PERFORMANCE DEGRADATION ANALYSIS OF FAULT-TOLERANT AIRCRAFT SYSTEMS

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ABSTRACT

This article shows the recent developments of the software tool SYRELAN (**Sy**stem **Rel**iability **An**alysis), which provides an environment for system engineers to model and analyse complex systems of various technical backgrounds. The core of each system model is the hybrid model, imaging the failure-free system architecture with the use of RELIABILITY BLOCK DIAGRAMS and the system behaviour and interactions of the components with the use of CONCURRENT FINITE STATE MACHINES. In light of the fact that for modern and complex fault-tolerant systems not just the nominal behaviour but also the degraded system states with available performance levels are essential for system design, the existing environment has been enhanced by a PERFORMANCE DEGRADATION ANALYSIS which considers active and standby system components. The new method is demonstrated using the electrical power supply system of the AIRBUS A320.

KEYWORDS

Aircraft Power Systems; Degraded System; Fault Tolerance; Finite State Machine; Performance Degradation; Redundancy Management; Reliability Analysis; Reliability Block Diagram; System Design

ABBREVIATIONS AND SYMBOLS

APU	**A**uxiliary **P**ower **U**nit
ATA	**A**ir **T**ransport **A**ssociation
CFSM	**C**oncurrent **F**inite **S**tate **M**achines
CSM/G	**C**onstant **S**peed **M**otor/**G**enerator
MMEL	**M**aster **M**inimum **E**quipment **L**ist
PDA	**P**ower **D**egradation **A**nalysis
RAT	**R**am **A**ir **T**urbine
RBD	**R**eliability **B**lock **D**iagram
TR	**T**ransformer **R**ectifier

a	$[-]$	active state
f	$[-]$	transfer function
$\mathbf{F}$	$[-]$	input vector
g	$[-]$	output function
K	$[-]$	component indicator variable
$\mathbf{K}$	$[-]$	set of components
L	$[-]$	performance indicator variable
M	$[-]$	minimal path
P	$[-]$	propability
p	$[\%]$	performance
ϕ	$[-]$	system function
λ	$[\mathrm{s}^{-1}]$	failure rate
$\mathbf{x}$	$[-]$	state
$\mathbf{Y}$	$[-]$	output vector
$\mathbf{Z}$	$[-]$	state vector
$\hat{\mathbf{Z}}$	$[-]$	initial state vector

1 INTRODUCTION

Safety-critical systems such as aircraft systems have always been subject to rigorous testing and analysis to fulfill the requirements of industry standards, such as those set by the JAA (**J**oint **A**viation **A**uthority) [6]. To conform to these strict requirements and to design economically viable systems fault-tolerant systems have been established.
Fault-tolerant aircraft system design entails not only knowledge about the fault-free, nominal behaviour of the system, but more important about how the system behaves under the influence of single or multiple component failures, that is, when the system is in a degraded state.
The design of such fault-tolerant systems, comprising all kinds of aircraft systems, such as computer, communication and actuation systems, is complex and multidisciplinary. Additionally recent developments in *More Electric Aircrafts* enlarge the complexity of the connection between power supply and power consumer. New power supply concepts with several electrical power systems together with

the corresponding development of power consumers, such as electromechanical actuators, offer vast implementation potential and are at the same time cause for increasing combinatorial complexity. Consequently, a software tool is necessary which supports the work of system engineers already in the predesign phase [2, 7]. The tool SYRELAN offers system engineers an intuitive, familiar modelling environment using RBDs with positive logic mapping of the real system architecture. For analysing the dynamic behaviour like reconfiguration after failures SYRELAN offers the ability of CFSMs to define different states for each component and dependencies between the components by the state transitions. The interaction of the RBD and the CFSMs, called the hybrid model, enables the user to analyse the reliability for any system in the nominal state and for each degraded state with residual reliability.
Chapter 2 introduces the hybrid system model using RELIABILITY BLOCK DIAGRAMS and CONCURRENT FINITE STATE MACHINES. The following chapter outlines the background of the PERFORMANCE DEGRADATION ANALYSIS, on the one hand for systems with only active components and on the other hand for systems with both active and standby components, which is valid for most aircraft systems. In chapter 4 the method is demonstrated using the AIRBUS A320 electrical power supply system with consideration of three different system states, nominal, first degradation by the loss of a transformer rectifier (dispatchable) and second degradation by a failure of an integrated drive generator (not dispatchable).

2 HYBRID SYSTEM MODEL

The reliability modelling of fault-tolerant aircraft systems using SYRELAN can be divided into two modelling levels, one mapping the system architecture, the other defining the redundancy management. Therefore the SYRELAN tool uses RELIABILITY BLOCK DIAGRAMS (RBDs) for the definition of the nominal system architecture. To map the switching conditions of different, redundant components CONCURRENT FINITE STATE MACHINES (CFSMs) are implemented. Both methods form the hybrid system model approach for the reliability analysis.

