“D8.6.2 – Benchmark for the estimation of the reliability and availability for the data center”

“Sub Work Package 8.6 : Data Center”

“Work Package 8 : Demonstrator”

MODRIO (11004)

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Executive summary

NOTICE : Only reliability data already published in public domain documents will be used in this deliverable. Degradation models as described in already published work will be taken into account in this study.

The document D8.6.2 describes the demonstrator "reliability study of Data center structure" of the MODRIO along with the study on this subject which will completed subsequently.

A data center is a system with high level of reliability and availability ("Tier I to Tier IV level"). Probabilistic reliability analysis of such a system has been already done at EDF R&D with EDF's reliability tool (FIGARO Tool).

The goal of this document is to compare the estimation of reliability and availability of a data center with already existing EDF R&D reliability tool (KB3 FIGARO tool) and the new library of component elaborated with MODELICA for electrical component and air conditioning component with failure of data center.

The benchmark with different approaches to estimate the reliability and availability of data center shows the elements as follows :

- The KB3 tool is a very powerful tool to study the reliability of industrial electrical network. But these tool rely on some assumption about the failure of component that are sometime not relevant on site (failure constant with time and independant failure of component
- The study done in the context of the analysis of the data center with the MODRIO project has shown different point
    - The proof of concept with the library state machine [1] to do system reliability analysis with MODELICA and Monte Carlo simulation
    - The type of result which is different of the usual result obtained with classical reliability tool such as KB3. For example in the case of the « air climate room » one can obtained the probability that the temperature is over a thresold
    - Nevertheless some improvement has perhaps to do into the MODELICA language to do easier probabilistic and reliability analysis with MODELICA.

The collaboration between the MODRIO partners about this subject was very fruitful mainly between EDF R&D and DLR.

Summary

1. Introduction

The context of the demonstrator reliability study for Data Center has been presented in the MODRIO deliverable D861.

2. Goal of this document

The goal of this document is to compare the estimation of reliability and availability of a data center with already existing EDF's KB3 reliability tool (FIGARO tool) and the new library of component elaborated with MODELICA for electrical component and air conditioning component.

The study will be located into the context of the "V" cycle project for a new system. That means that different role will be define such as the owner of the system and the manufacturer of the system. Each part has his own task to do. The agenda of the document will be some reminder about the reliability center structure and TIER Classification. Then different task of the "V" cycle will be presented and the reliability requirement and study will be described. By this way the interest of the modelica tool to demonstrate the reliability level of the DataCenter will be described

3. Remind about the reliability Requirement of the Datacenter

3.1. Remind about TIER Classification

The TIER classification indicate the different type of requirement for the DATA CENTER. These classification has been define by the Uptime Institute.

	TIER I	TIER II	TIER III	TIER IV
Number of power delivery paths	Only 1	Only 1	1 active 1 passive	2 active
Redundant component	N	N+1	N+1	2 (N+1) or S+S
Utility voltage	208 , 480	208, 480	12 kV – 20 kV	12k V – 20 kV
Year of first construction	1965	1970	1985	1995
Annual IT Downtime due to site	28.8hrs per yr	22.0 hrs	1.6 hrs	0.4 hrs
Site Availability	99.971 %	99.749 %	99.982%	99.995%

Table 1 : Presentation of the level of reliability for the different TIER classification for Data center

3.2. Presentation of an example of electrical diagram of TIER IV data center structure

The figure below presents a classical diagram of electrical supply for very reliable data center (TIER IV).

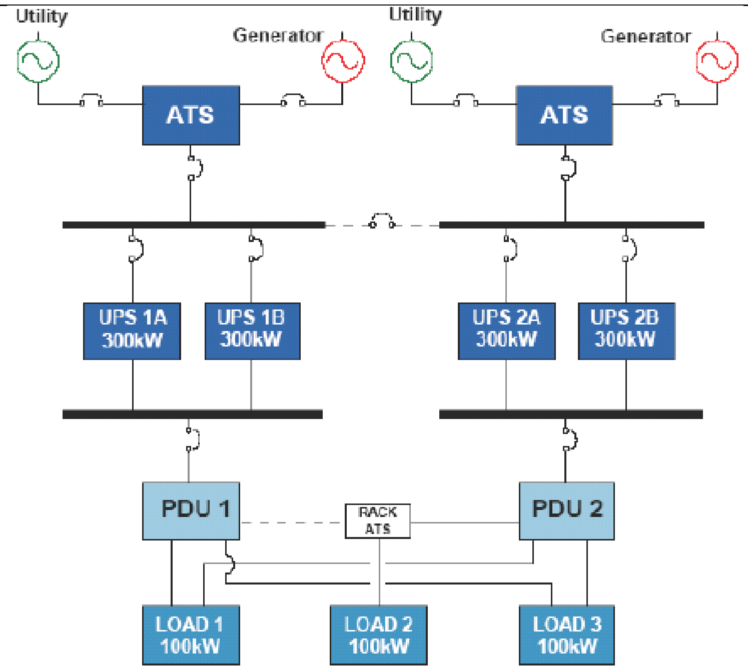


Figure 1 : Example of the structure of electrical network for a TIER IV Data Center

3.3. Some remark about TIER classification

Some hypothesis are assuming in the previous diagram to ensure high level of reliability and availability of the structure. The assumption are mainly about the independence of the failure for different components

That means that potential common cause of failure are not taking into account in this system.

4. The Reliability KB3- K6 FIGARO Tool

4.1. Implementation of the data center structure into the Reliability FIGARO tool

The previous structure of the electrical part of the data center has been model with the EDF's KB3-FIGARO tool. In this KB3 tool main electrical component such as, generator, electrical line, transformer, circuit breaker, … has been represent with an icon.

Each icon is associated with a logical representation of the reliability behavior of the component with its failure mode and failure rate and time to repair.

One can built the structure studied by drag and drop the different electrical component of the system.

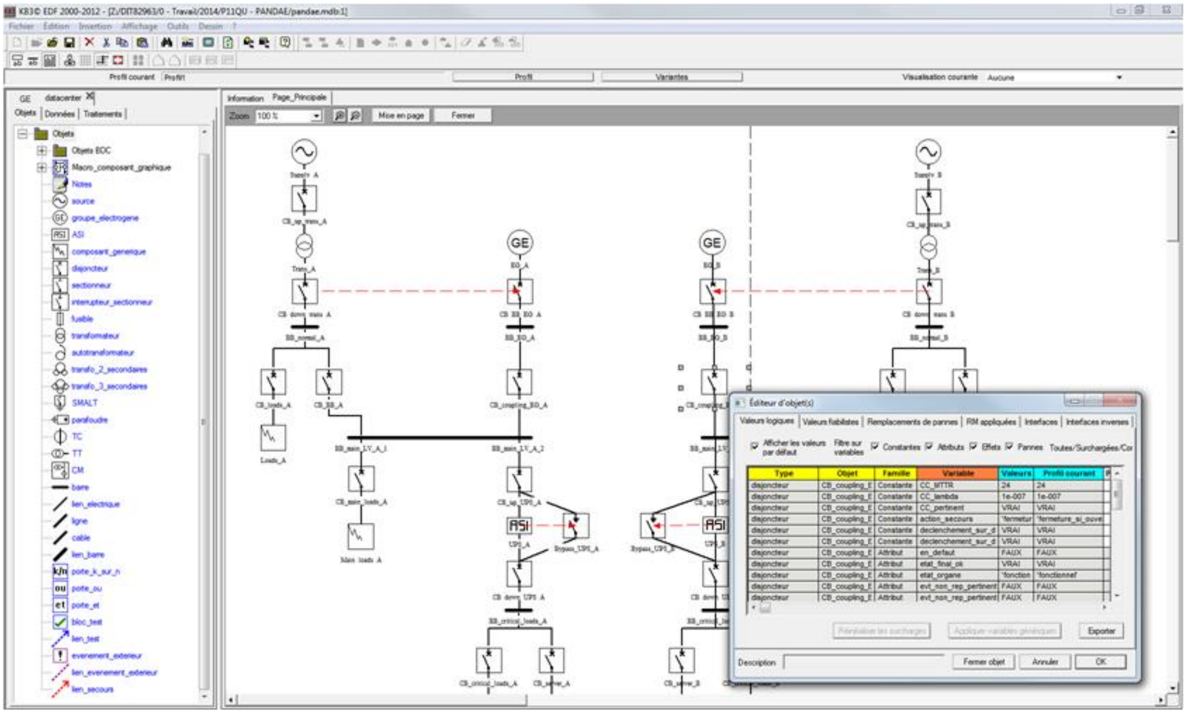
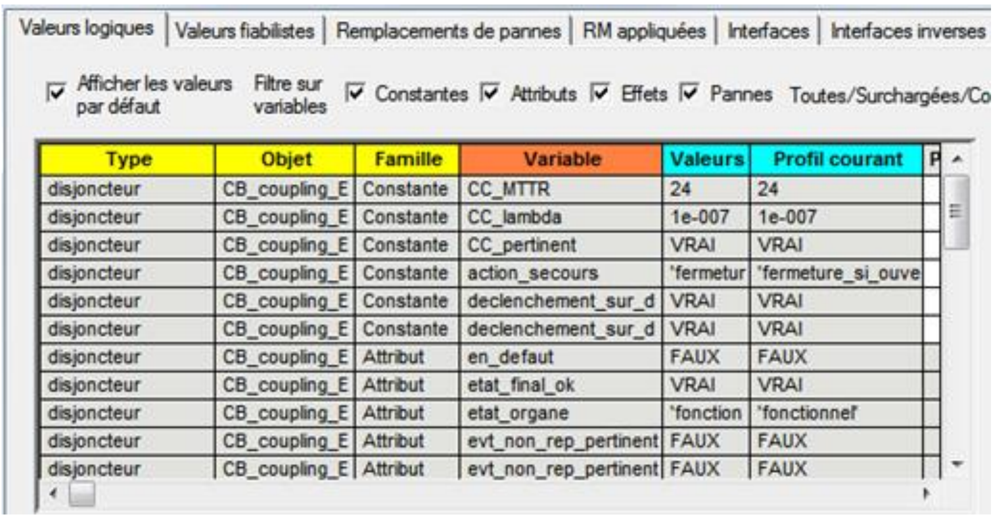


