International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 17 (2017) pp. 6919-6928
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NHPP Model based Reliability Growth Management of a Hybrid DC-DC Converter

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Abstract

This paper examines reliability growth management of a hybrid DC-DC converter by using a Crow-AMSAA model. Reliability growth management consists of reliability growth planning and assessment. First, the main activity of planning involves constructing a planning curve that establishes interim reliability goals throughout the program. It is essential to determine the initial mean time between failures (MTBF) of a target system to implement the planned reliability growth curve. In this study, reliability block diagrams were employed to estimate initial MTBF from the reliability function. Second, the assessment of reliability involves periodically evaluating reliability during a test program and comparing the results to planned reliability goals and a growth curve. With respect to reliability growth management, required data was collected from 27 hybrid DC-DC converters that were installed in the field for almost two years. The results indicated that the reliability target of the systems was achieved via reliability growth management.

Keywords: AMSAA model; Non-Homogeneous Poisson Process; Reliability Block Diagram; Reliability growth management

INTRODUCTION

Reliability is defined as the probability that an item performs a required function without failure under stated conditions for a stated period of time [3]. It is extremely important to improve the reliability goal of products in the development stage to satisfy manufacturers and customers because unreliability of products can lead to high warranty costs for manufacturers and inconvenience customers.

Initial prototypes for a complex system may involve significant performance deficiencies that cannot be forecasted in the early development stage, and thus there is some room for improvement in the reliability of a system. Therefore, prototypes are subject to a development testing program to reveal problems in system design. Although, a final demonstration is performed to determine compliance with reliability requirements, it is insufficient to achieve reliability objectives with respect to allocated resources in several cases. It is necessary to utilize reliability growth management to accomplish the reliability requirement.

Reliability growth management is the management process associated with planning for reliability achievement as a function of time and other resources, and it includes controlling the ongoing rate of achievement by reallocating resources based on comparisons between planned and assessed reliability values. Reliability growth management procedures were developed to improve the reliability of Department of Defense (DoD) weapon systems. The use of reliability growth management realizes the following benefits. 1) Locating unforeseen deficiencies, 2) designing improvements with respect to indicated problems, 3) reducing risks associated with a final demonstration, and 4) increasing the probability of satisfying objectives.

Several studies examined reliability growth management of operating systems due to the benefits of reliability growth management. In 2002, Kumaraswamy [4] described Duane's growth model based reliability growth management aspects procedure during the prototype development of an advanced light helicopter. In 2006, Jung and Kim [8] proposed a practical method to efficiently monitor a reliability growth test process by using the AMSAA (Army Materiel Systems Analysis Activity) reliability growth model. In 2011, Crow [5], [13] addressed reliability growth models and procedures to assess reliability growth during development testing and in-service customer use. In 2014, Bell and Bearden [6] proposed an essential function failures based reliability growth planning method that is more likely to identify and correct failure modes leading to system downtime, and thereby resulting in greater improvements in reliability. In 2014, Kim and Kim [7] developed a new test procedure for a guided missile based on reliability growth management by considering a continuous test, analysis, and fix and test for a guided missile. Although various extant studies investigated reliability growth management, there is a paucity of studies that perfectly examine the concept of reliability growth management.

The objective of the present study involves analyzing reliability growth management for a hybrid DC-DC converter based on a Crow-AMSAA model for operating systems. The rest of this study is organized as follows. Section 2 provides a detailed explanation for a Crow-AMSAA model based on reliability growth management. In Section 3, a hybrid DC-DC converter is introduced and its reliability block diagram (RBD) is addressed. The experimental results for reliability growth management are analyzed in Section 4. Finally, concluding remarks are addressed in Section 5.

AMSAA MODEL BASED RELIABILITY GROWTH MANAGEMENT

Reliability growth management consists of reliability growth planning and reliability growth assessment. First, reliability growth planning addresses program schedules, amount of testing, resources available, and the reality of a test program in achieving reliability requirements. The main activity of reliability growth planning involves constructing a reliability growth planning curve that establishes interim reliability goals throughout the program. It is necessary to construct the reliability growth plan curve based on the activities and objectives of the program. Additionally, with respect to each test phase, the curve should indicate the levels of reliability that are expected to be achieved, as to whether reliability is constant or growing, the objective at the end of the test phase, and as to whether corrective actions are incorporated in the test phase. There are three possible responses for each identified failure mode.

When a failure is observed in a test-fix-test program, testing stops until a corrective action is incorporated into the system. The system exhibits incrementally better reliability when the corrective action is completed. In contrast to the test-fix-test program, the test-find-test program does not incorporate fixes into the system during the test. The program inserts the fixes into the system at the end of the test phase and prior to the next testing period. A large number of fixes are generally simultaneously incorporated into the system, and this typically corresponds to a significant improvement in system reliability at the end of the test phase.

Finally, there is another program for reliability growth management that is termed as a test-fix-test with delayed fixes program. The program corresponds to a combination of test-fix-test program and test-find-test program. Therefore, specific fixes are incorporated into the system during the test while other fixes are delayed until the end of the test phase. As a result, system reliability is generally considered as a smooth process during the test phase and that subsequently exhibits a jump because of the implement of the delayed fixes. The aim of the present study involves demonstrating the reliability growth with a test-fix-test program such that once a failure is observed, testing stops and corrective action is immediately incorporated into the system.

