New Tool to Determine the Safety-Parameters Based on Safety Standard

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Abstract. FRCaS is a newly developed Software-Tool to calculate the failure rates from diverse components. This tool offers the user the opportunity to determine the failure rate for diverse components on the basis of various Standards of Siemens SN 29500, Military Handbook (MIL-HDBK 217F) and CENELEC. The user is able to obtain results with this tool without previous knowledge of the details of the applied standards. A further development and objective is the integration of the Program Package OrCAD into the developed Software-Tool, in order to determine the failure rates of individual components, which are developed in OrCAD electronic circuits.

Keywords*:* Reliability, Failure rate, Safety-Standard, Safety-Parameters, Failure probability.

1 Introduction

The current research work in the department of computer architecture and system programming at the University of Kassel, developed a calculation tool to determine the expectation values of components. This tool provides the ability to determine the failure rate of components for reference and operating condition on basis of the Siemens-Norm SN 29500. The failure rate plays an important role in reliability and is normally highly dependent on the working conditions. The values that are given in the standard reference conditions are determined default rates resulting from long experimental observations of a large number of identical components, which are used by the Siemens AG as a uniform basis. The failure rate is the risk of one component failing and is normally highly dependent on various factors. The course of the failure rates over the time can be presented by the bathtub curve. By factors such as e.g. the environment, a conversion can be calculated by referring to operating condition.

With the calculation tool, it is possible to represent the inputs and outputs through a user interface. The user takes the opportunity to choose, for example, switches and buttons, as well as alarm and signal lights with the necessary properties. Within an output range, the reference and operating condition can be calculated. Thus, the user has the opportunity to compare, save, and open the result in a data table. A chart in environment and voltage dependence is used to visualize the failure rate in operating condition. The calculation tool is developed on basis of JAVA application.

2 Mathematical background

2.1 Weibull distribution

The Weibull distribution is one of the most commonly used distributions in reliability engineering because of the many shapes it attains for various values of β (shape parameter). It can therefore model a great variety of date and life characteristics. The shape parameter is what gives the Weibull distribution its flexibility. By changing the value of the shape parameter, the Weibull distribution can model a wide variety of data. The Weibull distribution makes it possible to represent time dependent failure probabilities $F(t)$ of components. For this it is necessary to possess the determined function parameters from observed data. In principle these also have a technical important meaning. From these data it is possible to determine whether we are dealing with early, random or aging failures. The required data is failure frequency, number of all components and failure times of the components. Also the Weibull distribution assumes for its application the simplified assumptions that single component failures are independent of each other. The probability of failure according to the Weibull distribution is defined as

$$F(t) = W(t;\beta;t_0;T) = 1 - e^{-\left(\frac{t-t_0}{T-t_0}\right)^{\beta}} \tag{1}$$

where t is the time, β is the shape parameter, t_0 is the correction parameter and T is the characteristic lifetime or position parameter.
The probability density function of a Weibull distribution is given by

$$f(t) = W(t;\beta;t_0;T) = \frac{\beta}{T-t_0} \cdot \left(\frac{t-t_0}{T-t_0}\right)^{\beta-1} \cdot e^{-\left(\frac{t-t_0}{T-t_0}\right)^{\beta}} \tag{2}$$

If $\beta = 1$, the Weibull distribution is identical to the exponential distribution. If $\beta = 2$, the Weibull distribution is identical to the Rayleigh distribution. If β is between 3 and 4 the Weibull distribution approximates the normal distribution.

2.2 Exponential distribution

The exponential distribution is useful in many applications in engineering, for example, to describe the lifetime X of a transistor. Therefore, the exponential distribution is the most known distribution. With this distribution it is possible to represent the time dependent probability $F(t)$ of components for which it is necessary to obtain observed data to determine X. The failure probability is defined by the exponential distribution as

$$F(t) = 1 - e^{-\lambda \cdot t} \tag{3}$$

where λ is the failure rate. Respectively with failure density

$$f(t) = \begin{cases} \lambda \cdot e^{-\lambda \cdot t} & for \quad t \geq 0 \\ 0 & otherwise \end{cases} \tag{4}$$

2.3 Reliability and failure probability

The reliability $R(t)$ is the probability that a unit is functional in one view period $(0,t)$. Fig.1 shows $R(t)$ as function of time.