Figure 2 : View of the KB3 interface



Valeurs logiques | Valeurs fiabilistes | Remplacements de pannes | RM appliquées | Interfaces | Interfaces inverses

☑ Afficher les valeurs par défaut — Filtre sur variables — ☑ Constantes ☑ Attributs ☑ Effets ☑ Pannes — Toutes/Surchargées/Co

Type	Objet	Famille	Variable	Valeurs	Profil courant	P
disjoncteur	CB_coupling_E	Constante	CC_MTTR	24	24	
disjoncteur	CB_coupling_E	Constante	CC_lambda	1e-007	1e-007	
disjoncteur	CB_coupling_E	Constante	CC_pertinent	VRAI	VRAI	
disjoncteur	CB_coupling_E	Constante	action_secours	'fermetur	'fermeture_si_ouve	
disjoncteur	CB_coupling_E	Constante	declenchement_sur_d	VRAI	VRAI	
disjoncteur	CB_coupling_E	Constante	declenchement_sur_d	VRAI	VRAI	
disjoncteur	CB_coupling_E	Attribut	en_defaut	FAUX	FAUX	
disjoncteur	CB_coupling_E	Attribut	etat_final_ok	VRAI	VRAI	
disjoncteur	CB_coupling_E	Attribut	etat_organe	'fonction	'fonctionnel'	
disjoncteur	CB_coupling_E	Attribut	evt_non_rep_pertinent	FAUX	FAUX	
disjoncteur	CB_coupling_E	Attribut	evt_non_rep_pertinent	FAUX	FAUX	

Figure 3 : Input reliability parameter for a component

Link (red arrow) can be added to represent the switching between the nominal supply chain and the back-up

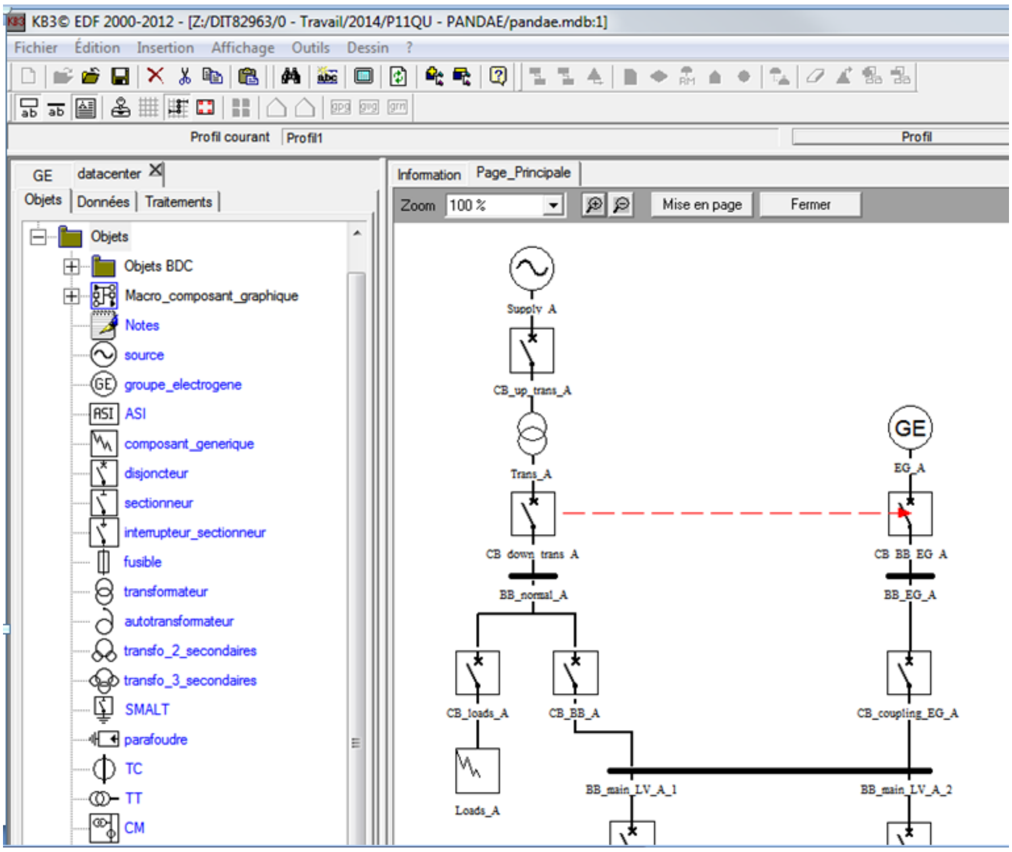


Figure 4 : Example of Electrical diagram in the KB3 Tool

5. Reliability study of the electrical network with KB3 tool

The reliability analysis with KB3 tool of an electrical network wich supplies the data center is presented.

5.1. Representation of the electrical system

The system studied consist of the upper part of the diagram of the electrical supply of a data center.

The goal of this system is to supply the busbar 5. A "test" box is associated to the busbar 5 in order to check if this busbar is linked to any power source. If yes the box is in green color. If not, the "test"box appears in a red color.

One has to notice that in a classical reliability study, the point of interest is "binary", that means :

- if the busbar 5 is supplied the "test" is equal to 1;
- if not, the "test" is equal to 0.

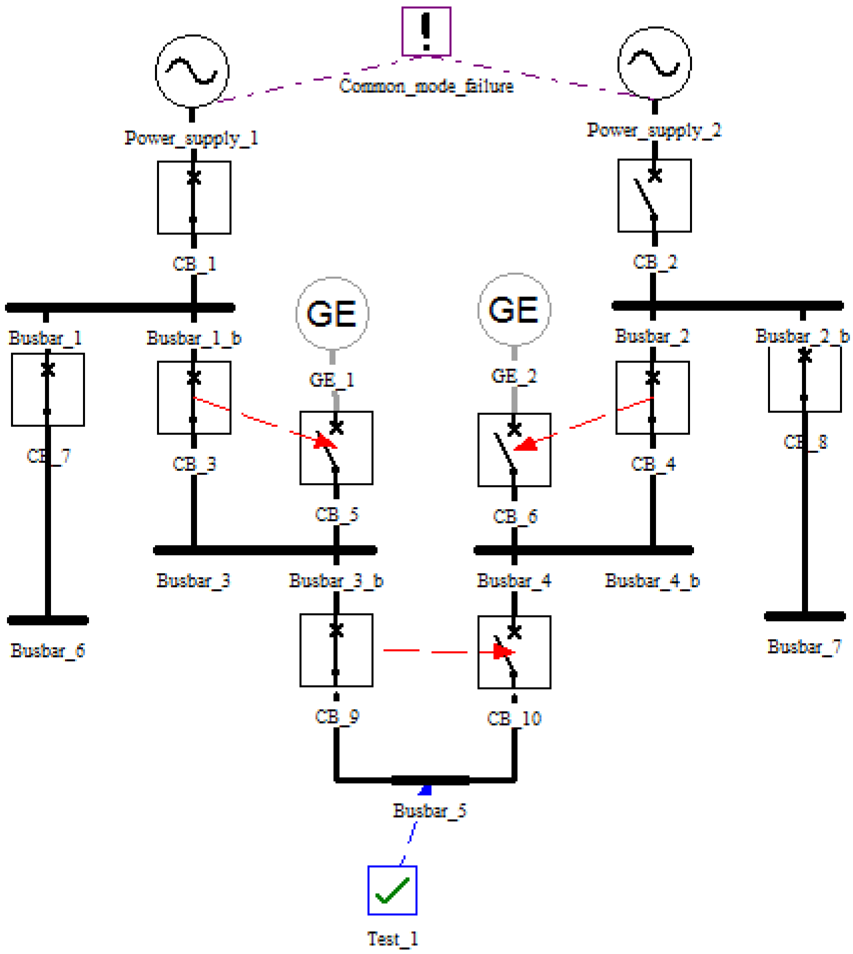


Figure 5 : Upper part of the electrical diagram of a data center

In nominal condition the data center is supplied by the external MV line named as "power supply 1". If this first line failed it is possible to supply the busbar 3 with the back up generator "GE 1". If the "GE_1" back up failed (after the power supply 1 failure) the structure of the electrical system will be connected to the second part of the electrical network that means the Power supply 2 and GE_2.

The red arrow indicate the type of back-up structure considered for the system.

If any short –circuit occurred on some busbar it has to be isolated by the opening of circuit-breaker associated. Nevertheless by this way it can leads to the loss of the link between some supply and the busbar 5.

The different connection during the modification of the structure requires the opening or the closing of the circuit-breaker. The failure mode of the circuit breaker are : fail to open or fail to close.

A possible common cause is added to represent the possible event of the simultanerous losses of the two external MV lines.

The different failure mode taking into account includes :

Component	Failure mode	Probability of failure on demand	Failure rate per hour	Time to repair (h)
GE : Stand-by	Fail to operate on demand	1^{e}-3		
Generator	Short Circuit		1^{e}-7/h	24 h
CB : Circuit	Fail to close on demand	1^{e}-3		
Breaker	Fail to open on demand	1^{e}-3		
Power supply	Failure on time		1^{e}-7/h	24 h
	Short Circuit		1^{e}-7/h	24 h
Busbar	Short –circuit		1^{e}-7/h	24 h
Common cause	Short –circuit		1^{e}-7/h	24 h

Table 2 : Hypothesis of failure rate taking into account for the reliability analysis of the electrical diagram (fig 5)

Even so the system seems simple, the different failure mode taking into account for both generator busbar and circuit breaker leads to a very large number of possible configurations

5.2. Example of the simulation of the behavior of the system

The KB3 tool offers the possibility to simulate the behavior of electrical network when some failure of component will occurred.