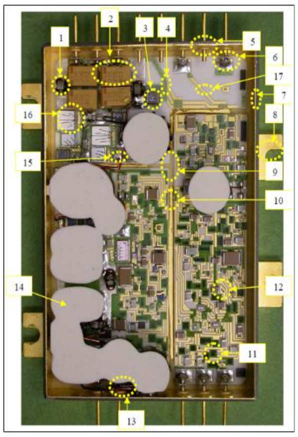
In reliability growth management, reliability growth assessment is essential to achieve the reliability goal of target system. The basic objective of reliability growth assessment involves periodically assessing reliability during a test program and comparing the reliability goals and the reliability growth curve with the reults. Reliability growth assessment is performed by reliability growth tracking in accordance with the timing of fixes. Reliability growth tracking is a tool based on actual test data to assess reliability that corresponds to a current attained reliability calculated by mathematical assessment. If reliability growth planning is constructed based on test-fix-test program, then it is necessary to perform reliability growth tracking to assess current reliability value of a target system.

Various models exist for each activity in reliability growth management. Although there are differences among the models, they possess a common objective. The objective of the present study involves demonstrating reliability growth management of a hybrid DC-DC converter, and thus only one model is addressed for each activity: 1) AMSAA Crow Planning Model for planning, and 2) AMSAA Reliability Growth Tracking Model – Continuous for tracking.

The purpose of the AMSAA Crow Planning Model includes constructing idealized system reliability growth curves, identifying test time and growth rate required to improve system reliability, and aiding in demonstrating the system reliability requirement as a point estimate [1]. The AMSAA Crow Planning Model assumes that reliability growth within a test phase is modeled as a Non-Homogeneous Poisson Process (NHPP) with a power law mean value function. Additionally, the cumulative failure rate is linear on a log-log scale based on the failures and test time within a test phase. It is possible to allow for generation of a target idealized growth curve and to utilize the same for discrete data when a large number of trials and low probability of failure exist. The methodology is based on initially specifying an idealized curve that achieves the expected number of failures at the end of each test phase with cumulative test times corresponding to $t_1, t_2, \ldots, t_k$. For planning purposes, the overall growth trend is represented only for $t > t_1$. This simply makes use of a constant or average failure rate over the first test phase. The constant failure rate is selected such that the expected number of failures is satisfied with $t = t_1$. Thus, the mean time between failures (MTBF) growth trend for $t > t_1$ and the idealized growth curve is given as follows:

$$M(t) = \begin{cases} M_I & 0 \le t \le t_1 \\ M_I \left(\frac{t}{t_1}\right)^{\alpha} (1-\alpha)^{-1} & t > t_1 \end{cases} \qquad (1)$$

In order to use Eq. (1), it necessary to determine a starting point M_I for the planned growth curve. This is determined by 1) using information from previous programs on similar systems, 2) specifying a minimum level of reliability that is required by the management to be demonstrated early in order to ensure that the reliability goals are satisfied, and 3) conducting an engineering assessment of the design in conjunction with any previous test data that may exist such as a bench test and a prototype test. In this study, the starting point M_I from RBD of a hybrid DC-DC converter is determined. It is used to determine that the goal MTBF value M_G at time T is set as equal to $M(t)$, i.e., $M_I\left(\frac{t}{t_1}\right)^{\alpha}(1-\alpha)^{-1}=M_G$. In the application of the reliability growth, the parameters M_I and t_I of the model involve physical interpretations in which M_I corresponds to the initial average MTBF for the system and t_I corresponds to the length of the first test phase in the program. Additionally, the parameter α corresponds to a growth rate.



1. Coil attached to substrate with solder
2. Tantalum chip capacitors
3. Ceramic chip capacitor, conductive epoxy termination attachment
4. Solder mask
5. Glass to metal seals
6. L-bracket connections from substrate to package pin
7. Plated device package
8. Mounting flange
9. Multiple substrates in single package
10. Gold wire bonds across substrates
11. Thick film resistors (integral with the substrate)
12. Thick film chip resistors
13. Magnet wire from transformer soldered to substrate pad
14. Polymer staking
15. Magnet wire from transformer soldered to substrate pad
16. Aluminum wire bonds from die to substrate
17. Gold substrate trace

✂ Figure 1: An example of a hybrid DC-DC converter (courtesy of NASA GSFC) ✂

In order to demonstrate the system reliability using the test failure data, the AMSAA Reliability Growth Tracking Model – Continuous for tracking (RGTMC) is used in the reliability growth management program for each test phase. The purpose of the AMSAA RGTMC involves assessing the reliability improvement within a single test phase of a system during the test program. The model assumes that the test duration is continuous and failures during a test phase occur based on an NHPP with a power law mean value function such as the AMSAA Crow Planning Model. An NHPP with failure intensity for the model is represented by a parametric function as follows:

$$\lambda(t)=\alpha\beta t^{\beta-1} \quad (2)$$

where α denotes the scale parameter, β denotes the shape parameter because it describes the shape of the intensity function, and t denotes the cumulative test time. Given these parameters, the function of MTBF is as follows:

$$MTBF(t)=\frac{1}{\lambda(t)}=(\alpha\beta t^{\beta-1})^{-1} \qquad (3)$$

It is interpreted as the instantaneous MTBF of the system at time t. When $t=T$ corresponds to the total cumulative time for the system, then $MTBF(t)$ corresponds to the demonstrated MTBF in its present configuration of the system at the end of the test. According to Eq. (2), when the failure intensity changes with time from interval 1 to interval 2 (t_1 to t_2), then $\lambda(t)$ is considered to follow an NHPP. When $\beta=1$, $\lambda(t)=\alpha$ implies that the process follows a Homogeneous Poisson Process (HPP) with a mean number of failures corresponding to the form αt. If $\beta>1$, $\lambda(t)$ corresponds to an increasing function, and it implies increased occurrences of failures as time passes. When $\beta<1$, $\lambda(t)$ corresponds to a decreasing function with less occurrences of failures over time [14].

With respect to a repairable system under the test, it is necessary to use the method of maximum likelihood to provide point estimates for the parameters of the failure intensity function. If this system is observed continuously from time 0 to time t_i ($i=1,\dots,k$), then this corresponds to the operating time or age of the system. The maximum likelihood estimates (MLE) for parameters α and β are as follows:

$$\hat{\beta}=\frac{N}{\sum_{i=1}^{N} ln\left(\frac{T}{t_i}\right)} \quad (4)$$

$$\hat{\alpha}=\frac{N}{T^{\hat{\beta}}} \qquad (5)$$

where N denotes the number of observed failures with respect to time T (the test termination time). It is assumed that the test commences from $t=0$, and thus t_i corresponds to the i th failure arrival time through T.

Specifically, the hypothesis is as follows:

$$H_0 : \beta = 1\ (HPP),$$

$$H_1 : \beta \neq 1\ (NHPP).$$

With respect to the null hypothesis H_0, it is shown that the statistic $2N/\hat{\beta}$ is distributed as a chi-square random variable with a degree of freedom corresponding to $2N$. Given the significance level θ, the rejection criterion for the null hypothesis is as follows:

$$Reject\ H_0\ if\ \frac{2N}{\hat{\beta}} < \chi^2_{2N,\frac{1-\theta}{2}} \text{ or } \frac{2N}{\hat{\beta}} > \chi^2_{2N,\frac{\theta}{2}} \ (6)$$

In a few specific situations, failure intensity may eventually level off. With respect to this type of failure intensity pattern, it is necessary to use the AMSAA RGTMC based on Eq. (2).

HYBRID DC-DC CONVERTER

A hybrid DC-DC converter corresponds to an electronic circuit or electromechanical device that converts a source of direct current (DC) from one voltage level to another. They are used in portable electronic devices, such as cellular phones and laptop computers, which are primarily supplied with power from batteries. These types of electronic devices typically contain several sub-circuits each with its own voltage level requirement that differs from that supplied by the battery or an external supply. Additionally, they are available from multiple sources in military standard Class K and Class H as well as other grades of commercial products. The converters are available in low-profile standard package sizes ranging approximately from 1 square inch to 3 to 4 square inches based on the output power level [15].

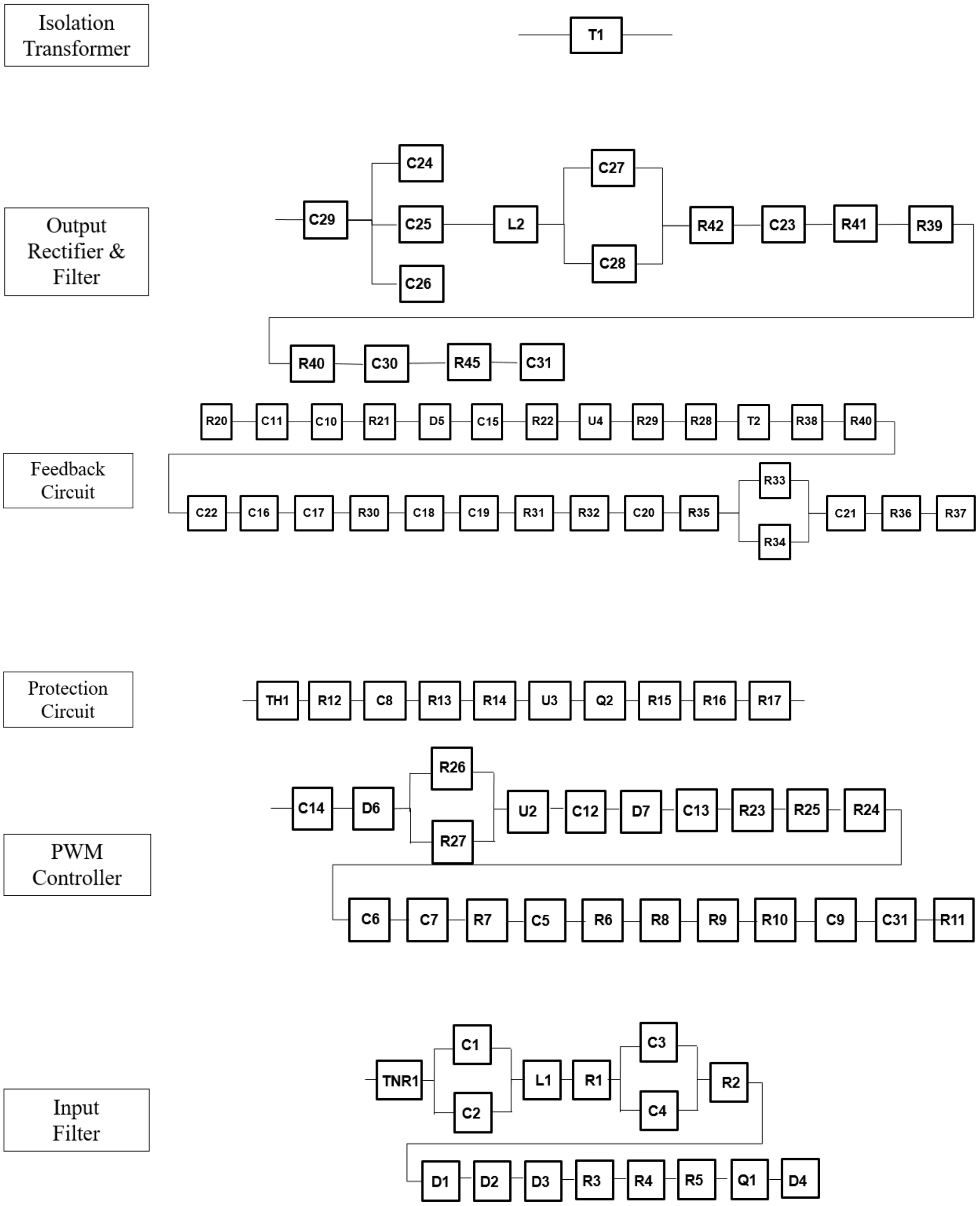
Most hybrid DC-DC converter circuits also regulate output voltage. For example, in the case of domestic electronic appliances, it is preferable to rectify the mains voltage to DC, use switch-mode techniques to convert it to high-frequency AC at the desired voltage, and typically to rectify it to DC. The entire complex circuit is cheaper and more efficient when compared to a simple mains transformer circuit of the same output.