The probability that the operational time T is within the considered time interval $(0..t)$ is for small t almost equal to one. For larger values of t the probability decreases more and more.

$$R(t) = e^{-\int_0^{\infty} \lambda(t)dt} \qquad (5)$$

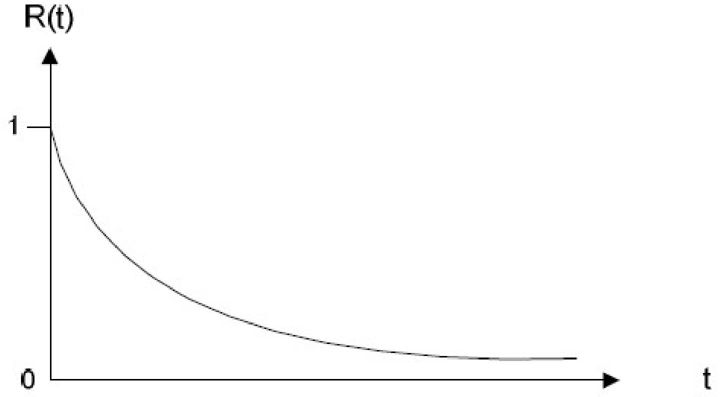

Fig. 1. Reliability function $R(t)$ as function of time

If an exponential distribution for the reliability is valid, then the failure rate is constant:

$$\lambda(t) = \lambda \qquad (6)$$

Thus the equation can be rewritten as:

$$R(t) = e^{-\lambda \cdot t} \qquad (7)$$

An important reliability parameter is the MTTF value (Mean Time To Failure)

$$MTTF = \int_0^{\infty} R(t)dt = \frac{1}{\lambda} \ . \qquad (8)$$

Within the interval $(0,t]$ the probability of failure $F(t)$ is calculated applying the reliability function

$R(t)$.

$$F(t) = 1 - R(t) \qquad (9)$$

$$F(t) = 1 - e^{-\lambda \cdot t} \qquad (10)$$

$$F(t) \approx \lambda \cdot t \quad for \quad \lambda \cdot t << 1 \qquad (11)$$

Generally, the time t is applied by T1. The time from point in time zero to time T1 is characterized as proof test interval. At time T1 a periodical test or the maintenance of a safety system is taking place. Tests are carried out to allocate undetected, dangerous failures. After a proof test, the system is regarded as new. The calculated PFD-value depends on the value T1.

3 Failure Rate Calculation Tool FRCaS

Many organizations use the standards to perform, for example, the calculation of PFD-values of components. However, the reference conditions do not always apply, for example, components are temperature dependent and the temperature changes with time. When this happens, the reference conditions are damaged.

3.1 Objectives of the Tool

The objective is the new development of a Software-Tool, which calculates the failure rates of components.

This Software Tool offers the user some of the basis of following Standards

- Siemens SN 29500
- Military Handbook MIL-HDBK 217F
- CENELEC

The failure rate for the various components is determined. The user is able to use this Tool without knowing exact details of the standards, and obtain valid results thereof. Next, the Program package OrCAD should be included with the Software-Tool in order to determine the failure rate of the components of the developed circuit in OrCAD.

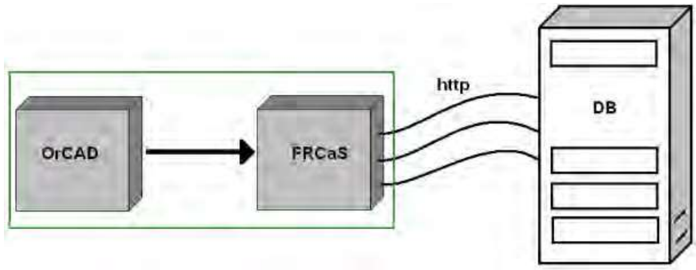

Fig. 2. Assembly of the Structure

The FRCaS-Tool should offer the user the opportunity based on this standard, to determine the failure rates of components in operating condition. There are two types of components: local components and components already in the Databank. In order to stimulate a component in the Databank, one must be the authorized user. First, the authorized user can determine the failure rate for the operating condition of chosen components. In addition, the opportunity exists that the FRCaS Tool has the ability to connect with the program package “OrCAD“. The following picture shows the relationship between the OrCAD, the FRCaS-Tool, (Clients) and the Databank. The Databank, which is accessible by www, manages neither the components nor the assignment of user privileges.