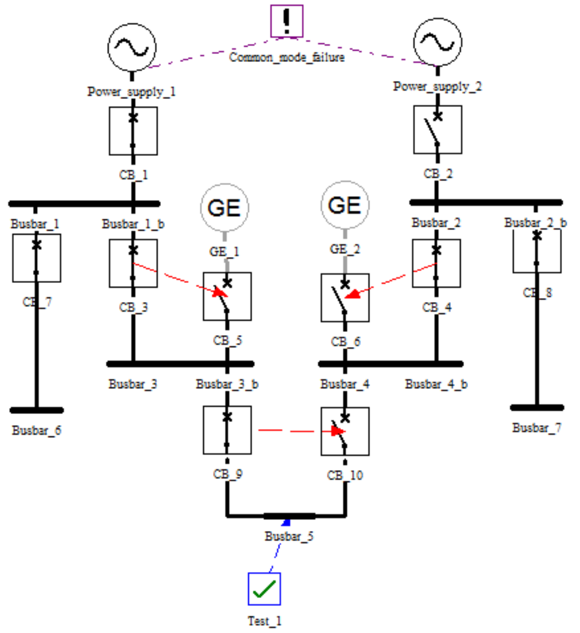


Figure 6 : Nominal operation

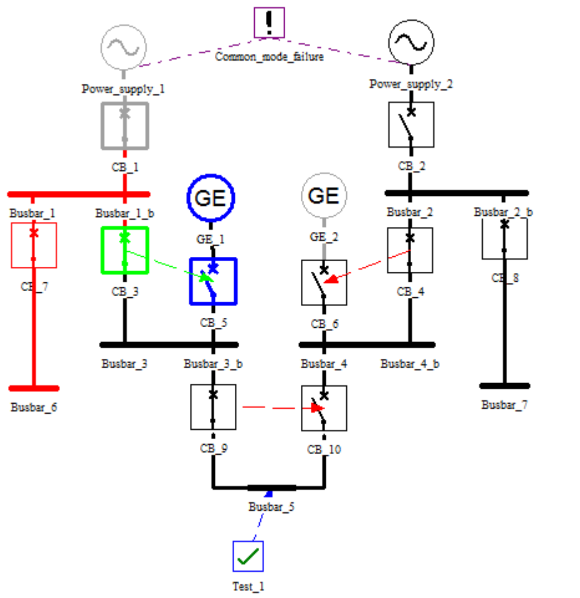


Figure 7a : Simulation of failure : short circuit on the busbar 1. This lead to the first sollicitation opening the CB3 and secondly Closing the CB5

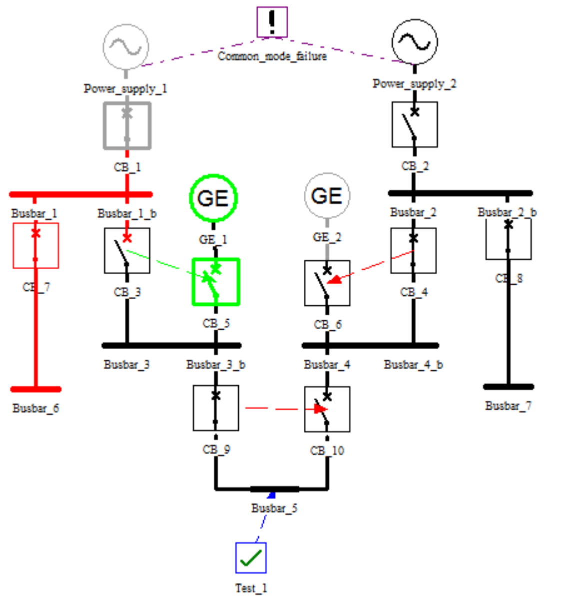


Figure 7b : Opening of the CB3 and sollicitation to close the CB5

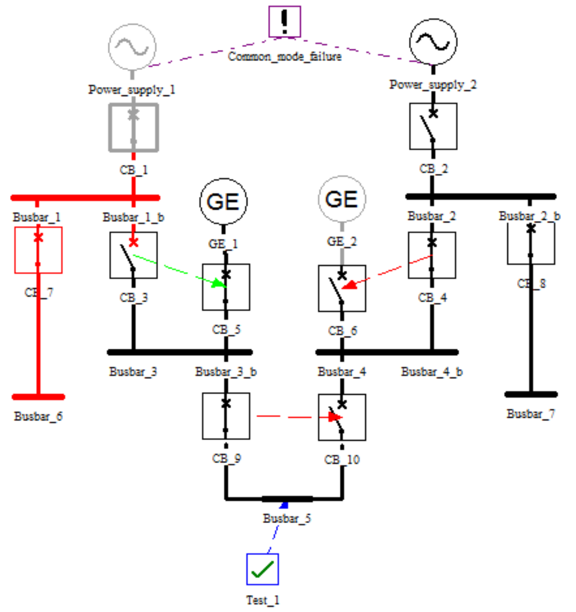


Figure 7c : Closing the CB5. End of the sequence. Test 1 still supply

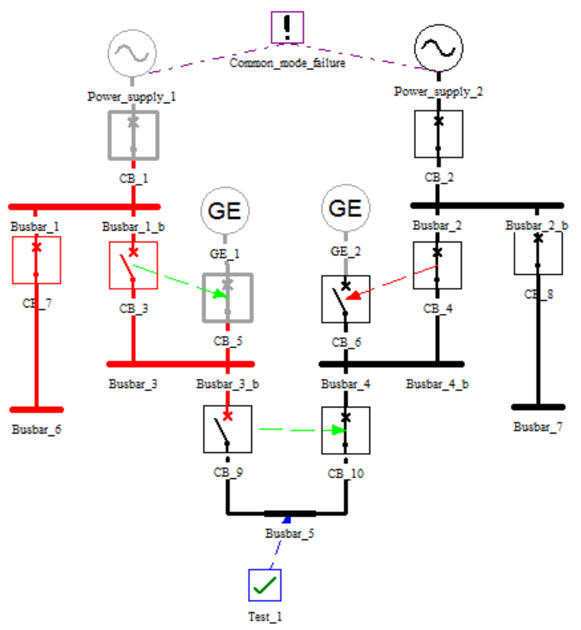


Figure 8a : Diagram after on the busbar 3

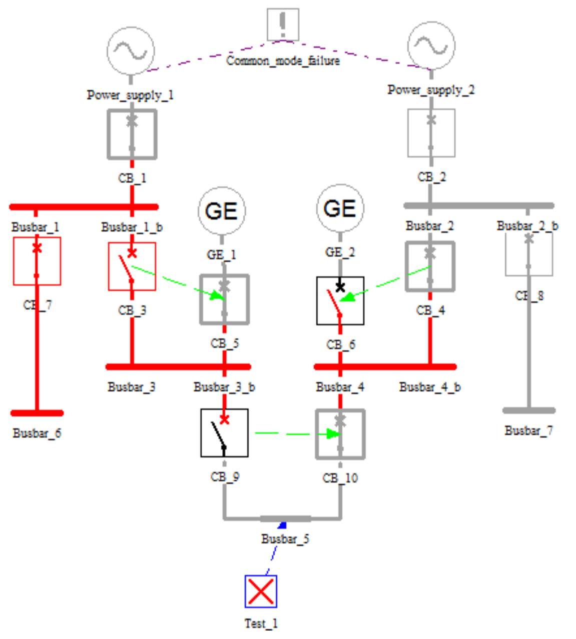
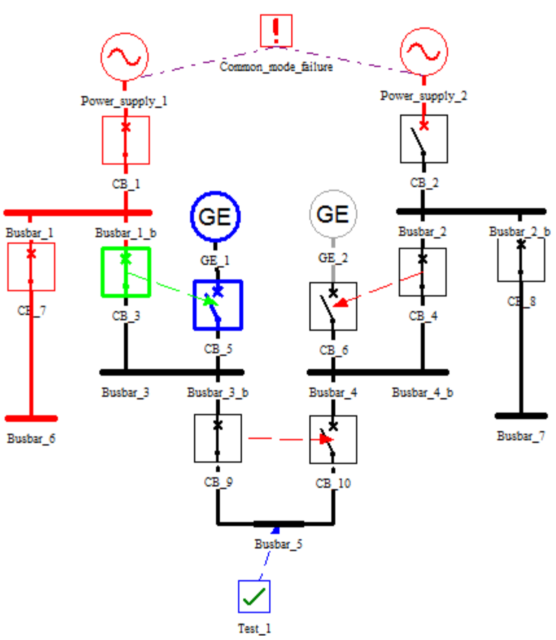
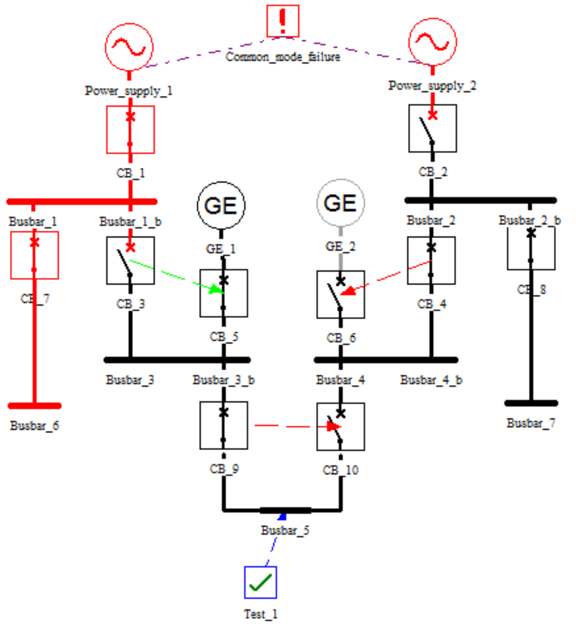


