required accumulation of the stresses recorded, service life can be predicted if stress limit is known. Using stress statistics, the actual operating stress of the assembly can be evaluated as well, so that inferences about stress reserves, circuitry downsizing, functional changes or drift-type operating point shifts can be drawn. In the final analysis, the recording of variables also provides information about actual climatic conditions, which are the basis for optimized circuit design.

Using a demonstrator, the operation intervention procedure and the multiparameter regulator have been studied in an exemplary manner on an electronic inductance switching element through simulation and in a technical lab. Without MPR intervention, failure in all assemblies ranges between $1.006 \cdot 10^7$ and $1.008 \cdot 10^7$ cycles. Through the action of the multiparameter regulator, failure is shifted to the $1.02 \cdot 10^7$ to $1.06 \cdot 10^7$ cycle ranges.

References

[1] Mansuroglu, B.: *EMV im Elektronikschrank* (EMC in the Electronics Cabinet) at http://www.polyscope.ch/site/assets/files/20863/ps0612_36_37.pdf, (retrieved on May 02, 2017)

[2] Infineon, EconoDUAL at http://www.infineon.com/cms/en/product/promopages/econodual3/, (retrieved on May 02, 2017)

[3] Infineon, PrimePACK with IGBT5 and .XT at http://www.infineon.com/cms/de/about-infineon/press/market-news/2015/INFIPC201505-054.html, (retrieved on May 02, 2017)

Authors

Dipl.-Ing. (FH) Marco Hartung

studied Computer Engineering at the University of Applied Sciences Nordhausen. Since 2009 he is working as research assistant in Electronics Engineering for University Nordhausen. In 2012 he started writing a dissertation in cooperation with University of Rostock about stress reduction and service life extension of electronic assemblies.

marco.hartung@hs-nordhausen.de

Prof. Dr.-Ing. Matthias Viehmann

studied Industrial Electronics and Electrical Engineering. He did the doctor’s degree at Otto-von-Guericke-Universität Magdeburg. In some Electronics Industry Companies Viehmann was responsible for Electronics Engineering. In 2003 he was appointed Professor Industrial Electronics at the University of Applied Sciences Nordhausen.

matthias.viehmann@hs-nordhausen.de

Prof. Dr.-Ing. habil. Mathias Nowottnick

studied Electrical Engineering at TH Wismar, did his doctor's degree at Humboldt-Universität zu Berlin and habilitated at TU Dresden. From 1993 to 2005 he worked for Fraunhofer IZM in Berlin, then he was appointed to a professor at the University of Rostock, where he has been the director of the Institute for Electronic Appliances and Circuits since 2009.

mathias.nowottnick@uni-rostock.de