3.2 Calculation of failure rates on basis of SN 29500

The Siemens-Norm SN 29500 is composed of a total of 15 parts and is used to determine the failure rates of components. The titles of the individual parts of the Siemens-Norm SN29500 are as follows:

SN29500-2: Expected values for integrated circuits. This Part is used for reliability calculations such as for example, memory, microprocessors, digital and Family analogs ASICs.

SN 29500-3: Expected values for discrete semiconductors. The failure rates apply for leaded and SMT- components. This part is used for reliability calculations such as e.g. Transistors, diodes, and power semiconductors.

SN 29500-4: Expected values for passive components. The passive components belong to groups such as capacitors, resistors, inductors and other passive components. The failure rates apply for leaded and SMT- components.

SN 29500-5: Expected values for electrical connections, electrical connectors and sockets. This part is used for reliability calculations such as clips, screws, or coaxial.

SN 29500-6: withdrawn; content has been integrated in part 5 and 12.

SN 29500-7: Expected values for relays. Relays are used in the field of control engineering, data processing, telecommunications and automotive electrical systems. For these applications there are types of relays such as low power relay, general relay, or automotive relays.

SN 29500-8: withdrawn

SN 29500-9: Expected values for switches and buttons. This part is used for reliability calculations of telecommunication and electronic products with high reliability requirements. There are switches and buttons used e.g. Dipfix or coding switches, buttons and switches for low power applications or higher electrical power handling with mechanical contacts. It is used in the field of control engineering, data processing, communications and process technology. It does not cover installation and high-voltage switch.

SN 29500-10: Expected values for signal and pilot lamps. This part is used for reliability calculations in reporting and signal lamps such as incandescent and neon lamps. The failure rates apply for soldered screwed and plugged devices.

SN 29500-11: Expected values for contactors. The application focus of this part is the control technology and switching of motors. This part is used for reliability calculations such as equal- and alternating current protectors.

SN 29500-12: Expected values for optical components. This part is used for reliability calculations such as optical semiconductors, light emitting diodes, opt couplers, optical sensors, transceivers, transponders, and optical subsystems.

SN 29500-13: withdrawn; content has been integrated in part 12.

SN 29500-14: withdrawn; content has been integrated in part 12.

SN 29500-15: Expected values of electromechanical protection devices. They are applied in areas of control and switchgear technology. For these areas of application there are electromechanical protecting devices such as circuit breaks for motor protection, overload relays, circuit breaks and residual current protection devices.

4 Using the Tool of loss in reference and operating conditions on the basis of Siemens Norm 29500-04

The Siemens-Norm part two is analyzed and implemented within the new Tool. Fig. 3 shows the assembly of the Tool.

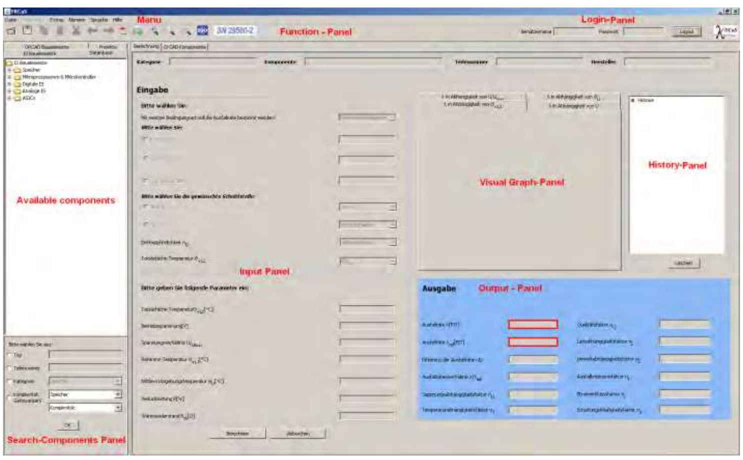

Fig. 3. Assembly of the new Tool

4.1 Calculation of failure rate with the new tool under the reference conditions

Reference conditions are the values given in a specific environment such as the average environment temperature at 40 °C or the operating current. These are the values that prevail without influences.

