A Review on Methods used for Reliability Assessment of Power Electronic Systems

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Abstract—**With wide-spread application of power electronic systems across many different industries, their reliability is being studied extensively.This paper makes a comparative study on the major aspects in the assessment of power electronics reliability available in literature. Also it provides a brief overview on the assessment methods for reliability of power electronic systems.**

Keywords: physics of failure, MILHDBK, fault tree analysis, Matlab/Simulink.

I. INTRODUCTION

POWER electronic systems play an increasingly important role in adjustable-speed drives, unified power quality correction, utility interfaces with renewable energy resources, energystorage systems, and electric or hybrid electric vehicles (HEVs). The power electronic techniques provide compact and high-efficient solutions to power conversion. However, introduction of power electronic techniques into these application fields challenges reliability of the overall systems. One of the concerns related to reliability lies in the power semiconductor devices and electrolytic capacitors that are the most vulnerable links. Most of power electronic converters are not equipped with redundancy. Therefore, any fault that occurs to the components or subsystems of the system will lead to shutdown of the system.

These unscheduled interruptions not only cast significant safety concerns, but also increases system operation cost and partially offsets the benefits of introducing power electronic systems.Over the past several decades, much attention has been directed to the reliability of power electronic systems. The three major aspects of power electronics reliability are discussed, respectively, which cover from physics-of-failure(PoF) analysis of critical power electronic components, state-of-the-art design for reliability process and robustness validation, and intelligent control and condition monitoring to achieve improved reliability under operation.

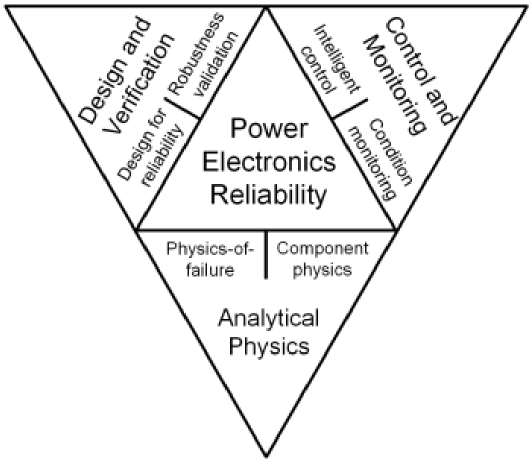

Fig.1 power electronic reliability research needs seen from today.

To map the reliability from component level to the system level, Reliability Block Diagram (RBD), Fault-Tree Analysis (FTA) and state-space analysis (e.g. Markov analysis) are widely applied methods. the three methods are conventionally applicable to constant failure rate cases, which are corresponding to the handbook based reliability prediction methods. It should be noted that the system reliability depends not only on components, but also on packaging, interconnects, manufacturing process, and human errors.There are several major challenges and opportunities in the research on reliability for power electronic systems[1]. Various methods for the assessment of reliability of power electronic system have been suggested in literature namely

II. SYSTEM LEVEL RELIABILITY BASED ON PHYSICS OF FAILURE (POF).

IGBT modules are focused in the case study for study of thermal effect based on root cause failure mechanism analysis, defects and stress on product reliability,for a 2.3 MW wind power converter .Also lifetime prediction of these modules are evaluated [2], [4]. The case study for DC-link capacitors is performed on a 1 kW 400 V DC-link PV inverter. According to the electrical stress analysis, the thermal stresses of the capacitors are estimated based on their specific thermal models. The lifetime of the selected capacitors is therefore estimated based on the mission profile, operation mode and specific lifetime model [3].

II. BY CALCULATING FAILURE RATES BASED ON MILHDBK, MILITARY HANDBOOK FOR THE IDENTIFICATION OF ELECTRONIC COMPONENTS.

Prediction of power converter reliability using part stress method can be performed once the thermal and electrical stresses are known. The MILHDBK[20] documents provide useful details on thermal and electrical stresses in components and the MIL-STD-756 [21] provide details on reliability analysis which become an integral part of the design process [5].Comparative reliability evaluation of four DC/DC converters including buck, forward, fly backand push-pull, designed for a Low Earth Orbit five-year space mission is performed. Converters reliability predictions were done by calculating failure-rates, based on MIL-HDBK-217F [6].The mean time between failures MTBF, which is the reciprocal of the failure rate λ, can be calculated using the procedure outlined in the MIL-HDBK 217.This handbook lists the failures rates λb for electronic devices; however, to predict the reliability of an electronic assembly, the listed value must be multiplied by the πfactors that take into account the stresses (electrical, thermal, etc.) on the devices .A Mosfet includes four stress parameters: π_A, related to the application (switching, linear, power, etc); π_E, related to the environment (missile, aerospace, ground benign, ground mobile, etc). π_Q, related to the device quality (commercial, military); π_T, related to the temperature. A capacitor includes five stress parameters: π_C, related to the capacitance value; π_E, related to the operational environment; π_Q, related to the capacitor quality; π_T, related to the temperature; π_V, related to the voltage rating. The actual failure rate is

$$\lambda = \lambda_b \left(\prod_{i=1}^{n} \pi_n \right)$$

The mean time between failures is given by

$$MTBF = \lambda^{-1}$$

The reliability R can be calculated as:

$$R = e^{-\lambda t}$$

Therefore, in order to assess how well the converter complies with the operating-time goal, the mean time between failures (MTBF) of the hard-switching converter is calculated [7]. Reliability of two-stage interleaved boost converter, Single-stage flyback converter and two-stage boost forward PFC converter is calculated. The reliability calculations are done by referring the MIL-HDBK 217. It can be concluded that as the number of components decreases, reliability of a system increases [8]. The actual reliability calculations are performed using RELEX, a commercial software package that includes a database with the component failure rates and executes the procedure in MIL-HDBK 217. It calculates the stress factors when maximum voltage, current, and power dissipation for each component are provided. It also calculates and plots reliability parameters, such as failure rate or MTBF, and its behaviour over temperature or time [9].