2.1 Reliability Block Diagrams

The basis for modelling system architectures using SYRELAN is a structural image of the fault-tolerant aircraft system using RELIABILITY BLOCK DIAGRAMS (RBDs). These RBDs are defined by a TOP EVENT, which describes the system state to be analysed. This TOP EVENT is defined in positive logic, e.g. *probability of power on a busbar* for an electrical power system, whereas FAULT TREES analyse the event of a system failure. Mathematically, the TOP EVENT is described by BOOLEAN algebra, which is based on binary logic [9]. In doing so, each component is represented by an indicator variable K_i, for which the following applies [9]:

(1) $K_i = 1$ for component is functional

and

(2) $K_i = 0$ for component is **not** functional.

Using the indicator variable K_i an expectation value $E(K_i)$ is established which is equal to the component reliability R_i, where the component reliability can be described with arbitrary distributions [9]. In the case of aircraft systems, component failures are generally assumed to be independent of age and are purely random based on the bath-tub curve, so that an exponential distribution $R_i(t) = e^{-\lambda_i \cdot t}$ with a constant failure rate λ_i is used [9].
The TOP EVENT of the analysis is described by a system function $\phi(\mathbf{K})$ which is generated by determining the minimal paths, where each minimal path represents a way which meets the TOP EVENT. To understand the way the system function is formed figure 1 demonstrates an example of a bridge structure with an unidirectional cross-connection.

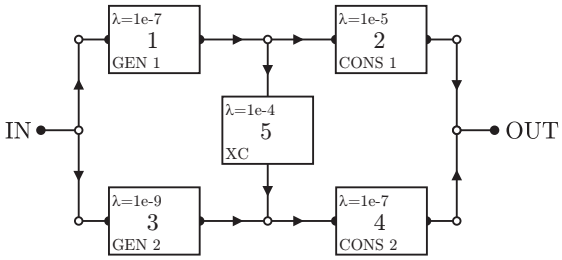

FIGURE 1: Example of an unidirectional bridge structure RBD

The resulting minimal paths of the system are:

(3) $M_1 = K_1 \wedge K_2, M_2 = K_3 \wedge K_4$ and $M_3 = K_1 \wedge K_5 \wedge K_4$.

Subsequently the derived minimal paths are combined by a logical **OR** under consideration of the monotony conditions [9]. In the resulting function several components appear multiple times, which would lead to an incorrect probability result of the defined TOP EVENT. To avoid this yet allow multiple usage of single components, an orthogonalization algorithm called HEIDTMANN-Algorithm is used which eliminates the multiple components and allows the user to analyse even complex RBDs in a reasonable computation time. The resulting function is the system function $\phi(\mathbf{K})$, which is defined as follows [9]:

(4) $\phi(\mathbf{K}) = 1$ for system is functional,

and

(5) $\phi(\mathbf{K}) = 0$ for system is **not** functional,

where $\mathbf{K}$ describes the set of all aircraft system components

(6) $\mathbf{K} = \{K_1, K_2, \ldots, K_n\}$.

2.2 Concurrent Finite State Machines

As a lower modelling level CONCURRENT FINITE STATES MACHINES (CFSMs) are used to image the state discrete dynamic behaviour of the system components, e.g. redundancy management [7]. Figure 2 shows the MOORE

CFSMs embedded in the RBD block and the possibility to access the hybrid model using the component failure vector **F**. The interconnection between both modelling levels will be described in section 2.3.

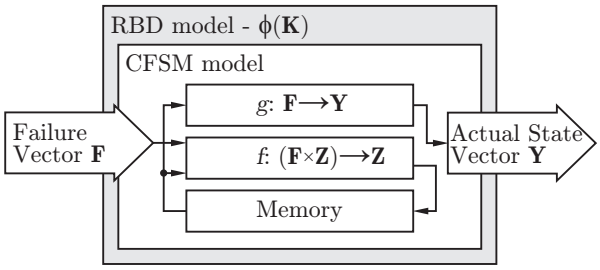

FIGURE 2: CFSM model embedded into RBD model

The CFSMs can be described using a 6-tuple $\mathbf{A} = \langle \mathbf{F}, \mathbf{Y}, \mathbf{Z}, \hat{\mathbf{Z}}, f, g \rangle$ [4]:

- **F** is the input vector,
- **Y** is the output vector,
- **Z** is the state vector,
- $\hat{\mathbf{Z}} \subseteq \mathbf{Z}$ is the initial state vector,
- $f : \mathbf{F} \times \mathbf{Z} \rightarrow \mathbf{Z}$ is the next following state vector,
- $g : \mathbf{Z} \rightarrow \mathbf{Y}$ is the output function.