Failure criterion: Complete failures and changes of major parameters that would lead to a failure in the majority of applications. The failure rates λ_{ref} stated in Fig.4 should be understood for operation under the stated reference conditions as expected values for the stated time interval and the entirety of lots. Within the scope of the variations of values, in exceptional lots, the actual value may differ from the expected one a factor of up to two and half.

Kondensator/ Capacitor		λ_{ref} in FIT	θ_i [1)] in °C	U_{ref} / U_{max}
Metallfolie/ *Metal foil*				
Polystyrol	**KS**	1	40	0,5
Polypropylen / *Polypropylene*	**KP**	1		
Polycarbonat / *Polycarbonate*	**KC**	2		
Polyethylenterephtalat / *Polyethylene terephtalate*	**KT**	1		
Metallisierter Belag / *Metallized film*				
Polyethylenterephtalat / *Polyethylene terephtalate*	**MKT**	0,7		
Polycarbonat / *Polycarbonate*	**MKC**	0,7		
Polypropylen / *Polypropylene*	**MKP**	0,7		
Zelluloseacetat / *Acetyl cellulose*	**MKU**	0,7		
Metall-Papier(-Kunststoff) *Metallized paper (film)* [2)]	**MP, MKV** [2)]	2		
Glimmer / *Mica*		1		
Glas / *Glass*		2		
Keramik / *Ceramic*	**NDK / *LDC*** COG, NPO	1		
	MDK / *MDC* X7R, X5R	2		
	HDK / *HDC* Z5U, Y5V, Y4T	5		
Al-ELKO / *Aluminium electrolytic*				
flüssiger Elektrolyt / *non solid electrolyte*		5		0,8
fester Elektrolyt / *solid electrolyte*		3		
TA-Elko / *Tantalum electrolytic*				
flüssiger Elektrolyt / *non solid electrolyte*		10		0,5
fester Elektrolyt / *solid electrolyte*		1		
Veränderbare Kondensatoren / *Variable*		10		–

1 FIT = 1x10^{-9} 1/h (ein Ausfall pro 10^9 Bauelementestunden) — 1 FIT equals one failure per 10^9 component hours

Die genannten Ausfallraten gelten für die Qualitätsklasse LL. Für die Qualitätsklasse GP werden im Abschnitt 4.3 Umrechnungsfaktoren angegeben. — The stated failure rates apply to quality class LL. Conversion factors for quality class GP are given in section 4.3.

1) Kondensatortemperatur — 1) Capacitor temperature

2) Gilt nicht für Leistungskondensatoren nach VDE 0560-T12 — 2) Does not apply to power capacitors according to VDE 0560-T12

3) Der Schaltkreiswiderstand bei Tantal-Kondensatoren hat Einfluß auf die Ausfallrate. Entsprechende Zusammenhänge sind einschlägigen Normen oder Datenbüchern zu entnehmen. Die angegeben Ausfallraten gelten für einen Widerstand von > 3 Ohm/Volt — 3) The circuit resistance of tantalum capacitors influences the failure rate. Corresponding connections are to be taken from the standards in question or from data books. The failure rates given apply to a resistance of ≥ 3 Ohm/Volt.

Durchführungskondensatoren und -filter (DUKO, DUFI) siehe Tabelle 4 — Feed-through capacitors and filters see Table 4

Fig. 4. Failure rates for Capacitor

As an example, the failure rate can be determined with the new Tool for operational amplifiers with the Degree of integration. Fig. 5 shows the calculation.