TABLE 1
BOM LIST OF HYBRID DC-DC CONVERTER

Part Name	Design No.	Part Number	Manufacturer	Part Type	Count
Capacitor	C1C2	TCSCN1V236KD	Panasonic	CSR-Capacitor, Fixed, Electrolytic (Solid Electrolyte), Tantalum	2
Capacitor	C3	1206B472K251CT	Walsin	CK-Capacitor, Fixed, Ceramic Dielectric (General Purpose)	1
Capacitor	C4C5C6	TCSCN1A477KD	AVX Corporation	CSR-Capacitor, Fixed, Electrolytic (Solid Electrolyte), Tantalum	3
Capacitor	C7	TCSCN1C476KC	AVX Corporation	CSR-Capacitor, Fixed, Electrolytic (Solid Electrolyte), Tantalum	1
Capacitor	C8	1206B102K251CT	Walsin	CK-Capacitor, Fixed, Ceramic Dielectric (General Purpose)	1
Capacitor	C9C20C26	CL21B105KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	3
Capacitor	C10	CL21B474KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	1
Capacitor	C11C12C15	CL21B561KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	3
Capacitor	C13	CL21B271KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	1
Capacitor	C14	CL21B221KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	1
Capacitor	C16C17	CL21B101KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	2
Capacitor	C18	CL21B332KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	1
Capacitor	C19C27C28	CL21B104KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	3
Capacitor	C21	CL21B103KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	1
Capacitor	C22C23	TCSCN1V226KD	AVX Corporation	CSR-Capacitor, Fixed, Electrolytic (Solid Electrolyte), Tantalum	2
Capacitor	C24C25	TCSCN1D107KD	AVX Corporation	CSR-Capacitor, Fixed, Electrolytic (Solid Electrolyte), Tantalum	2
Capacitor	C29	CL21B105KB	Samsung	CDR-Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric	1
Capacitor	C30C31	EEEFK2A470AQ	Panasonic	CU, CUR-Capacitor, Fixed, Electrolytic (Aluminum Oxide)	2
Semiconductor	D1D2D3D4	MUR160	Fairchild	Power Rectifier with High Voltage Stacks	4
Semiconductor	D5D7	SMFB16	KEC	Power Rectifier with High Voltage Stacks	2
Semiconductor	D6	BZX55C6V2	Fairchild	Power Rectifier with High Voltage Stacks	1
Inductor	L1	DR74-2R2-R	Coiltronics	Fixed Inductor or Choke	1
Inductor	L2	ETQP6F2R0LFA	Panasonic	Fixed Inductor or Choke	1
Inductor	L3L5	DR73-2R2-R	Coiltronics	Fixed Inductor or Choke	2
Inductor	L4	DR73-470-R	Coiltronics	Fixed Inductor or Choke	1
Semiconductor	Q1Q2	IRF3315S	IR	MOSFET	2
Resistor	R1	RC2012F683CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R2R6	RC2012F100CS	Samsung	RM-Resistor, Fixed, Film, Chip	2
Resistor	R3R36R37	RC3216F471CS	Samsung	RM-Resistor, Fixed, Film, Chip	3
Resistor	R4	RC2012F512CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R5	RC2012F3R0CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R7	RC2012F000CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R8R9R12	RC2012F472CS	Samsung	RM-Resistor, Fixed, Film, Chip	3
Resistor	R10	RC2012F221CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R11R23R27	RC2012F123CS	Samsung	RM-Resistor, Fixed, Film, Chip	3
Resistor	R13R14R21R22	WSL2512R0300FEA	Samsung	RD-Resistor, Fixed, Film (Power Type)	4
Resistor	R15R25R30	RC2012F103CS	Samsung	RM-Resistor, Fixed, Film, Chip	3
Resistor	R16	RC2012F303CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R17	RC2012F202CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R18R19	RC2012F202CS	Samsung	RM-Resistor, Fixed, Film, Chip	2
Resistor	R24	RC2012F124CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R26	RC2012F204CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R28R29	RC2012F223CS	Samsung	RM-Resistor, Fixed, Film, Chip	2
Resistor	R31R33	RC2012F104CS	Samsung	RM-Resistor, Fixed, Film, Chip	2
Resistor	R32	RC2012F302CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R34	RC2012F182CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R35	RC2012F102CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Resistor	R38	RC3216F102CS	Samsung	RM-Resistor, Fixed, Film, Chip	1
Inductor	T1	P2033	Micro Tec.	Flyback (< 20 Volts)	1
Inductor	T2	P2033	Pulse	RF(10KHz-10MHz)	1
Resistor	TH1	NCP18XW223J03RB	Murata	RTH-Thermistor, (Thermally Sensitive Resistor), Insulated	1
ICs	U1	IR1167	IR	Gate/Logic Arrays and Microprocessors	1
ICs	U2	TC4420EOA	Microchip	Gate/Logic Arrays and Microprocessors	1
ICs	U3	LM5020MM-1	NSC	Gate/Logic Arrays and Microprocessors	1
ICs	U4	UC1901D	Texas Instrument	Gate/Logic Arrays and Microprocessors	1
ICs	U5	LM193MD8	NSC	Gate/Logic Arrays and Microprocessors	1
ICs	U6	LM5007MM	NSC	Gate/Logic Arrays and Microprocessors	1
Semiconductor	TNR1	MDE-14D101K	Murata	Transient Suppressor / Varistor	1