The input vector **F** contains the failed-injected components of the set **K**. Using the output function g the outputs **Y** of the internal states **Z** are independent of the input function. For the state vector with a length i, where i is the number of components, five different states $Z_i \in \{Z_1, \ldots, Z_5\}$ are possible for each component [7]:

"active" ← **GREEN**: from the start of the mission, the working component a is subjected to full stress. The failure rate is λ_a.

"active–hot" ← **YELLOW**: from the beginning of the mission, reserve element h is subjected to the same stress as the actual working component a. For the failure rate the following applies: $\lambda_h = \lambda_a$.

"passive–warm" ← **ORANGE**: the reserve element w is subjected to less stress until failure of working component a, (or until w itself fails). For the failure rate the following applies: $0 < \lambda_w < \lambda_a$.

"passive–cold" ← **LIGHT BLUE**: until failure of working component a, reserve element c is not subjected to any stress. For the failure rate the following applies: $\lambda_c = 0$.

"isolated" ← **RED**: Failure state of the component. The ending is „i".

Between these five discrete states 16 transitions T_i can be defined, depending on the set of possible states for each component and an initial state for the nominal system state. Figure 3 illustrates the five different states and the transitions between them.

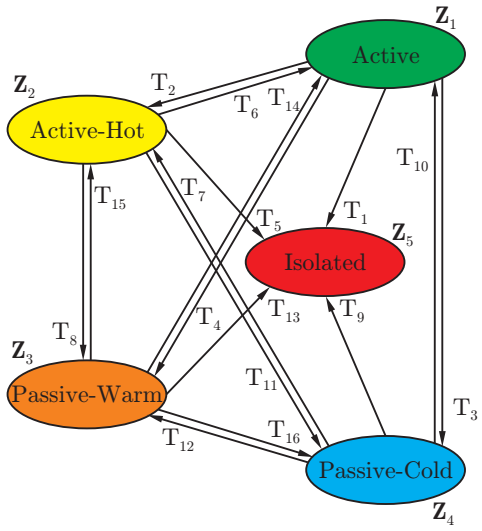

FIGURE 3: Different states and transitions of the CFSMs

The conditions of the state transitions are defined by logical syntax, addressing the system component and the component state. Additionally, it is possible to address not just single component states but also logical combinations of different component states by setting combined conditions. Apart from the different states it is also possible to use three different component types, *Hardware*, *Multifunctional Hardware* and *Multifunctional Software* blocks [7]. The simple *Hardware* block is used to image hardware components such as generators or contactors and uses one CFSM in the lower level. To image multifunctional hardware components the *Multifunctional Hardware* block can be used, e.g., for I/O ports. This type of block runs several dependent CFSMs in the background, so a single failure will lead to a simultaneous loss of all applications of the block. The third block is the *Multifunctional Software* block running several partitions with independent associated CFSMs, so that each partition can be independently declared as failed [7].

2.3 Hybrid Modelling Approach

The coupling of the RBD and the CFSM environment forms the hybrid modelling approach as shown in figure 4 [7]. This enables a user not only to consider different component states but also individual failure rates depending on their actual state as defined in section 2.2 [7].
As a result of the reliability analysis using the hybrid model a state tree is generated which lists the nominal and all degraded system states sorted by the component failures. Depending on the analysis settings the state tree contains information of the system $\phi(\mathbf{K})$, namely, the probability $P_x^s[\phi(\mathbf{K})](t)$ being in the current system state x, the residual reliability $R_x^s[\phi(\mathbf{K})](t)$ and the residual failure probability

$F_x^s[\phi(\mathbf{K})](t)$. Additionally it is possible to include for each system state the results based solely on a RBD analysis, which assumes only active components.

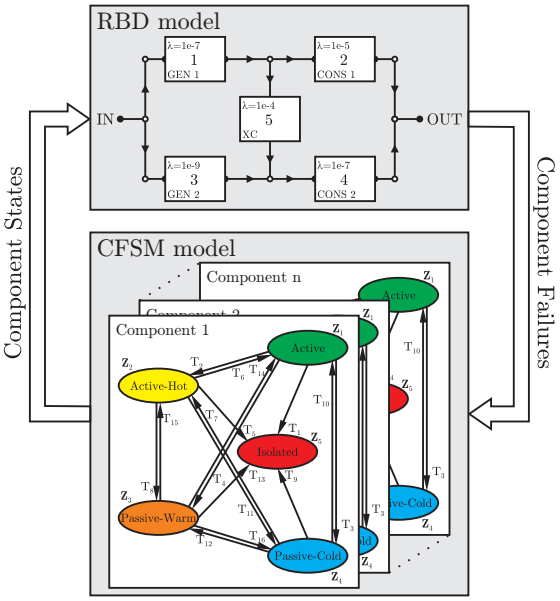

FIGURE 4: Coupling of the RBD and CFSM models

3 PERFORMANCE DEGRADATION ANALYSIS

This chapter presents the background of the PERFORMANCE DEGRADATION ANALYSIS (PDA). In section 3.1 the method is explained for active components. This method is based solely on the RBD model, as no information about the actual state of each component is used for the analysis. For the analysis of fault-tolerant aircraft systems with active and standby components, such as aileron actuactors in active/standby configuration or electrical power systems, the PDA is enhanced in section 3.2 to consider different component states.