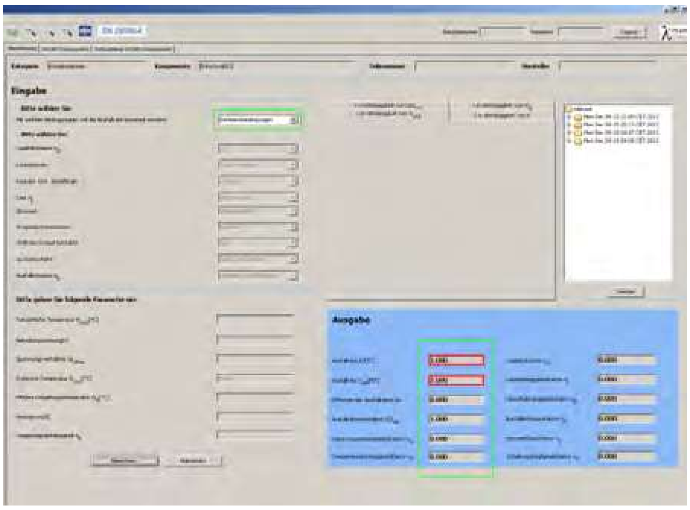

Fig. 5. Calculation under the Reference condition

Also, various changes can be made with the Tool. For example, the degree of integration can be changed in the Tool and therefore a fast calculation reference-failure rate can be achieved.

4.2 Conversion from reference to operating conditions

An operating condition by a manufacturer for the use of a device specified condition. To calculate for different operating conditions, conversion models are used. They contain constants, which were determined according to the state of the technology. The values given in the Siemens 29500 constants are averages of DIN EN 61709.

If the passive components are not under the electrical stresses and at the average ambient temperature as stated in the reference conditions, the result can be failure rates which differ from the expected value given in for example in Fig. 4. To account for the actual electrical stresses and the average ambient temperature that occur during operation, the expected values under reference conditions need to be converted with the relevant π factors. The failure rate under the operating conditions λ is calculated for operations as follows:
For capacitors:

$$\lambda = \lambda_{ref} \times \pi_U \times \pi_T \times \pi_Q (12)$$

where λ_{ref} is the failure rate under reference conditions, π_U is the voltage dependence factor, π_T is the temperature dependence factor and π_Q is the quality factor.

The voltage dependence factor π_U for capacitors is taken into account as the following equation:

$$\pi_U = \exp\left(C_3 \times \left(\left(\frac{U}{U_{max}} \right)^{C_2} - \left(\frac{U_{ref}}{U_{max}} \right)^{C_2} \right) \right) \quad (13)$$

Kondensatoren / *Capacitors*	Constants		
	U_{ref}/U_{max}	C_2	C_3
Papier, Metallpapier (MP), Metallisierter Kunststoff (MKP,MKT, MKU), MKV / *Paper, metallized paper, metallized polypropylene film, metallized polyethylene terephtalate film, metallized acetyl cellulose film, metallized paper film*	0,5	1,07	3,45
Polycarbonat (KC, MKC) / *Polycarbonate film metal foil, metallized polycarbonate film*	0,5	1,5	4,56
Polyethylenterephtalat (KT), Folien-Polypropylen (KP), Polystyrol (KS) / *Polyethylene terephtalate film metal foil, Polypropylene film metal foil, polystyrene film metal foil*	0,5	1,29	4
Glas / *Glass*	0,5	1,11	4,33
Glimmer / *Mica*	0,5	1,12	2,98
Keramik / *Ceramic*	0,5	1	4
Al-Elko, flüssiger Elektrolyt / *Aluminium electrolytic, non-solid electrolyte*	0,8	1	1,36
Al-Elko, fester Elektrolyt / *Aluminium electrolytic, solid electrolyte*	0,8	1,9	3
Ta-Elko, flüssiger Elektrolyt / *Tantalum electrolytic, non-solid electrolyte*	0,5	1	1,05
Ta-Elko, fester Elektrolyt / *Tantalum electrolytic, solid electrolyte*	0,5	1,04	9,80

Fig. 6. Constants π_U for capacitors

Also the Temperature dependence is taken into account for capacitors according to equation. The following formula applies up to the maximum permissible junction temperature only.

