2581-4575

International Journal For Recent Developments in Science & Technology

Crossref

A Peer Reviewed Research Journal

SOLICITATION OF CONSISTENCYTRADE METHODOLOGY IN NEXT COMPEERS SATELLITE CLOUT SYSTEM DESIGN, MANUFACTURING, AND TESTING

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ABSTRACT

Space systems are complex and need to perform under extreme environmental conditions for its expected life, so it is vital to use methodological risk identification and validation of the product in the design stage. For this purpose, the reliability analyses, inspections, and environmental tests mentioned in this paper have been performed methodically during several projects in TUBITAK UZAY. In this paper, TUBITAK UZAY reliability engineering methodology, where ECSS, European Cooperation on Space Standardization standards are used as a guideline, are presented and a real application has been performed for TUBITAK UZAY's Next Generation (NG) Power Distribution Module, UYGAR. Since UYGAR is designed as a part of TUBITAK UZAY's NG power system architecture for Low Earth Orbit, Geostationary Earth Orbit, and Science Missions with a long life high reliability expectation; reliability engineering approach at the beginning of the project becomes crucial. Moreover, power system special requirements are tailored according to European Standard for Space and Electronic Equipment "ECSS-E-ST-20C" and Electrical Power Systems for Unmanned Spacecraft "AIAA-S-122-2007", by considering single point failure and failure propagation free design to make the electronic design more challenging/robust and make reliability engineering involved in all phases of the project life.

INTRODUCTION

Recent developments in microelectronics and additive manufacturing have enabled miniaturization of systems and the implementation of distributed architecture, thus leading to the development of constellation and mega-constellation of mini and nanosatellites. These new concepts imply the utilization of a standard, low cost satellite bus and the reduced reliability and decreased lifetime become acceptable considering that the huge number of orbiting satellites can overcome problems due to single satellite failure. This new paradigm in conceiving

space missions sees a growing role for the reliability analysis in spacecraft design. Besides traditional design sciences, risk management and reliability engineering are becoming increasingly more relevant in the space domain. As for aviation, the future of space safety presents even a greater challenge about providing models and methods for supporting decision-making, to free decisions from hidden goals, biases, and subjective emotions.

The remainder of the paper is organized as follows. It provides an overview of the development and application of FMECA in space operations, detailing the current state of research and industrial practice, with particular reference to CubeSat architectures. Details the proposed method, clarifying the definition of specific FMECA coefficients valuable for the case under analysis. Section 4 presents an extended case study related to the application of the proposed risk management process for the purpose of managing risks of a university CubeSat. Finally, the conclusions summarize the contributions of the paper, providing potential paths for future research.

Environmental tests

For the environmental tests, TUBITAK UZAY has known the importance of getting early reliability feedback by test. Environmental tests should be completed before the end of qualification level to validate design. By this way, finding design weaknesses as early in the product design cycle as possible is ensured and substantial profit is added to the bottom line. In prototype model, assembly methods of MOSFETs, linear/DC-DC regulators, or other large components have been investigated; different application methods are issued on bare boards, the applied samples has been set under vibration tests. The feedbacks are issued in qualification model waiting for the qualification level tests. For the qualification test approach, ECSS – Testing “ECSS-E10-03C”, Test Requirements for Launch, Upper Stage, Space Vehicle “MIL-STD-1540E” for vibration and thermal-vacuum cycles tests and the combination of MIL-STD-461F and AIAA-S121-2009 for EMI/EMC tests are followed as a guideline. The qualification test approach were explained in [8] in detail.

Reliability and Hazard Functions

Reliability is the probability that a product will operate or service will be provided properly for a specified period of time under the design operating condition without failure. Reliability of a system is analyzed based on the reliability analysis of components of that particular system on the basis of failure data from devices in-service. Performing a direct reliability analysis requires that the most adequate probability distribution for the reliability analysis to be chosen from a family of commonly employed distributions for such components is selected on the basis of a combination of all these aspects. The most adopted reliability models for electrical components of any power system are Gamma, Normal, Lognormal and Weibull. Recently Inverse Gaussian distribution, the Inverse Weibull distribution, the Birnbaum-Saunders distribution, the Log-logistic distribution and more are significantly used for electrical components reliability in power systems.