3.1 Consideration of Active Components

The software tool SYRELAN currently provides the functionality of calculating the performance degradation probabilities based on the high-level RBD environment, without any information about the low-level CFSMs. Therefore the set of components $\mathbf{K}$ has to be enlarged by the parameter of a performance indicator variable for each contained component [10].

$$\mathbf{K} = \{(K_1, L_1), (K_2, L_2), \ldots, (K_m, L_m)\} \quad (7)$$

The performance indicator variable L_i is defined in line with the component indicator variable in equation (1) and (2) as follows:

$L = 1$ K is a Performance Component (8)

and

$L = 0$ K is **not** a Performance Component. (9)

Without the CFSM modelling environment which defines component state behaviour the RBD modelling environment considers every component to either be *active* or *isolated* in the system. System performance is 100% when all performance-supplying components are functioning and contained in a non-failed minimal path [9]. Thus, performance probabilities are determined using the premise that a system's components posses the boolean states *active* and *failed* and thus the performance of a system, p_s, is defined by the following definition [10]:

Definition 1 *The performance of a system is given by the cumulative total performance of all non-failed components which are in at least one functioning minimal path, as the performance of a component only counts if it contributes toward system functionality, that is, is not isolated by a failed component in the same minimal path.*

Mathematically this definition can be expressed by the summation of all performance values of all performance-supplying components:

$$p_{\phi(\mathbf{K})}[\phi(\mathbf{K}) = 1] = \sum_{i=1}^{m} p_{K_i}[L_i = 1] \quad (10)$$

with

$$p_{K_i}[L_i = 1] = p_i \quad \forall \quad K_i \in \mathbf{K} \quad . \quad (11)$$

After the calculation of the achievable system performances these values have to be combined with their probabilities. This is done by the combination of the set of minimal paths and the corresponding system performances. For each performance class, e.g. 50 %, a boolean system performance function ϕ_{p_s} is generated by the combination with a logical **OR** of the according minimal paths. In line with the calculation of the RBD system reliability for each performance level the system performance function is orthogonalized and solved, so that the result is equivalent to the probability of achieving a certain performance class.
In the case of fault-tolerant systems this PDA leads to a significant failure increase, as standby performance suppliers are considered to be in an active state. Hence the calculated performance values are incorrect. To compensate for this inaccuracy in the case of active and standby components the existing PDA is enhanced in the following section by differentiation between the actual component states.

3.2 Consideration of Active and Standby Components

From the outset the RBD-model PDA is not able to distinguish between components in an active state and those in one of the three SYRELAN standby states: *active-hot*, *passive-warm* and *passive-cold*, as presented in section 2.2. System components in any of these three standby states do not contribute toward instantaneous system functionality and thus the integration of their standby performance levels in the system performance calculation presents an inaccurate result.
For consideration of the actual state of each performance-supplying component it is necessary to hand a complete

system $\phi(\mathbf{K})$ over to the PDA. On account of this the set of components as defined in equation (12) is expanded by an indicator of failure detectability C_i:

$$\mathbf{K} = \{(K_1, C_1, L_1), (K_2, C_2, L_2), \ldots, (K_m, C_m, L_m)\}, \quad (12)$$

where each component can be described by a number of CFSMs depending on its block type. Additionally each CFSM of a component can have several performance values. These relations can be summarized as follows [10]:

$$K_i = \{CFSM_1, CFSM_2, \ldots, CFSM_m\} \quad (13)$$

and

$$CFSM_i = \{p_1, p_2, \ldots, p_n\}, \quad (14)$$

where p_1 is the CFSM's initial performance and $p_2, \ldots, p_n$ are conditional values. The transition between two performance values is governed by a specific performance transition T_p, familiar to the state transitions in section 2.2, triggered upon the fulfillment of an activation condition based on component declaration K_m and defined state x_m [8]. A performance transition T_{p_i} can be declared by:

$$\underbrace{T_{p_i}}_{\text{Transition}} = (\overbrace{K_j, CFSM_k}^{\text{component \& CFSM}}, \underbrace{p_a \rightarrow p_b}_{\text{performance change}} \mid \overbrace{(K_m, x_m)}^{\text{activation condition}}) \quad . \quad (15)$$

The PDA for consideration of active and standby components can be defined according to definition 1 as follows:

Definition 2 *The performance of a system is given by the cumulative total performance of all* **active** *components which are in at least one functioning minimal path, as the performance of a component only counts if it contributes toward system functionality, that is, is not isolated by a failed component in the same minimal path.*