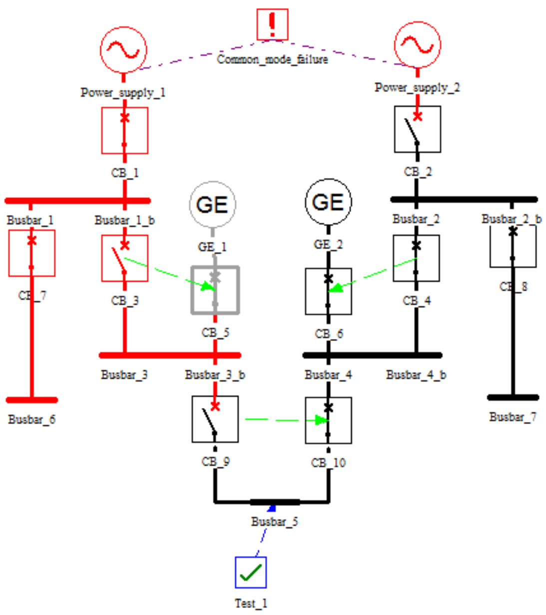
Figure 8b : Diagram after the failures on the busbar 3 and short circuit on the circuit breaker 6. Test 1 is out of supply



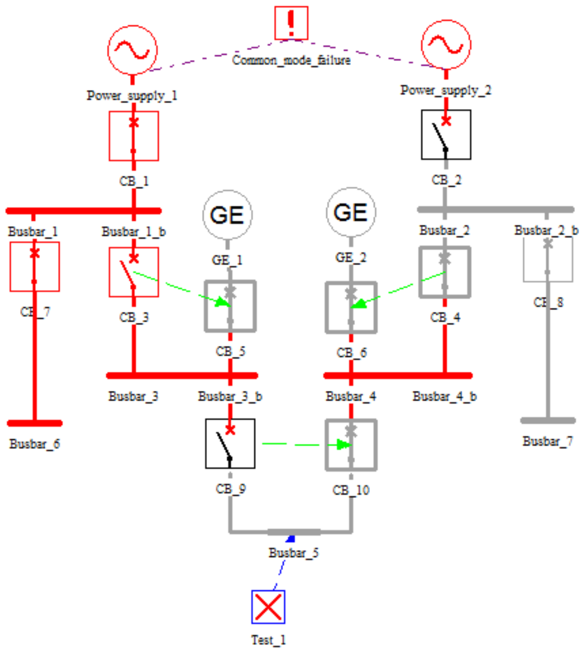
9.a : Common cause failure



9.b : GE 1 supply sur busbar 5



9.c : Short circuit Busbar 3 / GE_2 supply the busbar 5



9.d : Short circuit on busbar 4/ The test-1 point is not supply

5.3. Results of reliability and availability obtained with KB3-K6

➢ Global result

The KB3 tool give some global result about reliability for the system studied :

The equivalent failure rate for the system, the MTTF (mean time to fail), the reliability after one year, the Unavailability and the mean time when the global system failed

Result	Estimate value	Pessimistic value	Compute value
Equivalent Lambda	2,00E-07	2,00E-07	**2,00E-07**
MTTF	-	4,99E+06	**4,99E+06**
Reliability after one year	1,75E-03	1,75E-03	**1,75E-03**
Unavailability	4,80E-06	4,81E-06	**4,80E-06**
Mean time during a system failure	-	-	**2,40E+01**

Table 3 : Example of result of reliability computation with KB3 Tool

Time of observation : 1 year , 8760 hours

Result with Precision level : 1E-6

➢ Detailed results

Moreover the KB3 tool give all the sequence leading to the failure if the system. The exploration of the different sequences leading to the failure in function of the level of precision indicated initially

For example with a Result with Precision level : 1E-6

the KB3 tool identify the Number of sequences : 6

Num	Transitions			Proba	Time	Unavaila-bility
Seq.	Name	Rate	Type	Asympt.PA	average	Asympt.IA
1	Short_circuit(Busbar_5)	0,0000001	EXP	9,09E-02	2,40E+01	2,40E-06
2	Short_circuit(CB_9)	0,0000001	EXP	9,09E-02	2,40E+01	2,40E-06
	Short_circuit(Busbar_3)	0,0000001	EXP			
3	Open_fail(CB_9)	0,001	INS	9,09E-05	1,20E+01	1,20E-09
	Shrort_circuit(CB_3)	0,0000001	EXP			
4	Open_Fail(CB_9)	0,001	INS	9,09E-05	1,20E+01	1,20E-09
	Short_circuit(Busbar_3)	0,0000001	EXP			
	Open_OK(CB_9)	0,999	INS			
	Close_Fail(CB_10)	0,001				
5	Open_OK(CB_2)	0,999	INS	9,07E-05	1,20E+01	1,20E-09
6	Short_circuit(CB_3)	0,0000001	EXP	9,07E-05	1,20E+01	1,20E-09

Table 4 : Example of sequences leading to the loss of supply of the system (with level precision 1E-6)

With Result with Precision level : 5E-8

One obtains the Number of sequences : 44

(below some of the 44 sequences with the sequences 16, 34 and 36 where the common cause failure contribute to the failure of the system)

Num Seq.	Transitions			Proba	Temps	Indispo.
	Nom	Taux	Type	Asympt.PA	moyen	Asympt.IA
1	Short_circuit(Busbar_5)	0,0000001	EXP	9,09E-02	2,40E+01	2,40E-06
2	Short_circuit(CB_9)	0,0000001	EXP	9,09E-02	2,40E+01	2,40E-06
	Short_circuit(Busbar_3)	0,0000001	EXP			
3	Open_fail(CB_9)	0,001	INS	9,09E-05	1,20E+01	1,20E-09
	Shrort_circuit(CB_3)	0,0000001	EXP			
4	Open_Fail(CB_9)	0,001	INS	9,09E-05	1,20E+01	1,20E-09
	Short_circuit(Busbar_3)	0,0000001	EXP			
	Open_OK(CB_9)	0,999	INS			
	Close_Fail(CB_10)	0,001				
5	Open_OK(CB_2)	0,999	INS	9,07E-05	1,20E+01	1,20E-09
	Short_circuit(CB_3)	0,0000001	EXP			
	Open_OK(CB_9)	0,999	INS			
	Close_Fail(CB_10)	0,001				
6	Close_OK(Dj_2)	0,999	INS	9,07E-05	1,20E+01	1,20E-09
	Short_circuit(Busbar_3)	0,0000001	EXP			
	Open_OK(CB_9)	0,999	INS			
	Close_OK(CB_10)	0,999				
	Close_OK(CB_2)	0,999	INS			
7	Short_circuit(Busbar_4)	0,0000001	EXP	2,18E-07	1,20E+01	2,87E-12
	Short_circuit(Common_mode)	0,0000001	EXP			
	Open_Fail(CB_3)	0,001	INS			
16	Open_Fail(CB_9)	0,001	INS	9,09E-08	8,01E+00	8,01E-13
	Short_circuit(Common_mode)	0,0000001	EXP			
	Open_Fail(CB_3)	0,001	INS			
	Open_OK(CB_9)	0,999	INS			
	Close_Fail(CB_10)	0,001				
	Close_OK(CB_6)	0,999				
34	Start_OK(GE_2)	0,999	INS	9,06E-08	8,01E+00	7,98E-13
	Short_circuit(Common_Mode)	0,0000001	EXP			
	Open_Fail(CB_3)	0,001	INS			
	Open_OK(CB_9)	0,999	INS			
	Close_OK(CB_10)	0,999				
	Close_OK(CB_6)	0,999				
36	Start_Fail(GE_2)	0,001	INS	9,06E-08	8,01E+00	7,98E-13

Table 4 : Example of sequences leading to the loss of supply of the system (with level precision 5e-8)

5.4. Comment about the treatment of the reliability level with the KB3-K6 tool

The KB3-K6 tool is a very powerful tool to compute the reliability and availability of electrical network. The failure mode of component are integrate from the beginning into the knowledge database for electrical component. It is easy to integrate some modification into an existing electrical network and to compute the reliability and availability of the new system without doing a long new study of reliability

Nevertheless there are some assumptions done for the computation with KB3-K6 :

- Failure rate are constant with time (exponential law)
- The failure of component are independent
- The result give the probability after a time that the system is in good operation or in failure but can not give the probability that the system operate out of certain condition which correspond to a derated state

That why it can be interesting to explore the possibility of a new complementary approach based on MODELICA and Monte Carlo simulation to study the reliability and availability of electrical network.

6. Principle of reliability analysis of system with MODELICA

The different phases needed to do reliability analysis with MODELICA are presented in this chapter. The principle of Monte Carlo simulation into MODELICA will be described more precisely.

6.1. Steps of needed to do reliability analysis with MODELICA

The different step to be able to do a reliability analysis with MODELICA includes :

- The description of the nominal behavior with MODELICA library for the component studied
- The failure mode and effect analysis for the component studied
- Adding the failure mode into the model of the MODELICA component (example will be shown as follows)
- Perform Monte Carlo simulation in order to generate failure of some component during the time of the mission of the system

6.2. Description of the nominal behavior of component

Existing library such as MODELICA.ELECTRICAL. ANALOG can be used for electrical component or dedicated library such as THERMOSYSPRO (designed by EDF) for thermo-hydraulic component.

6.3. Failure mode and effect analysis and parameters associated

The main element of a reliability analysis of a component is to do the failure mode and effect analysis (FMEA). This study leads to the choice of the main failure to take into account for the reliability analysis of a component.