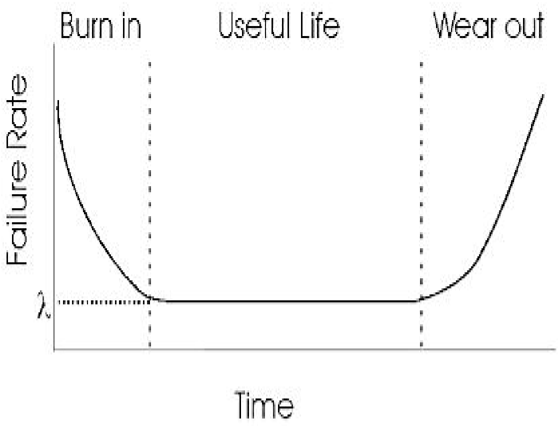
Hazard function h(t) is the conditional probability of failure in time interval ‘t’ to (t+dt), given that there was no failure at time ‘t’ divided by the length of the time interval dt.

$$h(t) = \frac{f(t)}{R(t)}$$

Where f(t) is probability density function and R(t) is reliability function. The cumulative hazard function H(t) is the conditional probability of failure in the interval 0 to ‘t’. If the total number of failures during the time interval 0 to t.

$$H(t) = \int_0^t h(\tau)d\tau$$

Hazard function is also referred as hazard rate or instantaneous failure rate in reliability theory. It is very important for power system design engineers, repair and maintenance people. Hazard rate is a function of time and it is a bathtub-shaped function.



Bath tub shaped hazard rate function graph

Many components in power systems exhibit constant failure rate during their lifetimes, this occurs at the end of the early failure region. Burn-in is performed by subjecting components to stress slightly higher than the expected operating stress for a short period in order to weed out the failure due to manufacturing defects. Most of the mechanical components in Powersystems such as rotating shafts, valves and cams- exhibits linearly increasing hazards rate due to wear out, whereas components such as sprigs and elastomeric mounts exhibit linearly increasing hazard rate due to deterioration. Relays in power systems also exhibit linearly increasing hazard rate. Most power system components (both mechanical and electrical) exhibit decreasing hazard rates during their early lives. When Hazard rate function [h(t)] cannot be represented linearly with time then Weibull model is used where

$$h(t) = \frac{\gamma}{\theta}\left(\frac{t}{\theta}\right)^{\gamma-1}$$

When components or products experience two or more failure modes then hazard rate is described by Mixed Weibull model. If the hazard function is initially constant and then begins to increase rapidly with time then exponential model is used, where

$$h(t) = be^{\alpha t}$$

Most of the mechanical components in power systems, subjected to repeated cyclic loads exhibit normal hazard rates. But there is no closed form expression for the reliability or hazard rate functions. The CDF of the life of a component is represented by:

$$F(t) = P[T \leq t] = \int_{-\infty}^{t} \frac{1}{\sigma\sqrt{\pi}}\left[-\frac{1}{2}\left(\frac{\tau-\mu}{\sigma}\right)^2\right] d\tau$$

For the life prediction analysis on UYGAR, four different conditions were taken into account. These were the three different types of power distribution switches in the system and then an imaginary condition which realizes all three types power distribution switches (total 12 switches) in the system working together as single unit. For three different types of switching each power distribution switch, the reliability value is greater than 0.99 @ End of Life (EOL) for the interface temperature of -35 °C and 70 °C. Moreover, considering the whole module with its all components, the total reliability figure is nearly 0.955 when the all power distribution switches as taken as a single unit in reliability block diagrams as an imaginary condition. During the reliability predictions, components duplications on the module have not been taken in account. Therefore, the reliability figures should be expected higher than the values given above. Another work with UYGAR is that when the PCB was added to calculations, the equivalent reliabilities of the system for four different working conditions became lower than the original reliability values. One more time, these have proved us that choosing high reliability components and performing redundancy increase the reliability while the PCB is a very critical part of the system and it can decrease the reliability dramatically. Thus, all inspection and quality control steps for the PCB were performed painstakingly before and after assembly procedures.

LITERATURE REVIEW

Recent blackouts in Victoria, Queensland, New South Wales and in other parts of the Australia due to bush fires, floods and other natural disasters including Fukushima nuclear disaster have, however, focused attention on the need for an investigation and evaluations of Electrical Power Systems. Power system is a complex system, has numerous facilities and structures, systems and sub-systems, components and equipment, and has a complex communication among all those. The basic function of a power system is to supply energy as economically as possible and with a reasonable degree of continuity and quality its intended system. Power system reliability can be assessed based on system configuration, aging, component reliability and delivery of power to the load. Due to its complexity, power system has many issues in the field of power systems reliability.

Reliability is one of the most important criteria, which must be taken into consideration during planning and operation phases of a power system. Electric power sector almost all over the world is undergoing considerable changes in regard to structure, operation and regulation which includes Smart Grids, Embedded Generation/Micro Generation (Roof top PVs, Wind forms, Geothermal and Gas-fired power stations), However, from the reliability point of view in this “new era”, methods, algorithms and computer software capable of assessing at least the adequacy of systems much larger than in the past are needed.