In mathematical terms the available performance against the active state a_i of each component can be given as

$$p^a_{\phi(\mathbf{K})} = \sum_{i=1}^{N} p_{K_i}[L_i = 1] \quad \forall \quad K_i \in \mathbf{K} \quad (16)$$

where

$$K_i \in \mathbf{K} = \{K_i | (K_i = 1 \wedge a_i = 1 \wedge L_i = 1\}, \quad (17)$$

The additional indicator variable a_i represents the component's active state, rendering the system performance directly dependent on the conjunction of the variables K_i, L_i and a_i, i.e. $(K_i \stackrel{!}{=} 1) \wedge (L_i \stackrel{!}{=} 1) \wedge (a_i \stackrel{!}{=} 1)$.
Similar to the RBD analysis different performance classes A_i are composed considering all degraded system states, formally A_i is announced as an event [5]. The set of all performance levels $\mathbf{A}$ is described by equation (18).

$$\mathbf{A} = \{A_1, A_2, \ldots, A_n\} \quad (18)$$

Each event consists of several elementary events u_j which represent the individual performance levels. The probability of having the performance level u_j is equal to the probability of being in that elementary state. Hence the probability of obtaining a particular performance class $P(A_i)(t)$ is achieved as given by the following summation of the individual probabilities of achieving an individual performance level equal to the performance class [10]:

$$P(A_i)(t) = \sum_{u \in A_i} P\{f(u)(t)\} \quad . \quad (19)$$

Equation (19) allows the user to calculate the probability of discrete performance values. In the case of safety-critical systems it is often not only interesting to achieve a certain discrete value but also the probability of being in a defined closed performance interval $[0, A_i]$ in order to support a required system function. Once the absolute performance class probabilities have been found it is possible to determine these performance class intervals.
The probability of obtaining a system performance level in the interval $[0, A_i]$ is given by [10]:

$$\begin{aligned} P[0, A_i] &= P(A_i) + P(A_{i-1}) + \ldots \quad (20) \\ &\quad + P(A_{m+1}) + P(A_m) + F_{\phi(\mathbf{K})} \\ &= \left(\sum_{x=m}^{i} P(A_x) \right) + F_{\phi(\mathbf{K})} \quad . \quad (21) \end{aligned}$$

Where $F_{\phi(\mathbf{K})}$ represents the overall failure probability of the system $\mathbf{K}$ which is equal to the performance level 0% and can be determined by

$$F_{\phi(\mathbf{K})} = 1 - \sum_{i-1}^{n} P(A_i) \quad . \quad (22)$$

4 CASE STUDY

This section demonstrates the presented method and the application of the tool for analysing the electrical power supply system of the AIRBUS A320, as it is shown in figure 5.

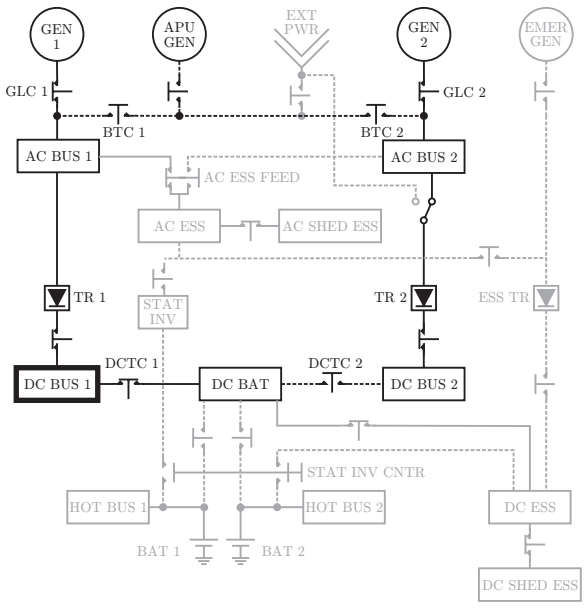

FIGURE 5: ATA 24 system layout of the Airbus A320

The ATA 24 system consists of two 90kVA integrated drive generators with a constant frequency and an auxiliary generator driven by the auxiliary power unit, which can replace either main generator. In the case of significant system failures the essential electrical consumers can be supplied by an 5kVA emergency generator powered by the ram air turbine. The time during the RAT unavailability is bridged by two batteries supplying the essential DC busbars, which also start the APU in flight and on ground [1].