$$\pi_T = \frac{A \times \exp(Ea_1 \times z) + (1-A) \times \exp(Ea_2 \times z)}{A \times \exp(Ea_1 \times z_{ref}) + (1-A) \times \exp(Ea_2 \times z_{ref})} \quad (14)$$

with

$$z = 11605 \times \left(\frac{1}{T_{U,ref}} - \frac{1}{T_2} \right) \quad (15)$$

$$z_{ref} = 11605 \times \left(\frac{1}{T_{U,ref}} - \frac{1}{T_1} \right) \quad (16)$$

Kondensatoren / *Capacitors*	Constants				
	A	Ea_1 in eV	Ea_2 in eV	θ_{Uref} in °C	θ_1 in °C
Papier, Metallpapier (MP), Metallisierter Kunststoff (MKP, MKT, MKU), Polyethylenterephtalat (KT), Folien-Polypropylen (KP),Polystyrol (KS), MKV / ***Paper, metallized paper, metallized polypropylene film, metallized polyethylene terephtalate film, metallized acetyl cellulose film, polyethylene terephtalate film metal foil, polypropylene film metal foil, polystyrene film metal foil, metallized paper film***	0,999	0,5	1,59	40	40
Polycarbonat (KC, MKC) / ***Polycarbonate film metal foil, metallized polycarbonat film***	0,998	0,57	1,63	40	40
Glas, Glimmer / ***Glass, mica***	0,86	0,27	0,84	40	40
Keramik / ***Ceramic***	1	0,35	-	40	40
Al-Elko, flüssiger Elektrolyt / ***Aluminium electrolytic, non-solid electrolyte***	0,87	0,5	0,95	40	40
Al-Elko, fester Elektrolyt / ***Aluminium electrolytic, solid electrolyte***	0,4	0,14	0	40	40
Ta-Elko, flüssiger Elektrolyt / ***Tantalum electrolytic, non-solid electrolyte***	0,35	0,54	0	40	40
Ta-Elko, fester Elektrolyt / ***Tantalum electrolytic, solid electrolyte***	0,961	0,27	1,1	40	40
Veränderliche / ***Variable***	1	0,15	-	40	40

Fig. 7. Constants π_T for capacitors

4.3 Database and Norm selection

The Tool works with a database where all standards and their data are saved. For all saved components the user can calculate the failure rate, in reference- or operation condition. In order to keep the database up to date conditions and maintain components can be added or removed, or values can be changed.
First step, selection of a component.

Fig. 8. Component selection

Second step, you can change values or put new components in the database.

Fig. 9. Insert component in database

As already mentioned, this Software Tool offers the user some of the basis of Standards. In this Tool the user can switch the standard in two steps.
First step, the user chooses a standard.

Fig. 10. Norm selection

Second step, the Selection of a category of the chosen standard.

Fig. 11. Selection Component from the Military Norm

The tool provides the user with the ability to determine the failure rate of components for operating conditions on the basis of the Military Handbook. Now, the user can compare between the failure rates of the Siemens Standard and the Military Handbook.

4.4 Calculation using the new tool of various elements

The Goal in this section is that a circuit from ORCaD can be uploaded to the new Tool (Fig.12).