III. USE OF FAULT TREE METHOD FOR ASSESSMENT OF RELIABILITY.

FTA (Fault Tree Analysis) is a top-down approach to identify all potential causes leading to system failure. The computation of the system's failure probability is the main goal of this analysis, as this value can be used to calculate other important system reliability parameters such as Failure Rates, Mean Time between Failures, and Reliability. The inverter module will be powered either by the rectifier (in normal operation) or by battery system (in back-up operation).Fig. 2. Shows Reliability Model of Online UPS (without Bypass).

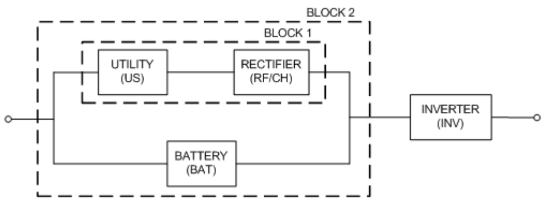

Fig2.Reliability Model of Online UPS

The fault tree diagram of the online UPS without bypass is shown in Fig. 3.

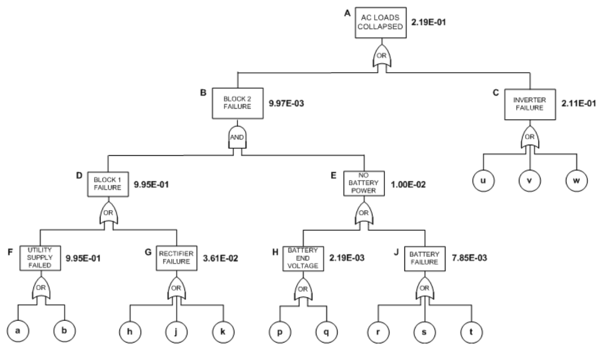

Fig.3. Fault Tree of Online UPS without Bypass.

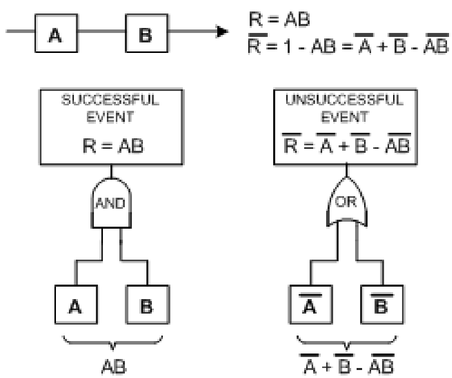

Fig.4. Transformation of Reliability Block Diagram to Fault Tree Logic Diagram.

The transformation of the two element series reliability block diagram to the fault tree logic diagram using the AND and OR gates are shown in Fig.4. The probability of failures of the UPS components from statistical data and their overall system failure probability is calculated [10].
In a system where different interconnected components function together, fault tree analysis (FTA) and event tree analysis (ETA) can be helpful in systematically identifying interdependencies in order to assess potential risks. Scenarios have to be identified where the system is not functioning properly or at all. They are expected to be combined in a Probabilistic
Safety analysis (PSA) based approach, being capable of giving a prioritization of the risks and the most dominant scenario associated to a specific situation [11]. In order to reduce the truth table of the tree corresponding to the considered fault, an expert system was developed, by using the programming language CLIPS. The specific algorithm developed in CLIPS language simplifies the table of truth for a logical complex circuit with more inputs (sources) and outputs [12].The traditional fault tree analysis method will face the combination explosion problem when using the minimum cutsets (MCS) to complete the large fault tree analysis. While when using the Binary Decision Diagram(BDD) method, the occurrence probability of the top event can be directly obtained from the graph by using BDD method analysis of fault tree, so as to simplify the process of the qualitative and quantitative analysis of the fault tree. A fault tree can be converted to BDD using an algorithm[13].Markov modeling and Fault tree analysis are the two analysis techniques that are mostly used by utilities to evaluate the reliability of Special Protection System (SPS).Comparing the two algorithms,FTA technique is much easier to model as compared to Markov modelling [14].A fault tree analysis method based on fuzzy theory to evaluate the reliability of protection system for the household appliances is suggested in [15] with an algorithm for the same.

IV. USE OF MATLAB SOFTWARE FOR THE ASSESSMENT OF RELIABILITY.

A Matlab program is developed which computes the component junction temperature using the conduction and switching loss formulations. Thus reliability analysis of the power conditioning system for a Permanent Magnet Generator based Small Wind Turbine system could be obtained[16].Optimal design of the Cuk converter based on reliability constraints can be obtained by optimizing duty cycle (D) and switching frequency (fs) of the converter.For different values of injected power to the load, duty cycle (D) and switching frequency (fs*)* are optimized considering different scenarios using MATLAB simulation software [17].By creating models using Matlab/Simulink reliability and safety assessment of engineering systems which are model-driven can be developed [18].A suitable Matlab Programme compares IGBT and diodes used in inverters based on failure rates for which the thermal stress are obtained from data sheets. IGBT based inverter will more reliable than diode based since failure rate of diode will higher than the IGBT [19].

CONCLUSION:

This paper has presented the methods used for reliability analysis of power electronics systems. This literature review has been developed to explore perspectives on various methods of reliability assessment for the benefit of researchers, reliability engineers ,industrialists and end users of power electronic systems. While this is not a detailed analysis of any one of the methods, this work is intended to be a reference to those who are working on this topic.

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