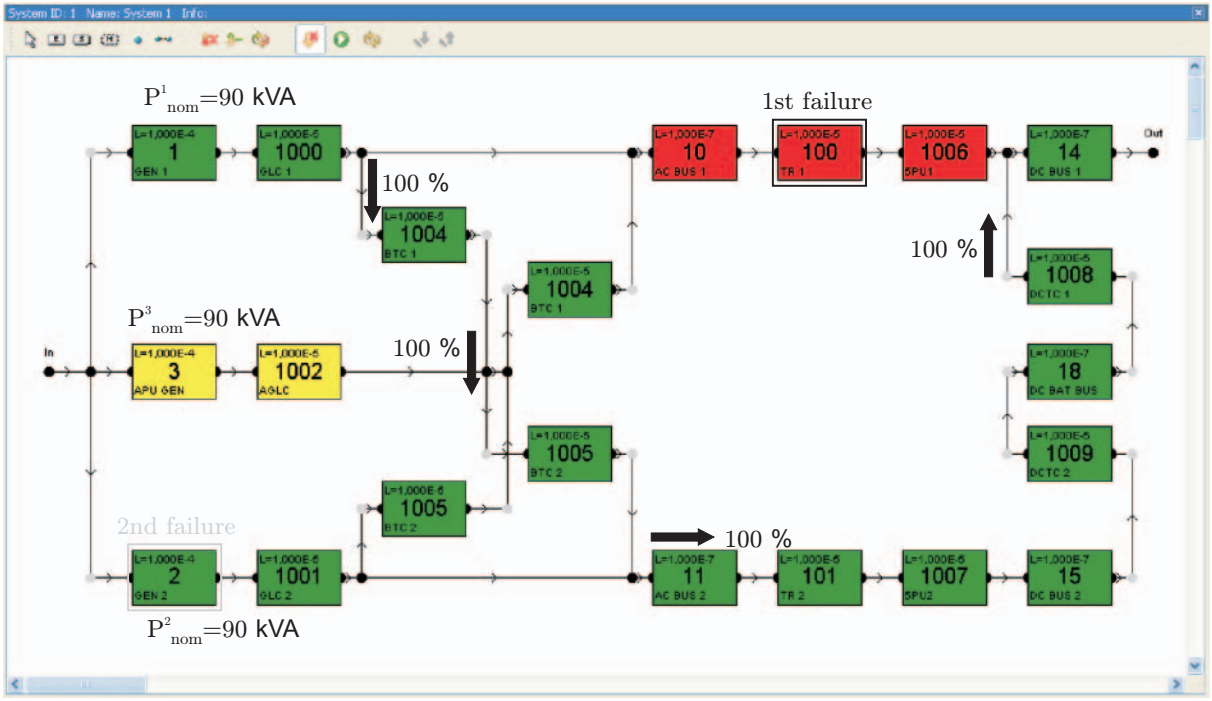

FIGURE 6: RBD for defined TOP EVENT *"Power Supply of DC Bus 1"*

4.1 System Model

Corresponding to the highlighted components in figure 5 *DC Bus 1* is taken for demonstration of the PERFORMANCE DEGRADATION ANALYSIS. Figure 6 shows the simplified RBD for the analysis of the defined TOP EVENT *"Power Supply of DC Bus 1"* after the first degradation modelled with the SYRELAN tool. Additionally to the RBD the performance flows are illustrated. The performance information is fictitious and not based on the actual system design, however it does properly illustrate the system behaviour in degraded states. In nominal state the DC busbar 1 is powered by the main generator 1.