✂ Table 1: BOM list of a hybrid DC-DC converter ✂

A few exceptions include high-efficiency LED power sources, and this correspond to a type of DC-DC converter that regulates the current through the LEDs and simple charge pumps that double or triple the output voltage. Hybrid DC-DC converters are available as integrated circuits (ICs) that require few additional components. Converters are also available as complete hybrid circuit modules that are ready for use within an electronic assembly. As shown in Fig. 1, this presents a courtesy example of NASA GSFC (Goddard Space Flight Center) for a hybrid DC-DC converter. Additionally, Table 1 shows a BOM (Bill of Material) list that consists of electronic parts including a capacitor, a semiconductor, an inductor, a resistor, and an IC (Integrated Circuit). There are several elements that include design number, part number, manufacturer, part type, and the number of parts to identify the parts.



✁ Figure 2: Reliability block diagram for a hybrid DC-DC converter ✁

Among the elements, the design number is used to present RBD of a hybrid DC-DC converter as shown in Fig. 2. It is necessary to appropriately construct the idealized reliability growth curve to demonstrate the reliability growth management of a target system. It is also essential to determine the initial MTBF of a target system to implement the idealized reliability growth curve. Although a commercial MTBF of a hybrid DC-DC converter exists, there is no information on the initial MTBF. In order to overcome this problem, RBD of the system is used to estimate the initial MTBF from reliability function. In this case, a part type as shown in Table 1 is necessary to calculate the reliability of the system from RBD based on MIL-HDBK-217F [2], [17]. A detailed description of this initial MTBF is provided in Section 4.

RELIABILITY GROWTH MANAGEMENT OF DC-DC CONVERTER

This study involves a demonstration on 27 hybrid DC-DC converters that were installed in the field for almost two years. There are three test phases including the first test phase (t_1), second test phase (t_2), and third test phase (t_3) corresponding to 2,160 h, 6,600 h, and 8,760 h, respectively for each phase. Different failure modes are observed for a period of 720 days with a total of 31 failures. Table 2 lists the collected field failure data. Times for the failure occurrences are also recorded for each phase. In the study, it is assumed that each DC-DC converter operates for 24 h a day and 7 days a week and that the system reliability is estimated based on AMSAA Reliability Growth

TABLE 2

TIMES FOR THE FAILURE OCCURRENCES DURING 2 YEARS

Failure Number	Cum. Failure Time (Hours)	Failure Number	Cum. Failure Time (Hours)
1	384	17	17520
2	384	18	22080
3	432	19	28872
4	960	20	36960
5	1344	21	37440
6	2640	22	38592
7	3000	23	41472
8	4536	24	44280
9	5280	25	47520
10	6624	26	50784
11	11040	27	58032
12	11040	28	58968
13	11040	29	60480
14	13440	30	84024
15	15792	31	120480
16	16824		

✂ Table 2: Times for failure occurrences over two years ✂

TABLE 3

PARAMETERS OF FAILURE INTENSITY (FAILURES/HOURS)

Parameter	Phase 1 (Hours 0 – 58,320)	Phase 2 (Hours 58,320 – 236,520)	Phase 3 (Hours 236,520 – 473,040)
α	0.9821	0.1642	0.0371
β	0.1849	0.3284	0.4112
Failure rate	2.3681×10^{-5}	1.3270×10^{-5}	6.9539×10^{-6}
MTBF	42,227.764	75,357.289	143,803.722

✂ Table 3: Parameters of failure intensity (failures/h) ✂

Tracking Model – Continuous for tracking (AMSAA RGTMC). The repair time is ignored because the time to replace a fault part is relatively short enough compared to the total operation time of the system. In order to achieve the reliability goals by using the reliability growth management, it is necessary to construct an idealized growth curve by using Eq. (1) for the target reliability of the system.