For example the function elimination of a short circuit need the set of components :

- sensor to detect the overcurrent due to the short circuit,
- protection relay which tests if the current is over a threshold. And if so the protection relay triggers the circuit breaker

- the mechanical part of the circuit breaker which mitigates physically the over current due to the short circuit

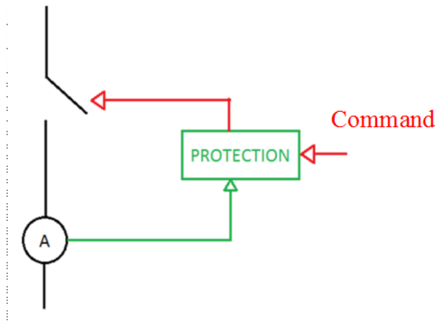


Figure 10 : Different part of the global Circuit -Breaker

With the FMEA of these component, the main failure to take into account are :

- Failure on time of the sensor which can lead to false information about the current and can lead to false tripping of the circuit-breaker
- Protection relay can fails and give false tripping of the circuit breaker
- The circuit breaker can be stuck open of close and refuse to operate on demand

These failure are taking into account and the reliability parameters associated includes :

Type	Name	Default	Description
Real	I_limit		maximum current before opening the circuit-breaker
Real	I_max		maximum current mesured by the sensor
Real	protection_failureRate	0.0001/h	failure rate for the protection
Real	protection_repairRate	10 h	repair rate for the protection
Real	break_gammaStuckClosed	0.1	probability of not opening on sollicitation
Real	break_muStuckClosed	10 h	repair rate from stuck closed
Real	break_gammaStuckOpen	0.1	probability of not closing on sollicitation
Real	break_muStuckOpen	10 h	repair rate from stuck open
Real	sensor_failureRate	0.0001/h	failure rate for the sensor
Real	sensor_repairRate	10	repair rate for the sensor

Table 5 : hypothesis for the failure rate of circuit breaker

6.4. Adding the failure mode into Modelica model of component

Considering the component “pipe” from the THERMOSYSPRO library (designed by EDF) for thermohydraulic component, the figure below presents the integration of the failure mode and the state diagram associated to cross from the different states of the component.

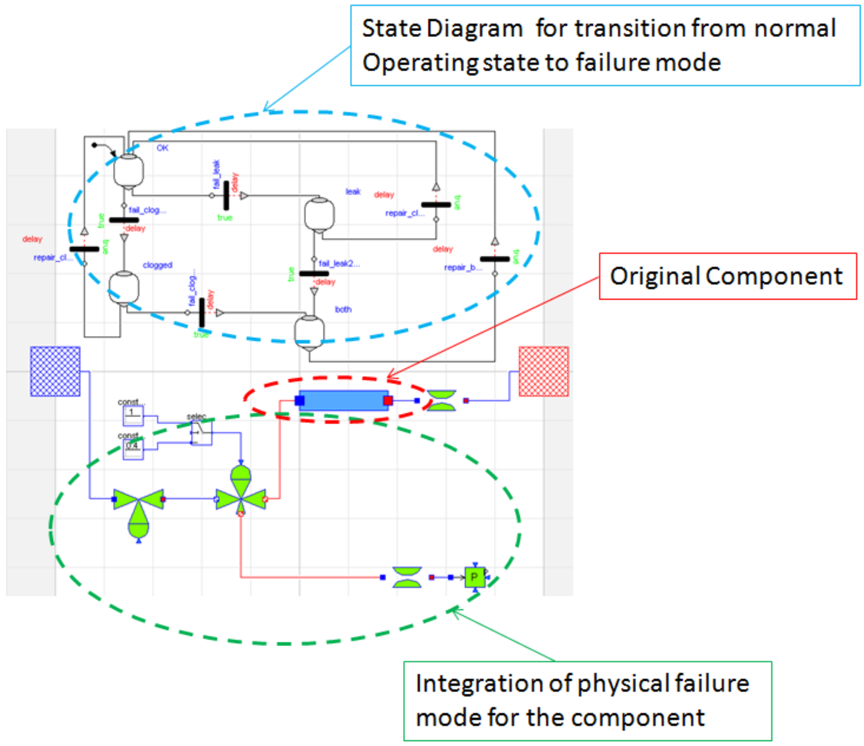


Figure 11 : Example of the integration of failure mode into MODELICA for the "pipe" component of the thermosyspro library

6.5. Monte Carlo simulation integrated into MODELICA and the example of the heated room

6.5.1. Principle of MONTE CARLO simulation integrated into MODELICA

In Modelica 3.3 exists the possibility for synchronous "state-machines" [1]. Here is an extract from their specification:

Any Modelica block instance without continuous-time equations or algorithms can potentially be a state of a state machine. A cluster of instances which are coupled by **transition** statements makes a state machine. All parts of a state machine must have the same clock. All transitions leaving one state must have different priorities. One and only one instance in each state machine must be marked as initial by appearing in an **initialState** statement.

In our case we don't want to rely on a clock, but instead have continuous-time state machines, containing continuous-time equations. This is a generalization of the Modelica 3.3 to continuous-time. This is enabled in Dymola by activating some Hidden flags. (This was studied by Hilding Elmqvist [1])

The principle of the MONTE CARLO simulation has been presented in the paper (Bouissou et al. [2])

Given a random time T whose cumulative distribution function (cdf) F is defined as :

$$F(t) = \Pr(T<t)$$

The corresponding hazard rate $\lambda(t)$ is defined as :

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{\Pr(T < t + \Delta t \mid T > t)}{\Delta t}$$

The hasard rate can then be expressed as

$$\lambda(t) = \frac{F(t)'}{1 - F(t)} \quad => \quad \frac{dF(t)}{dt} = (1 - F(t)) * \lambda$$

For Monte Carlo simulation, the time to the next event T, is determined by drawing a uniform random number, r in [0,1], and solving : F(T) = r

When λ is constant the solution to the differential equation is :

$$F(t) = 1 - e^{-\lambda t} \quad \text{and} \quad T = -\frac{Ln(1-r)}{\lambda}$$

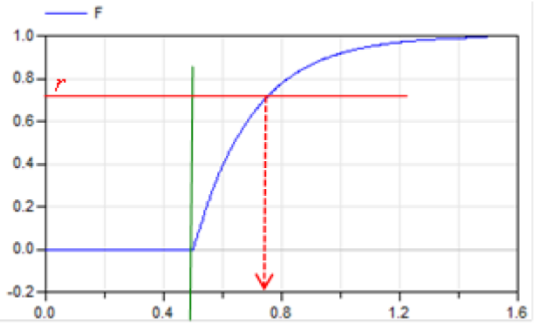


Figure 12 : Principle of Monte Carlo simulation implemented in MODELICA [2]

The « inverse cdf » technique for drawing a random number according to a given distribution

First Version	Second version

`outer GlobalSeed globalSeed;`
`Real r, t_next;`
`parameter Real hazardRate;`
 	
`equation`
`when enableFire then`
`r = globalSeed.random();`
`t_next = time - log(1-r)/hazardRate;`
`end when;`
 	
`if enableFire then`
`fire = time >= t_next;`
`else`
`fire = false;`
`end if;`
	`outer GlobalSeed globalSeed;`
	`Real r;`
	`input Real hazardRate(min=0);`
	`equation`
	`when enableFire then`
	`r = globalSeed.random();`
	`reinit(F,0);    // start at F=0`
	`end when;`
	
	`der(F) = (1-F)*hazardRate;`
	`if enableFire then`
	`fire = F >= r;`
	`else`
	`fire = false;`
	`end if`

Table 6 : example of implementation in MODELICA on Monte Carlo simulation

6.5.2. Example of the heated room [2]

A first simple example the "heated room" has been treated in the MODRIO project [2]. However, its simplicity enabled experimenting and developing our new method efficiently. This test-case has been solved by Bouissou et al. Modelica Conf 2014 [2].

The system consists of a room containing a heater. The heater is controlled by a hysteresis on the ambient temperature. If the ambient temperature falls below 15°C, the heater is switched on. If the ambient temperature reaches 20°C, the heater is switched off. The outside temperature is constant at

13°C. We suppose the ambient temperature follows the differential equation:

$$\frac{dT}{dt} = 0.1 \times \left(Outside_{temperature} - T\right) + 5 \times \left(Heater_{is_{on}}\right)$$

With Heater_is_on an indicator function equal to 1 if the heater delivers power, 0 otherwise. The time t is in hours and the ambient temperature T is in °C.

In nominal circumstances, the ambient temperature should be a deterministic succession of convex and concave exponentials between 15°C and 20°C.

However, we give to the heater a constant failure rate lambda=0.01/h and a constant repair rate mu=0.1/h. The aim is to study the influence of the random failures on the ambient temperature.

We model the heater as a state-machine with two states (OK+failed). With our Monte-Carlo simulations, we compute the mean value, the 1% fractile and the 99% fractile of the ambient temperature, for 1,000,000 simulations. This takes us about 1h30min.