To minimise the possibility of future blackouts, requires implementation of reliability policies that emphasize four factors essential to meeting the requirements of the new standards:

1. Continued development of sufficient electric generation resources, transmission delivery

infrastructure, and demand response programs to reliably meet forecasted future electricity demands.

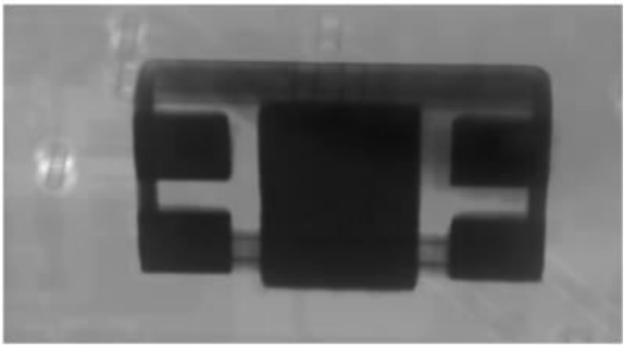
2. Effective and competent real-time operation and maintenance of that infrastructure to reliably produce and deliver electricity on a real-time basis, along with prompt restoration of adequate physical and cyber security to protect against malicious intrusion and attacks on critical facilities, diversity and redundancy of fuel supply.

The Australian Energy Market Operation (AEMO) is responsible for planning and directing the augmentation of the shared transmission networks. AEMO applies a probabilistic approach to planning the Victorian shared transmission network. Under that approach, investment only proceeds when the expected benefit exceeds the cost. The probabilistic approach involves the occurrence of plant outages occurring within the peak load season and weighting the cost of such an occurrences by its probability.

METHODOLOGY

Reliability inspections

For the inspections, bare board inspections, component inspections and assembled module solder joint stereomicroscope inspections have been done to ensure higher reliability quality assurance and improve module manufacturing process for space applications. The feedbacks from prototype model inspections are reflected to qualification model PCB design. X-ray Inspections were performed to solder joints of large SMD components mounted by vapor phase soldering to detect the voids, and avoid the use of assemblies with solder joint void. Moreover, the prototype assemblies of UYGAR have been inspected by thermal camera to detect the unexpected hot spots, failures, or thermal analysis validation. Visual and X-ray inspections were executed before assembly, after assembly and after vibration tests and verified according to ECSS quality control instructions. As an example, one of the X-ray output for the linear regulator on the PCB is illustrated in Figure 7. As a result, appropriate and inappropriate findings were listed and necessary actions, such as material change and renewal of soldier joint, were taken.



Life Prediction Analysis

Life Prediction Analysis is applied to optimize the reliability of a design, to predict the in–service reliability of a product and to provide failure probability data for the expected life time. To perform the life prediction analysis on UYGAR, the following steps were performed respectively:

- The failure rates related to each component obtained or calculated according to manufacturer data, related standards or related software,

- Failure rates and reliabilities of all blocks in the system were calculated for 5 years of lifetime and by exponential distribution, and the constant failure rate model was used in reliability calculations,
- The failure rate of the printed circuit board (PCB) was calculated according to the PCB parameters,
- First of all, the reliability of system was calculated according to only component failure rates without PCB, and with serial, parallel/redundant conditions between blocks,
- Later on, the reliability of system was calculated according to component and PCB failure rates but without serial, parallel/redundant conditions between blocks,
- Eventually, the reliability of system was calculated according to component and PCB failure rates and with serial, parallel/redundant conditions between blocks and with different working conditions.

The analysis was performed according to the standards below:

- IEC TR 62380, “Reliability data handbook – Universal model for reliability prediction of electronics components, PCBs and equipment”,
- ECSS-Q-ST-30-11C, “Derating - EEE components”,
- MIL-HDBK-217F, Notice 2, “Reliability prediction of electronic equipment”.

RESULTS

As a result of the performed analyses, mitigation methodologies for better cost effective reliability figures such as utilization of space qualified and flight heritage components, physically separated internal redundancy, performing screening-shielding wherever possible, utilization of transistor-transistor logic technologies, and PCB quality and mounting quality at relatively high levels have been better understood. These analyses have given as feedbacks to the designers for better circuit design and for redundancy approach within the electronic design and this resulted in a high reliable unit with many internal redundancy approaches. When the system level redundancy is considered for a power distribution unit, where the redundant platform modules and payloads have redundant power distribution switches in another power distribution module, the reliability of the power system is expected to be close to unity.

CONCLUSION

In this paper, TUBITAK UZAY reliability engineering methodology and application of this methodology in TUBITAK UZAY’s NG power distribution module, by concurrent engineering design of UYGAR are presented. Reliability analyses, their details, results, and reflection to electronic designs, inspection methods to ensure reliability and project quality assurance at prototype and qualification manufacturing phase, pre-reliability tests and qualification test approach.

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