Table 2 gives an example of failure time data in which 27 prototypes of a system are tested concurrently by incorporating design change. Following the system installation, 31 failures were recorded from the systems. In this study, the reliability growth management of the hybrid DC-DC converter is constructed based on a test-fix-test program. Therefore, the specific failure modes are defined as BC-modes that should be corrected during the test phase. In order to improve the reliability of the system, it is necessary to consider that the BC-modes incorporated are eliminated from the system. Using Eq. (2) – (5), the results of estimated parameters and demonstrated reliability are summarized in Table 3.

In order to determine the initial MTBF of the system, it is necessary to calculate the system MTBF from a RBD of a hybrid DC-DC converter. This is calculated as follows:

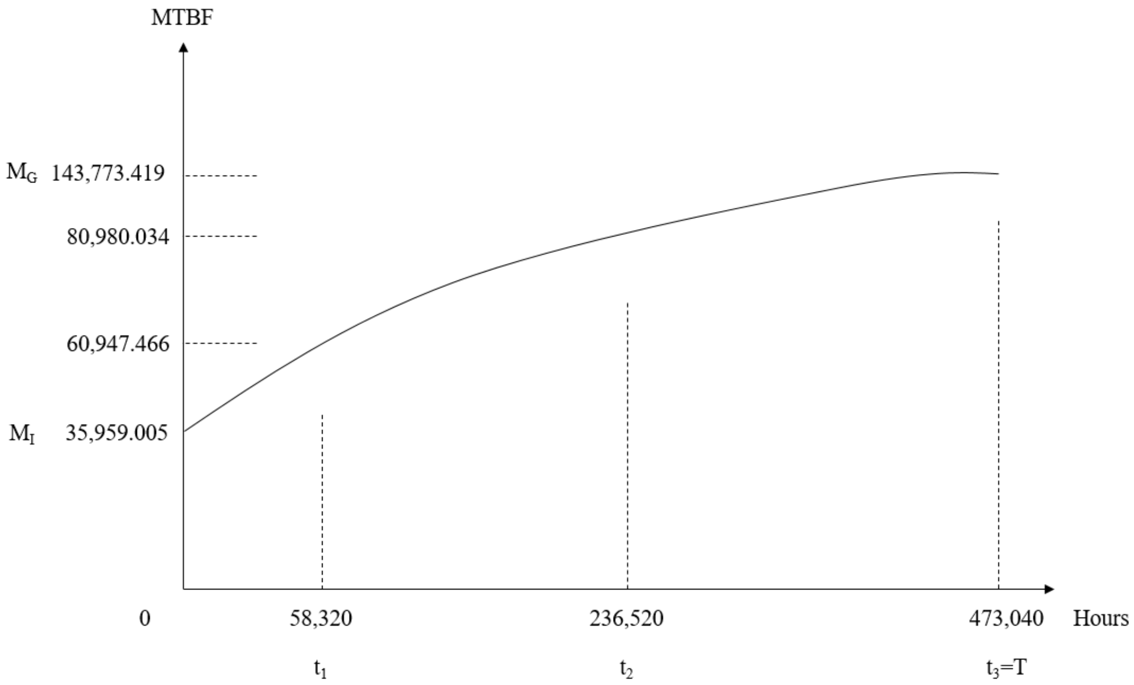
$$MTBF = \frac{\int_0^T R(t)dt}{1-R(t)} \qquad (7)$$

Eq. (7) is used, and the initial MTBF of a hybrid DC-DC converter corresponds to $M_I = 35{,}959.005$ at time t_0. It is subsequently used to determine the idealized growth curve that is expected or desirable, and this is used as a guide for the detailed planned curve. The idealized growth curve model is used, and the goal MTBF value $M_G = 143{,}773.419$ to be attained at time T is represented by $M(t)$ as shown in Fig. 3. This value corresponds to a reasonable result in the application of a hybrid DC-DC converter.