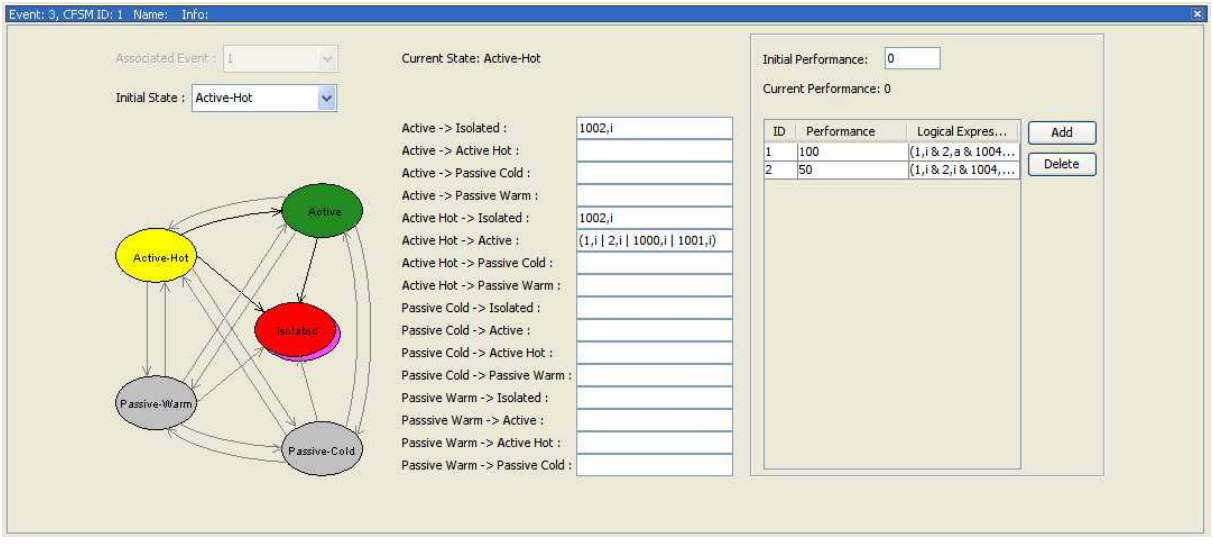

FIGURE 7: Definition of the APU generator CFSM and performance conditions

If one main generator channel fails it can be completely replaced by the APU generator channel over the bus tie contactors in bidirectional cross-connection between the three generation channels. If two generators fail the remaining generator is able to supply the two channels with certain reduced power. In the case of a failed distribution channel the DC busbar 1 can be supplied using the DC level cross-connection. The corresponding redundancy management of the system is modelled by the CFSMs. As the DC busbar 1 supplies only non-essential loads the CSM/G is not taken into account in the RBD. Therefore the performance logic has only to be defined for the main generators and the APU generator. The definition of the performance logic and the state transitions for the CFSMs of the APU generator is shown in figure 7.
The left side shows the possible state transitions graphically and their definition by logical terms. In the case of the APU generator three states are possible: *active-hot* (nominal), *active* and *isolated*. Additionally an initial state has to be defined for each component. The right side of the interface defines the performance values and the logic as well as an initial performance value relating to the analysed component, in this case the DC busbar 1.

4.2 System Performance Degradation Analysis

Three different scenarios are analysed using the PERFORMANCE DEGRADATION ANALYSIS. Figure 8 shows the results for the nominal system as it was presented before. It is obvious that nominal performance is most probable for the DC busbar 1. On the x-axis the different performance classes are imaged, wherein each bar is equivalent to a certain performance class. The y-axis represents the probability of achieving each single performance class. The values in the performance interval $[0, 100]$ % represent the degraded system states due to the interconnections on AC and DC level. A performance value of 0 % complies with a non-functional system as defined in equation (22).

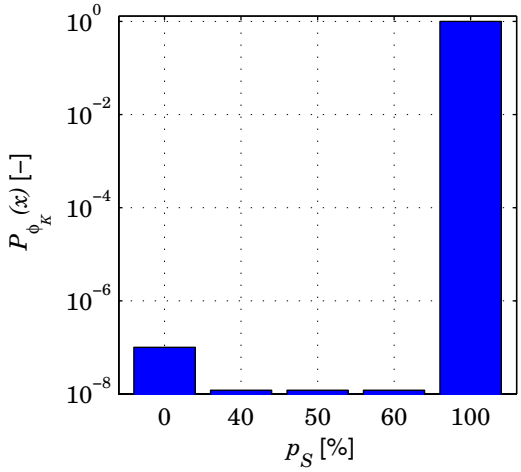

FIGURE 8: PDA based on a nominal system state

The results for the nominal state illustrate that the total loss of power on busbar DC 1 is dominated by the loss of the busbar itself, as the distribution network and the power generation are multiple redundant.
In figure 9 the results for the first degraded system state are presented. Degraded system states which still allow a take-off of the aircraft are defined in the Master Minimum Equipment List (MMEL). In this case the dispachtable loss of the Transformer Rectifier 1 (TR 1) is considered.

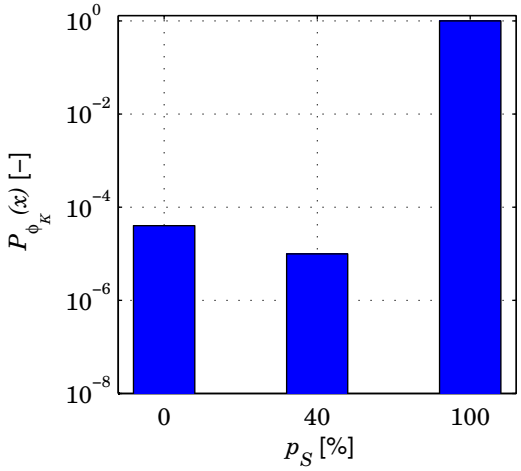

FIGURE 9: PDA based on a first dispatchable system state degradation

The analysis results show that the loss of the transformer rectifier 1 can be compensated by the interconnection on DC level by an adequate component layout which leads to a simplex power distribution. But based on the implemented CFSM logic the graph also illustrates that the set of performance levels $\mathbf{A} = \{A_{100\%}, A_{40\%}\}$ has decreased. Moreover, the probability of achieving a degraded system state or even loss of power supply on the DC busbar has significantly increased.