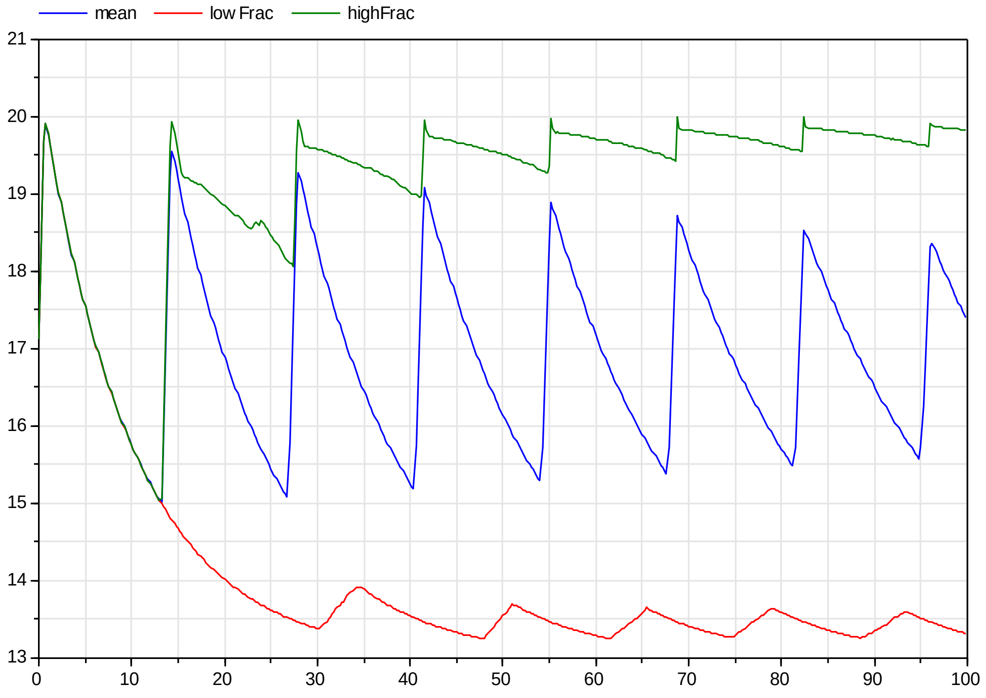


Figure 13 : Heated room case treated with MODELICA and Monte Carlo Simulation [2]

7. Modeling the reliability the data center with MODELICA

This example was proposed by EDF R&D, as part of the MODRIO project. Up until now, they have studied this kind of system with binary representations.

Data-centers are complex systems which require high levels of reliability and availability (99.99…%). They combine different fields such as electric, thermic and mechanic, with various kinds of influences between the different parts. For example, the level of use of the servers will modify energy asked to the power system to supply them, but will also influence the power asked to the cooling system. In return, the cooling system modifies the temperature, which greatly influences the failure rates of the servers. Modelica enables us to study all these different parts in the same model.

Data-centers are defined by their Tier-classification, made by the Uptime Institute, depending on their architecture. In our case, we study a Tier-IV architecture. The electrical part of this architecture with redundancies and back-up generators is similar to the one found in nuclear power plant or other critical systems. Here is a modelisation of this electric part of the data center with :

- The global circuit breaker with failure mode
- The back up Generator
- The UPS (Uninterruptible power supply)
- The control of generator (control command to connect the Back up generator)
- The data load

These component are described more precisely in the deliverable D741

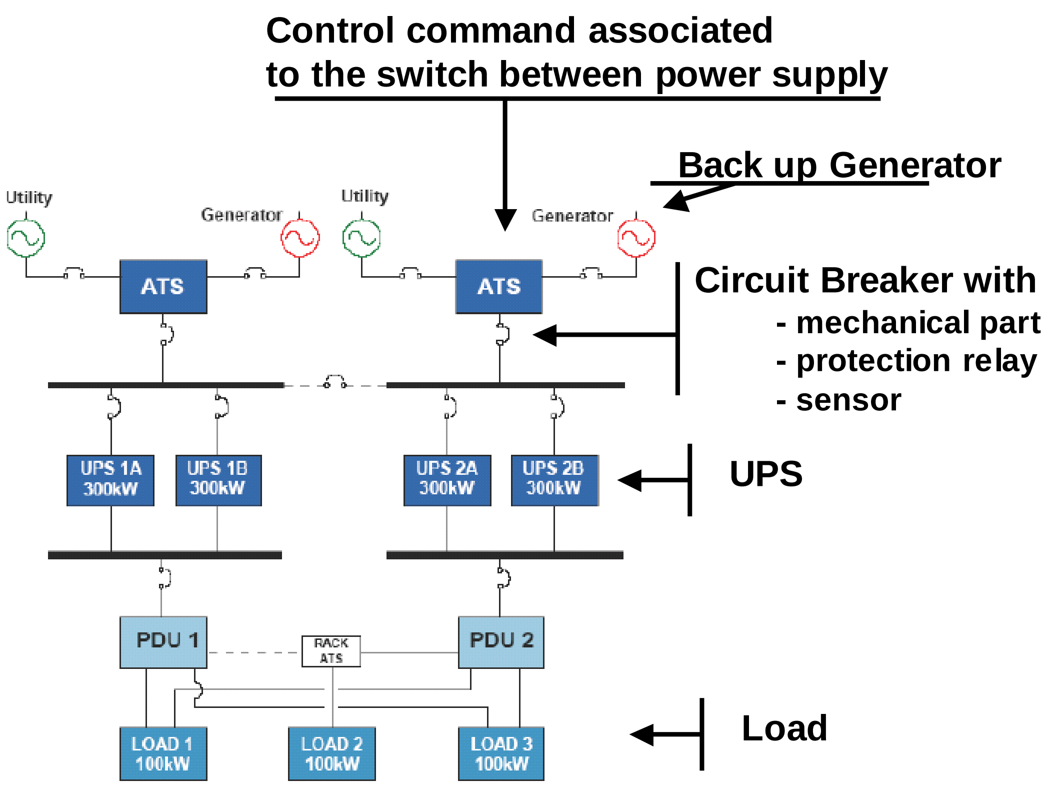


Figure 14 : Diagram of Electrical network of the Data Center

We modeled failures only on circuit-breakers. We chose to represent these circuit-breakers in three parts, each containing some kind of failures.

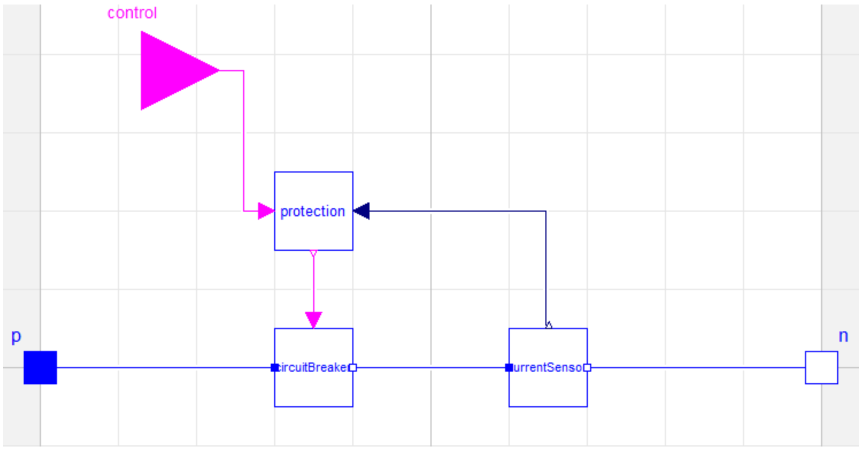


Figure 15 : Global Circuit Breaker

We first have the mechanical part. We add a state-machine to represent the two states open and close, and the failures on solicitation leading to being stuck open or stuck close. For the close state, we use the transitions on solicitations. For the open state, we use the transitions on solicitations with a delay, since it is a security position.

Second part, we have a current sensor. This sensor can be in a failed state, where its output value will be randomly determined, until repaired.

Third part, the protection. This is a control-command part, determining the decision to open or close the circuit-breaker by combining the instructions received from the global control-command and from the output of the current sensor. When failed, it gives a random instruction until repaired.

The Uninterruptible Power Supply (UPS) is represented in a simplified way. Its battery is made of a commanded voltage source. The amplitude of this voltage source varies depending of the loading or unloading of the battery. A commuting switch connects the "normal" alimentation or the battery alimentation depending on the potential level at the input of the UPS.

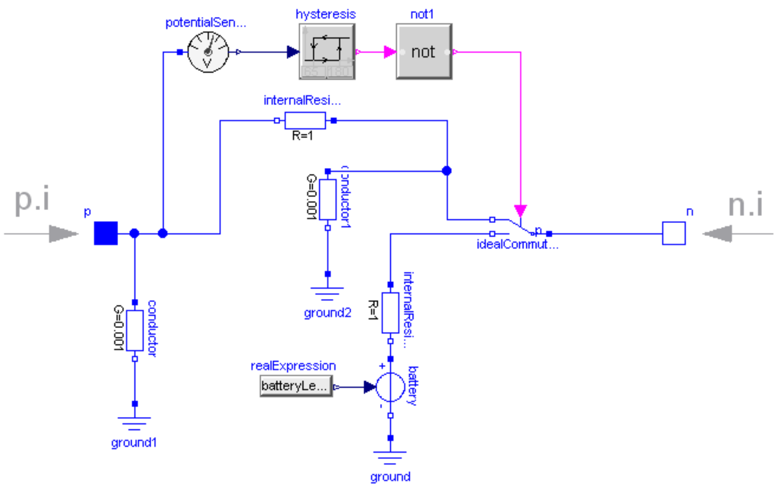


Figure 16 : The component UPS

7.1. Representation of the structure of the data center with MODELICA

Here is the presentation of the diagram integrated into MODELICA to represent half-part of the electrical network of the Data center