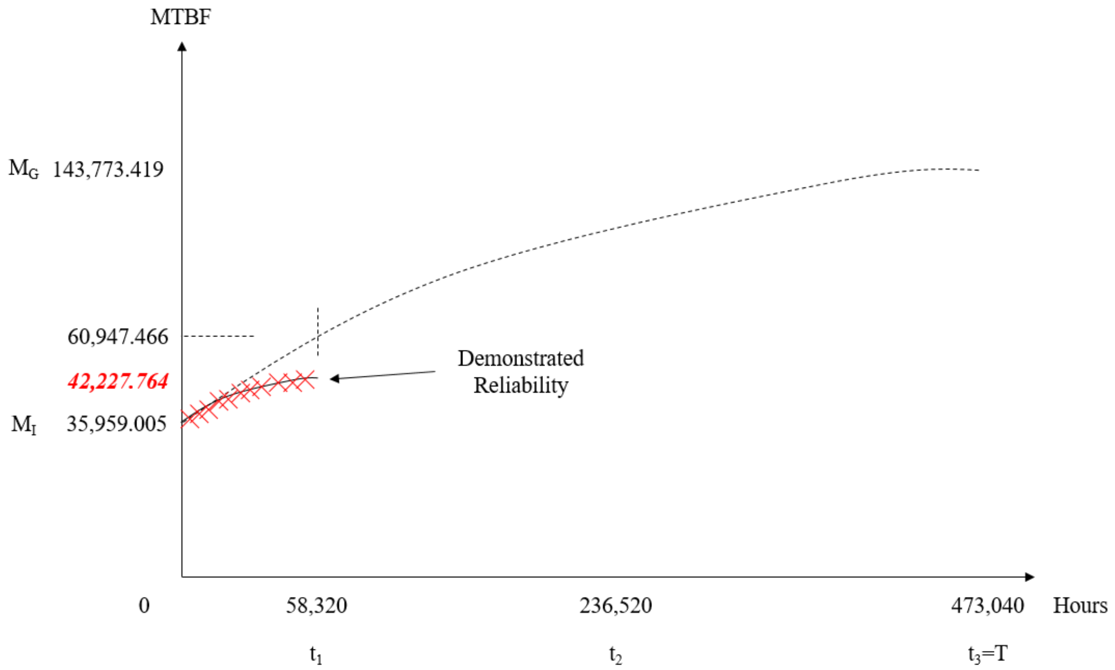
Phase 1 begins with 0 h and ends at 58,320 h (i.e. $t_1 = 58{,}320$ hours). Additionally, 11 failures are observed and treated as surfaced failures in that period. The number of surfaced failures in Phase 1 are used to estimate the failure intensity function and parameters α and β. The result is summarized in Table 3. In the analysis, the system MTBF value demonstrated in Phase 1 corresponds to 42,227.764 h less than the goal MTBF of Phase 1, and this corresponds to 60,947.466 as shown in Fig. 4. Given that it is not possible to achieve the system reliability at the end of Phase 1, it is important to perform the corrective actions that are appropriately incorporated in Phase 2.

When the actual time enters Phase 2, more failures are available and parameters α and β are updated by incorporting new failures that occur in Phase 2. In this period, 12 failures occur between 58,320 h and 236,520 h. Hence, the failure intensity function of Phase 2 is recomputed based on the actual failure data observed in Phase 2. Similarly, the system MTBF value at the end of Phase 2 is compared to the goal MTBF of Phase 2. As shown in Fig. 5, the system reliability cannot be slightly achieved although it is improved more than one in Phase 1. It should be noted that the system MTBF involves demonstrating the current reliability value of a target system.

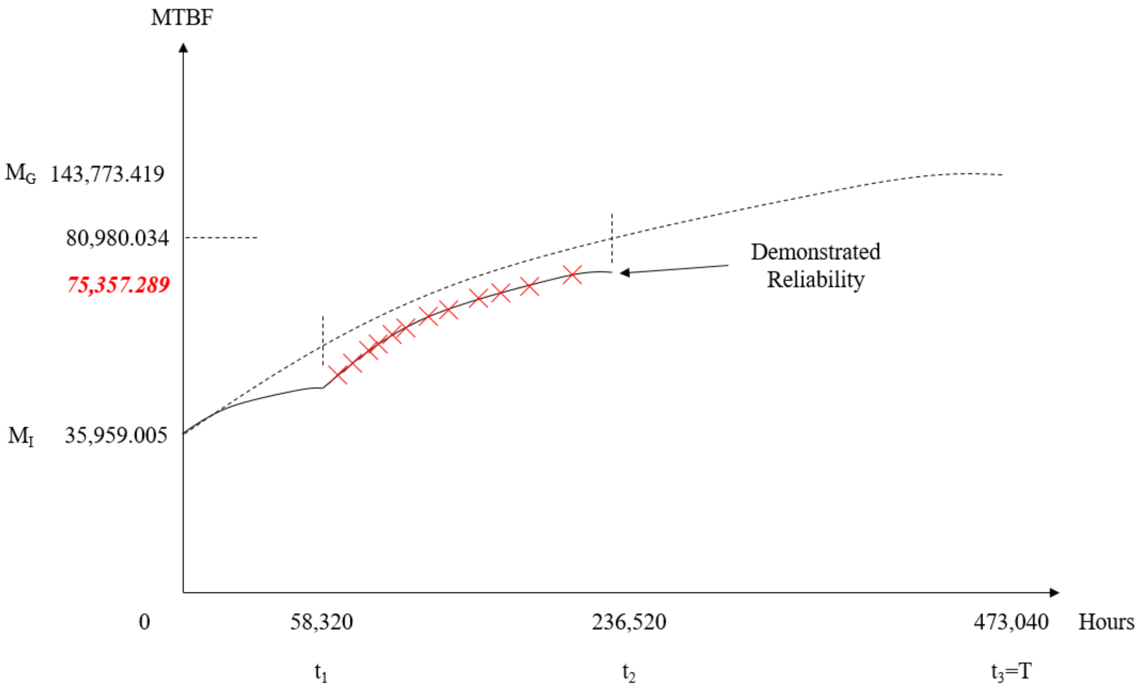
When the system moves into Phase 3 that corresponds to the final time period, the current time corresponds to 473,040 h ($= t_3 = T$). Failure data are collected from the system for surfaced failure modes, and parameters α and β are updated again. Simultaneously, 8 failures occurred between 236,520 h and 473,040 h. When the system reliability in Phase 3 corresponds to the final period in the reliability growth management program, it is essential to increase the system MTBF to achieve the final goal MTBF of a hybrid DC-DC converter. As shown in Fig. 6, the system final MTBF value demonstrated in Phase 3 is 143,803.722 h greater than the goal MTBF of Phase 3, namely 143,773.419. The case study demonstrated that the estimated failure intensity function effectively identifies the current reliability of a target system. Therefore, the goal MTBF of a target system is efficiently achieved by using a reliability growth management model based on Crow-AMSAA.