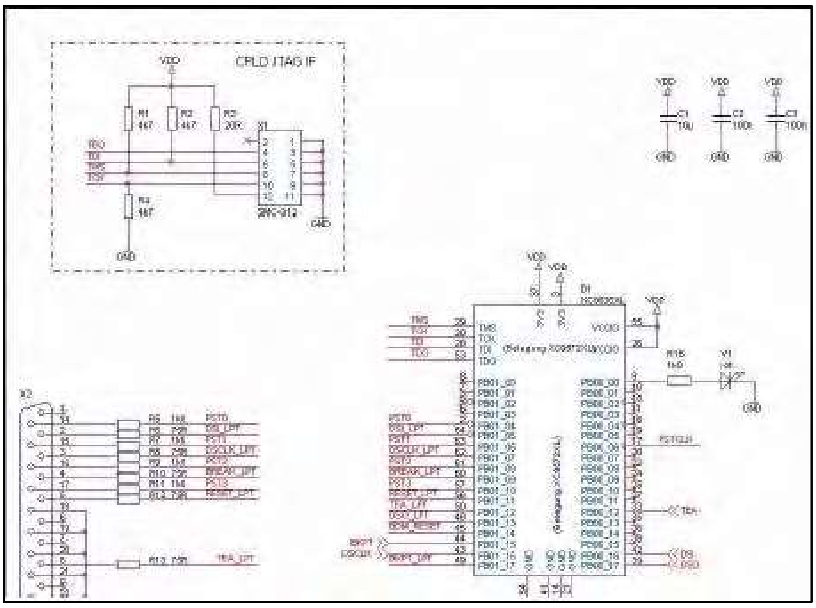

Fig. 12. Circuit design in ORCaD

The new FRCaS-Tool is designed in a way that the authorized user has the possibility to determine the failure rate of a component, which is present in the database for operating conditions based on this standard. As a prerequisite, an internet connection must be available. If no internet connection is available, the user may only work with the components that are locally present. The database manages the components out of the assignment of user privileges.

Fig. 13 shows the calculation with the help of an ORCaD – Circuit. To perform such a calculation, one must access the data bank. The database contains the reference failure rates. Using the standard Siemens-Norm, the desired operating failure rate can be determined.

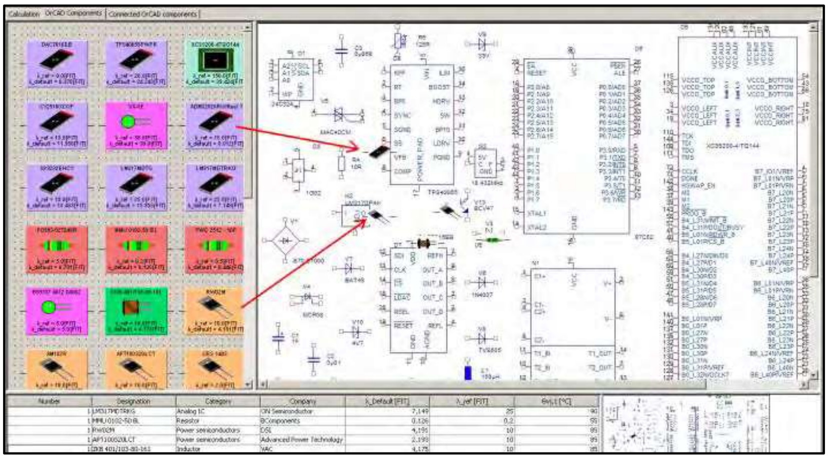

Fig. 13. Circuit design in ORCaD

Due to the operating condition, several temperature dependent functions can be determined. For example, the failure rate as a function of θ can be depicted. Fig. 14 shows the volume function.

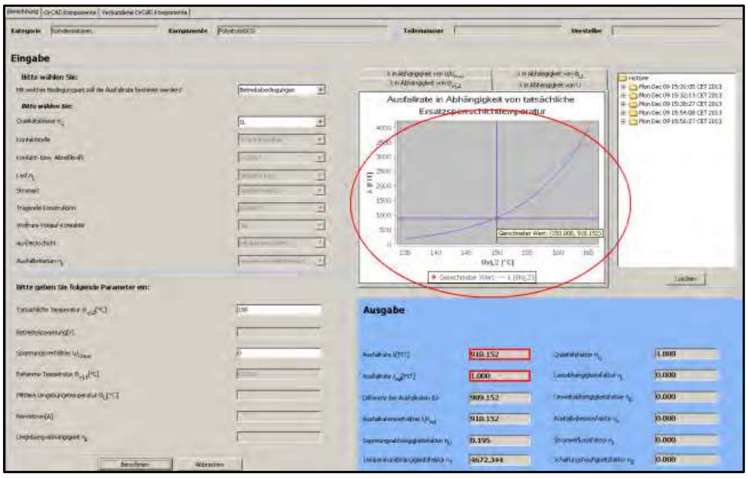

Fig.14. Failure rate as a function of temperature

With the help of ORCaD, it is now possible to build different architectures. It is possible to build both safety and availability systems in the new Tool. As an example a one out of tow (1oo2)-architecture is used. The 1oo2 architecture, see Fig. 15, possesses two channels in parallel, where each channel can execute the safety function by itself.