Data-Center - half

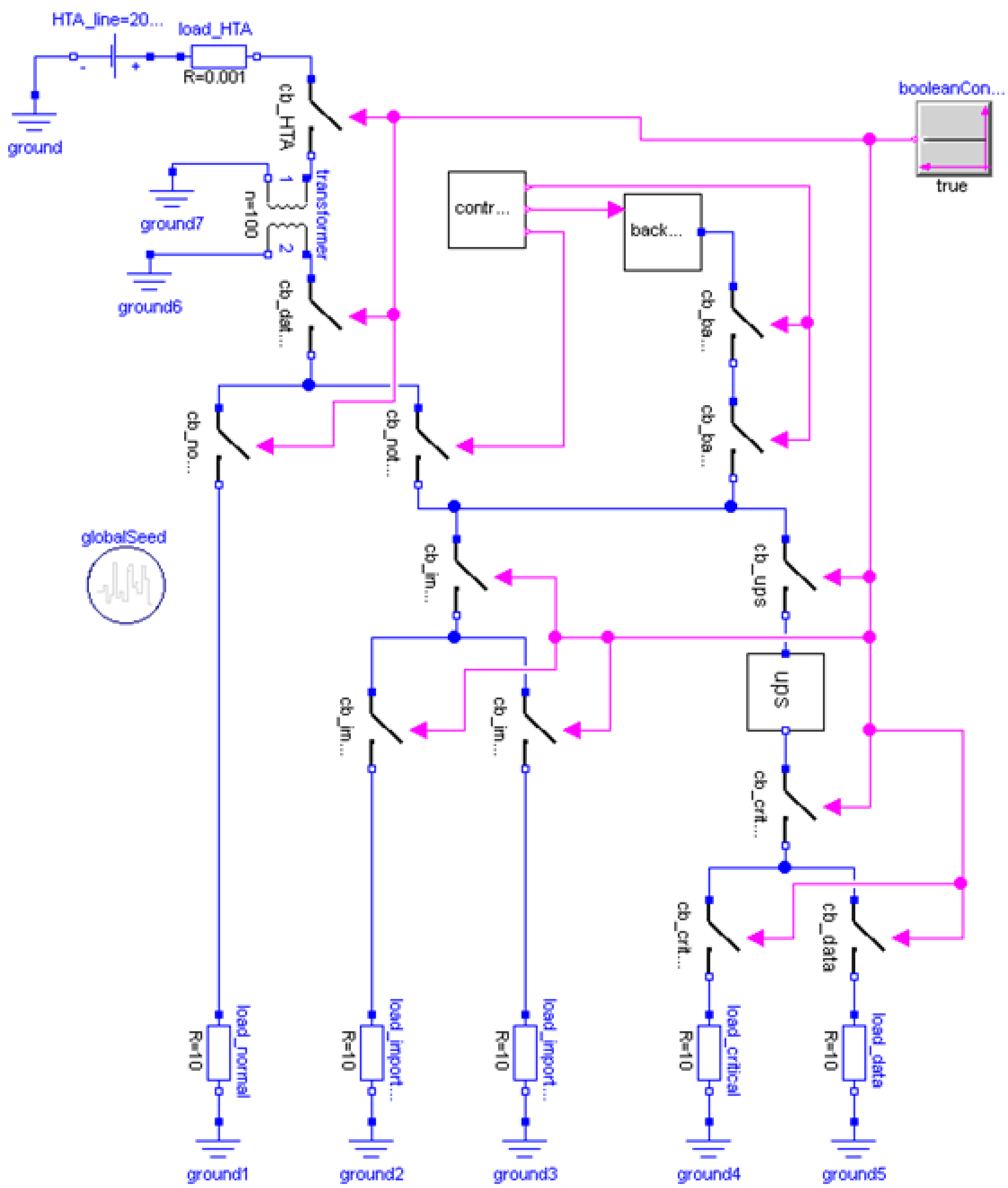


Figure 17 : MODELICA diagram of the half part of the electrical network of the Data Center

7.2. Modeling the reliability of electrical network of the Data center with MODELICA

For this study, we chose arbitrary numerical values, in order to be able to witness most kinds of possible events in one not-too-long simulation.

They correspond to having 200V at the output of the transformer, all gamma equal to 0.1 and all lambda equal to 1/day, except for the ones after the UPS, equal to 0.001/day.

These smaller lambda were to prevent having too much failures after the security systems, and thus not being able to directly see the effectiveness of these systems.

The interest point are the supply of the energy of one side (left in red arrow) of the data center and the secure busbar (arrow I blue) supplied by the two part of the data center

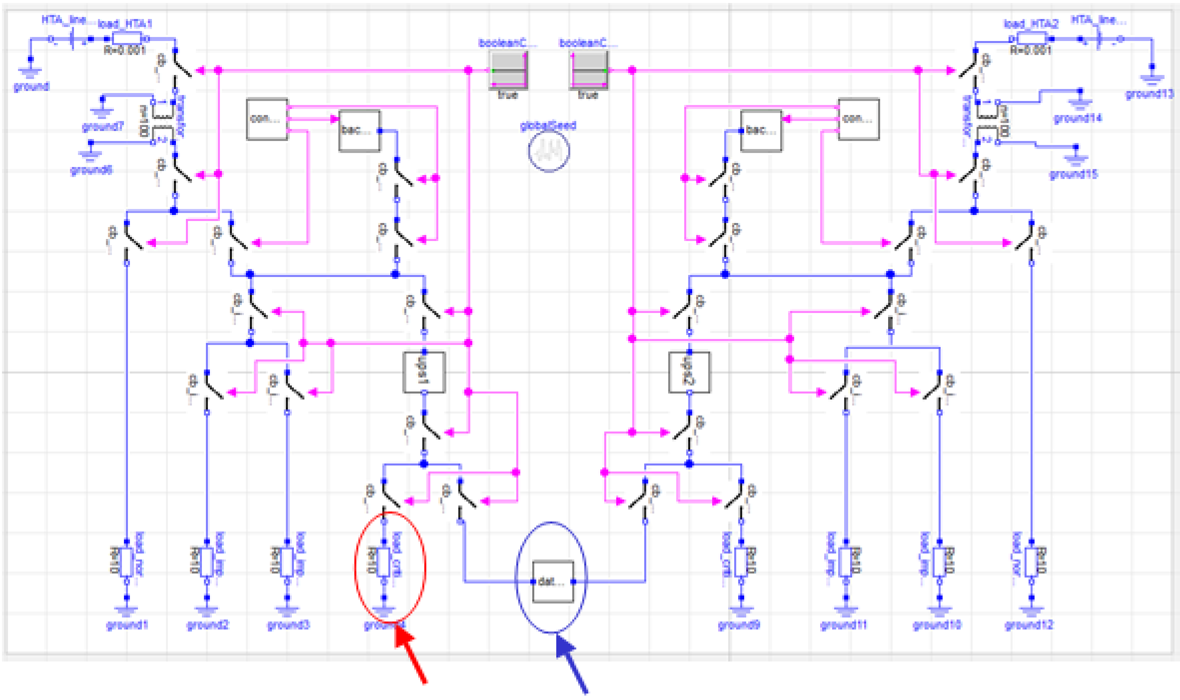


Figure 18 : Indication of the interest points (red and blue arrows) for the reliability study of the Data Center

One simulation, for 100 days, gives us the following plots for the alimentation of the servers (in blue) and the alimentation of the "left" cooling system (red)

The differences between the blue plot and the red plot immediately show the importance of the double-alimentation. Moreover, when focusing on the blue plot, we can identify the nominal tension at 173-174V, and the small fluctuations due to the reconfigurations depending on the failed circuit-breakers, the level of the battery in the UPS, the use of the back-up generator… These small fluctuations can have influences on the electric and thermic comportment of the servers. They also happen on all the other electric components of the data-center. This is why having Modelica, which computes the physical comportments of our system, instead of a binary representation, is very important for accurate studies.

By giving realistic laws of probabilities and load values, it is then possible to do Monte-Carlo simulations on the electric part of the data-center. Moreover, thanks to working in Modelica, we can also model the cooling system of the data-center, with its possible failures, and interface these two models, in order to have an even more precise model of the whole data-center.

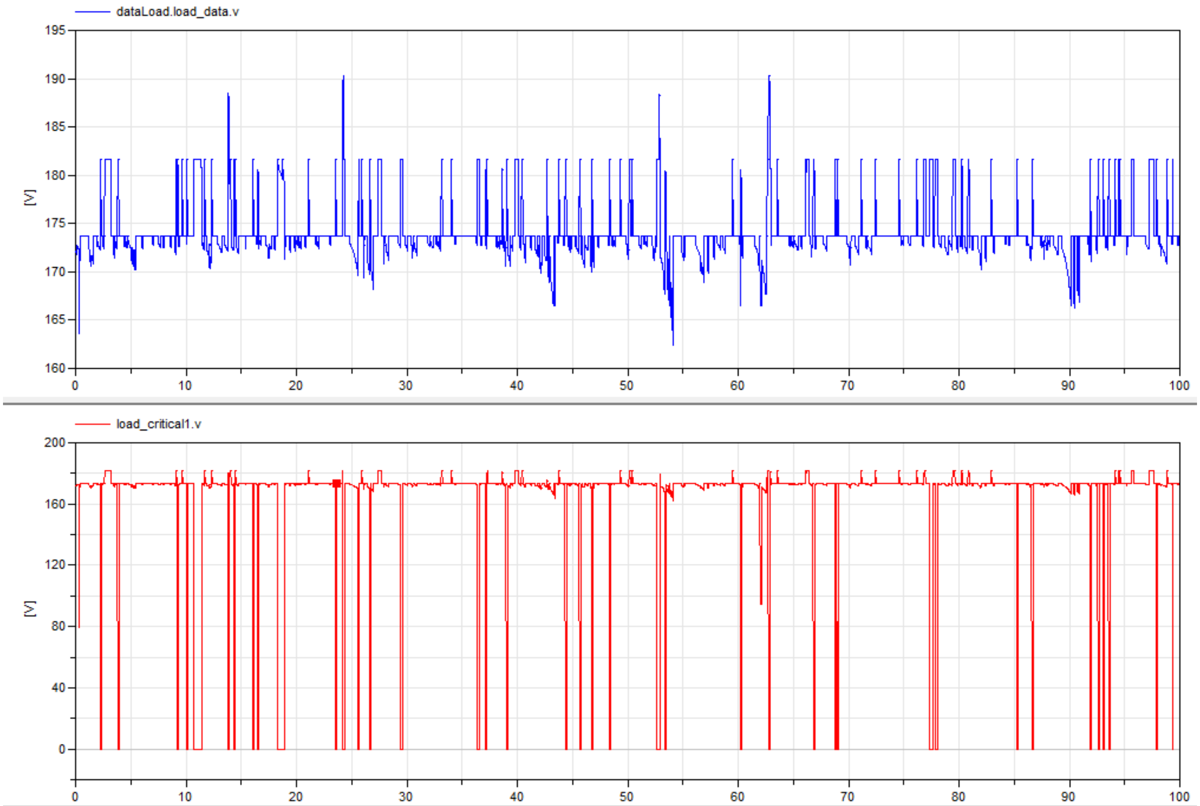


Figure 19a : Result of level tension for the blue and red point of interest

Figure 19b : Result of level tension for the blue and red point of interest

8. Model with MODELICA of the reliability the "air cooling room with computer" for the data center

In this example we took the reliability of "heated room" case treated by M. Bouissou [2], adapted it to the case of an "air climate room with computers" which is directly linked to the data center.