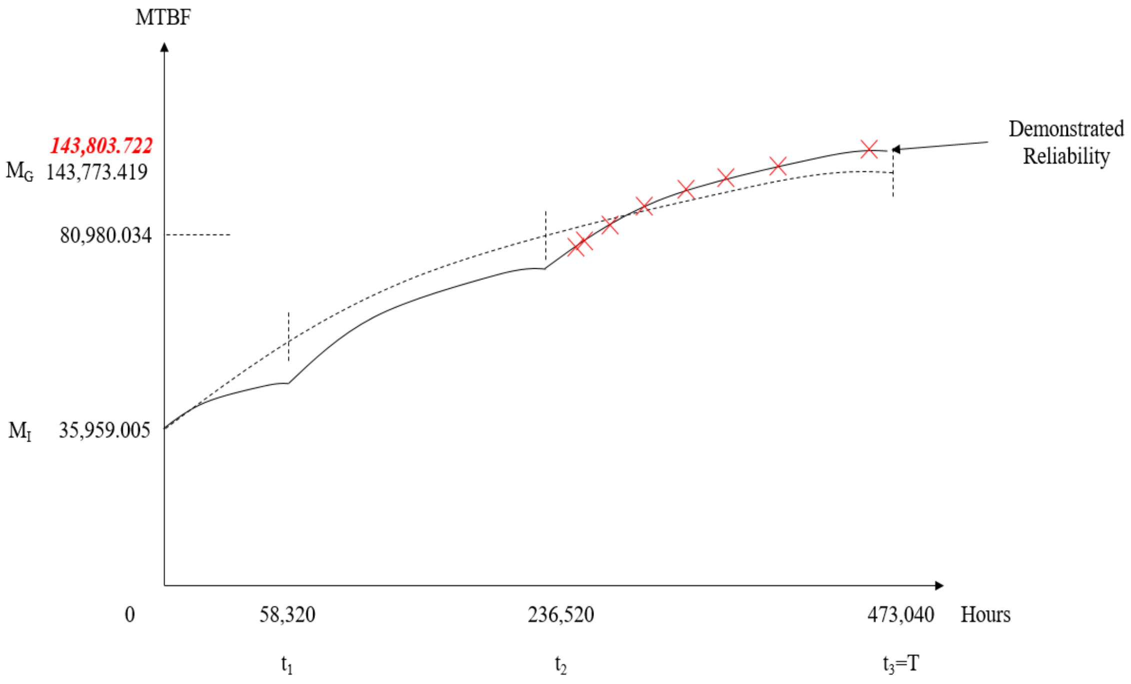
✂ Figure 3: Idealized growth curve for reliability growth management ✂



✂ Figure 4: Tracking growth curve for test phase 1 ✂



✂ Figure 5: Tracking growth curve for test phase 2 ✂



✂ Figure 6: Tracking growth curve for test phase 3 ✂

CONCLUSION

It is necessary to utilize reliability growth management to accomplish the reliability requirement for complex systems. The objective of this study involves analyzing reliability growth management for a hybrid DC-DC converter based on AMSAA models for operating systems. Although several previous studies examined reliability growth management, it is still difficult to appropriately implement the demonstration of reliability growth management. In this study, reliability growth management is performed by reliability growth planning and tracking. In order to prove the reliability growth management, this study uses an implementation of reliability growth management for a case study involving a hybrid DC-DC converter based on Crow-AMSAA models. The case study demonstrated that the estimated failure intensity function effectively identifies the current reliability of a target system, and this aids a decision maker to adopt corrective measures when activities reducing system failures are needed.

A future study will involve a demonstration of appropriate failure intensity functions. Although the Crow-AMSAA model corresponds to the most popular NHPP reliability growth model, it involves a problem wherein the estimation for an early time period is poor. Thus, it is of immense importance to consider other approaches to identify more appropriate failure intensity functions.

ACKNOWLEDGEMENTS

This work was partially supported by Defense Acquisition Program Administration and Agency for Defense Development (UD150042AD, UD1600BD); ICT R&D program of MSIP/IITP (R-20150505-000691); National Research Foundation (NRF-2015R1A2A2A01005871) by the Ministry of Education, Science and Technology, Korea**;** and a grant (17CTAP-C129828-01) from the Infrastructure and Transportation Technology Promotion research program funded by the Ministry of Land, Infrastructure and Transport of the Korean government.

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