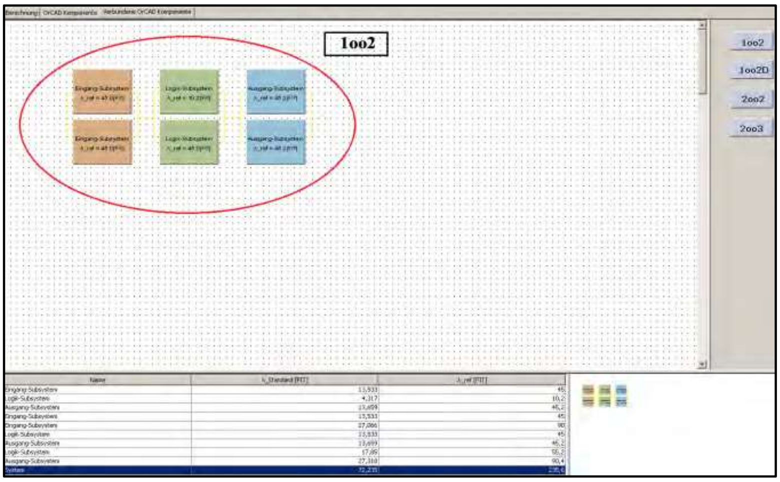

Fig.15. Calculation of 1oo2 – Safety Systems under operating conditions

Determining the probability failure on Demand (PFD) based on IEC Standard- 61508:

$$PFD_{avg\_1oo2} = 2[(1-\beta_D)\lambda_{DD} + (1-\beta)\lambda_{DU}]^2 t_{CE} t_{GE}$$

$$+\beta\lambda_{DD} MTTR + \beta \cdot \lambda_{DU}\left(\frac{T_1}{2} + MTTR\right)$$

It is also possible to summarize several differential systems. Therefore the safety-tool can be used for the calculation of different components for reference and company terms on the one hand. On the other hand different calculations can be realized with the help of OrCAD-circuits. Various scenarios can be generated in the Tool. Fig. 16 shows the versatility of the new safety tools. It is still possible to save all the calculations and modeling, and also print out a PDF version.

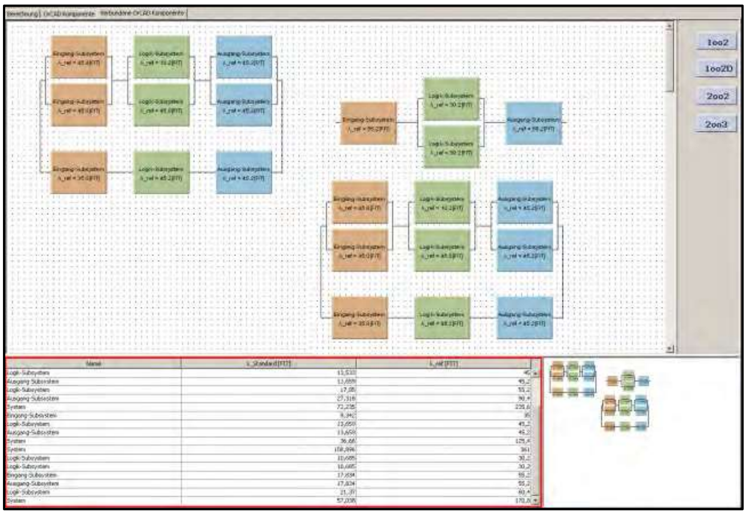

Fig. 16. Complex systems

The new Tool will then determine the overall failure rate for both the reference and operating condition.

5 Conclusion

Various and complex architectures can be built with the new developed safety tool. Based on the Siemens-Norm, the key safety parameters for both reference and operating conditions can be determined. Further work will be to stipulate that additional standards be implemented in the new Tool to carry out a comparison of the overall failure rates and the PDF value. The next approach will be that different analysis methods are used to achieve the safety parameters.

Thus, the user will have a very simple and convenient hand tool for complex circuit from OrCAD program to analyze and calculate the safety parameters.

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