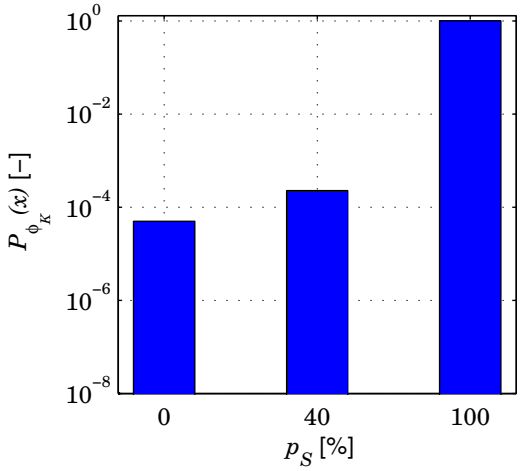

FIGURE 10: PDA based on a second system state degradation

If a second failure occurs during a flight with first-stage degradation it is possible that the reliability margin will be drastically reduced. Figure 10 illustrates the results of

a PDA for the loss of main generator 2, yielding second-stage degradation.
The loss of the main generator 2 is compensated by the APU generator, further reducing the redundancy of the power generation system. The probability of obtaining a reduced performance level of 40% raises and the probability of complete system loss increases slightly.
Because of the logarithmic y-axis of the previous figures, figure 11 illustrates for each of the three states the probability of not obtaining the performance class $p_{\phi_K} = 100\%$. In line with equation (22) this can be calculated by:

$$F_{\phi(\mathbf{K})}(p_{\phi_K} = 100\%) = 1 - P(p_{\phi_K} = 100\%) \quad . \tag{23}$$

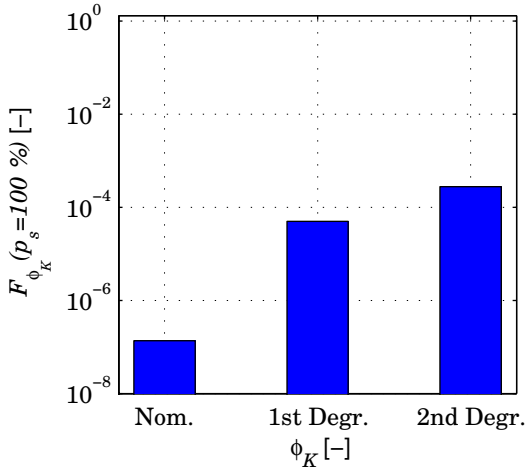

FIGURE 11: Increasing probability of not obtaining 100% performance level

As previously described, due to the reduction of the distribution and power generation redundancy the probability increases continuously.

5 CONCLUSION AND FUTURE WORK

This contribution has shown the recent advancements of the software tool SYRELAN, which can be utilized in the design and even predesign of fault-tolerant systems within the context of reliability analysis and redundancy management. The hybrid model forms the basis of the reliability analysis, consisting of an upper-level RELIABILITY BLOCK DIAGRAM and a lower-level CONCURRENT FINITE STATE MACHINE environment. The RBD can be used to image the system architecture in the nominal state and to assign each block an individual failure rate. The CFSMs enable the user to model the dynamic behaviour with the use of switching conditions and define different failure behaviour for certain discrete component states. Additionally, the CFSMs can be used to model three different components types, *Hardware*, *Multifunctional Hardware* and *Multifunctional Software*, each type with a different state behaviour.
An innovative, further analysis capability of the software tool known as a PERFORMANCE DEGRADATION ANALYSIS has been presented. The RBD environment already enabled the user to analyse the probability of obtaining different performance levels by defining performance components and summing up the individual performances. The new method considers also the state of each component in the PDA. This means that only active performance components contribute to system performance, while components in standby states are not considered for performance cumulation.
In a further step the new method has been demonstrated by analysing the electrical power supply system of the AIRBUS A320. For this purpose the system architecture for the defined top event „*Power Supply of DC Bus 1*“ has been imaged using the RBD modelling environment. Furthermore, the switching conditions have been implemented using the CFSMs. Based on the hybrid model of the electrical power system a PDA for three different scenarios has been undertaken. At first the nominal, failure-free system behaviour has been analysed resulting in five different performance classes and their corresponding probabilities. In a second step the effects of a dispatchable loss of a transformer rectifier has been analysed, showing a reduction of available performance classes and in reliability margins. At last a second, non-dispatchable degradation of an in-flight loss of an integrated drive generator has been analysed showing a further reduction of reliability margins and a much higher probability for further degradation of the system.
In the current state of implementation the PDA is only able to analyse a single point of a system, e.g. a busbar. To enable an overall analysis of aircraft systems it would be beneficial to analyse several points in one model and in one computational step. Currently the implementation of an INTEGRATED PERFORMANCE DEGRADATION ANALYSIS is ongoing which will offer the analysis of multiple performance points.
Additionally to handle the complexity of both the varying approaches to modern *More Electric Aircraft* approaches and the power consumer mapping based on PDA results, an algorithm is being developed to optimize the system architecture with respect to reliability.

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