8.1. Modeling the « air cooling room » case with MODELICA

In order to treat the « air cooling room with computers » it is necessary first to establish equation fir the evolution of the temperature.

The energy flow crossing into the air cooling system is caracterised by the differential equation :

$$\frac{dT}{dt} = 0.1*(T_{Out} - T) - 5*Cooling + HeaterComputer$$

With

- T_{out} : temperature outside the « air cooling room »
- T : temperature inside the air cooling system
- cooling : boolean variable equal to 1 when the cooling system is ON
- HeaterComputer : is the heater wasted by the computers

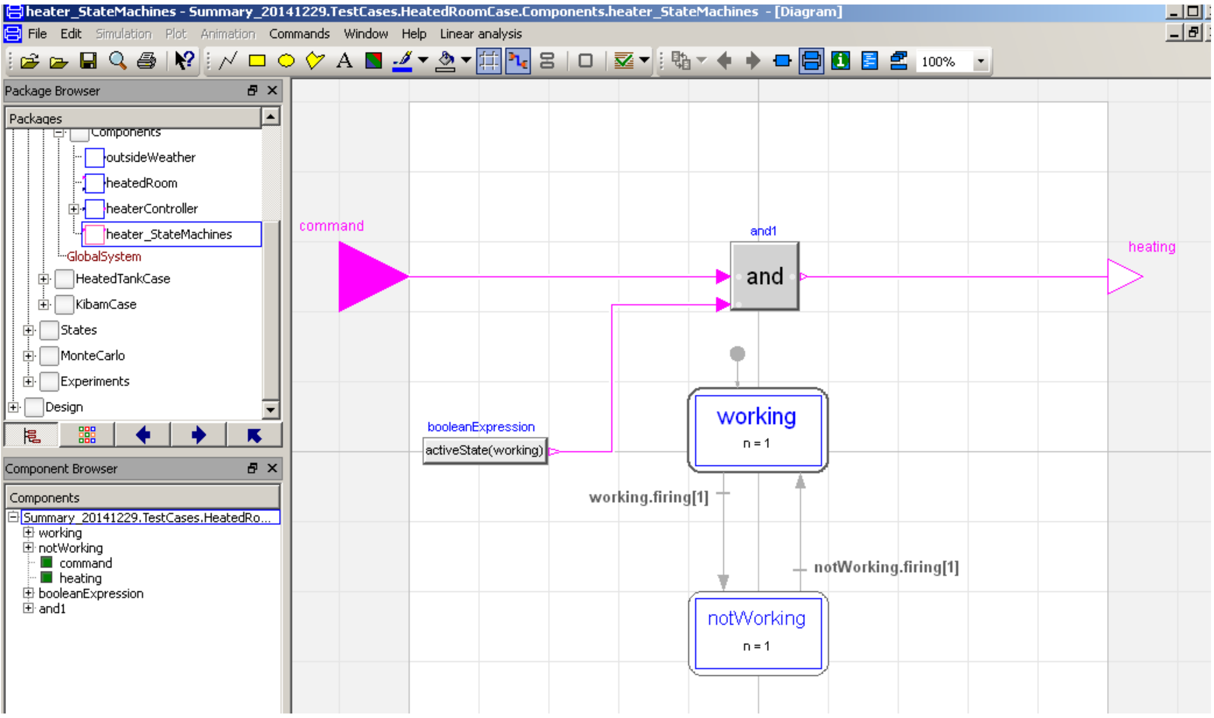


Figure 20 : State machine for the heated room [2] which has been adapted to the air climate room

8.2. Modeling the failure rate of the computer of the data center

The computer are mainly composed of electronic component with failure rate variable with temperature (Arrhenius law)

$$\lambda(T) = \lambda_0 * \exp\left[-\frac{E_a}{K}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

With λ_0 : the nominal failure rate of electronic component (/h)

E_a : Activation Energy (eV)

K : Boltzmann Constant ($J.K^{-1}$)

T : Temperature of air cooling system (K)

T_0 : Nominal Temperature (K)

8.3. Result of the simulation

We took for the failure rate of computer the assumption as follows :

Parameter	values
T_0	287.5 K
Ea	0.5 eV
K	8.62 E-5 J/K

The figure below shows an example of simulation of the regulation temperature of the air cooling with a failure which lead the temperature increase over 20°C until the cooling system will be repaired.

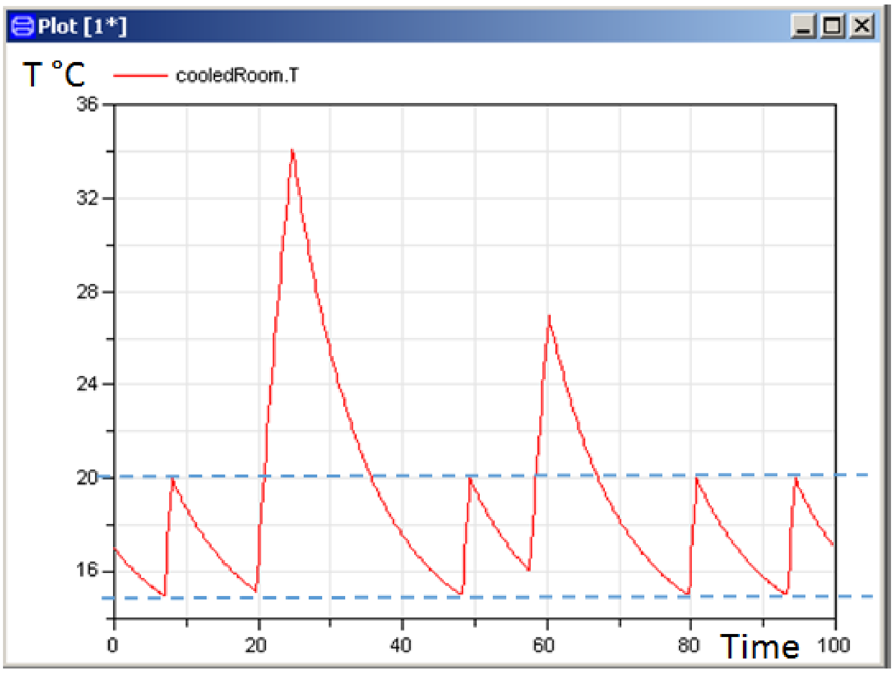


Figure 21 : Variation of the temperature of the « air cooling room »

One can notice the variation of the failure rate of the computer with the variation of the room The failure rate of the computer are directly linked to the temperature into the air cooling room.

The increasing of the temperature can accelerated the failure of the computer

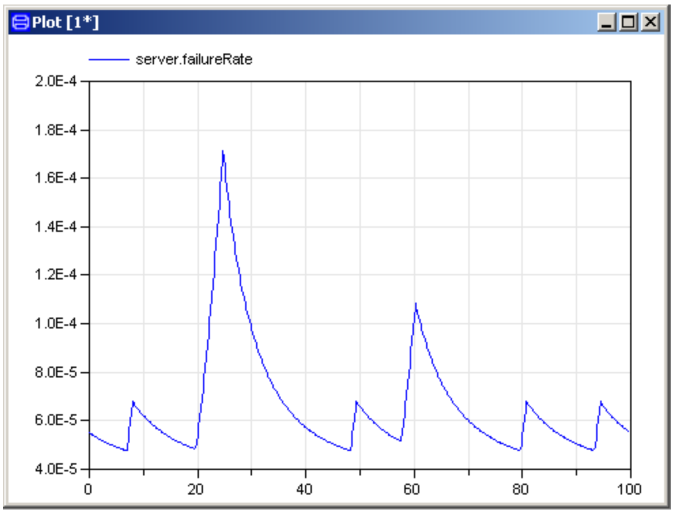


Figure 22 : Variation of the failure rate of computer with the temperature inside the air cooling room

9. Conclusions

The benchmark with different approaches to estimate the reliability and availability of data center shows the elements as follows :

- The KB3 tool is a very powerful tool to study the reliability of industrial electrical network. But these tool rely on some assumption about the failure of component that are sometime not relevant on site (failure constant with time and independant failure of component
- The study done in the context of the analysis of the data center with the MODRIO project has shown different point
    - The proof of concept with the library state machine [1] to do system reliability analysis with MODELICA and Monte Carlo simulation
    - The type of result which is different of the usual result obtained with classical reliability tool such as KB3. For example in the case of the « air climate room » one can obtained the probability that the temperature is over a thresold
    - Nevertheless some improvement has perhaps to do into the MODELICA language to do easier probabilistic and reliability analysis with MODELICA.

The collaboration between the MODRIO partners about this subject was very fruitful mainly between EDF R&D and DLR.

10. References

[1] Elqmvist H. Gaucher F., Mattsson S.E., Dupont F. (2012) : **State machines in Dymola**. Modelica 2012 Conference Munich Germany, Sept 3-5, 2012 Download: http://www.ep.liu.se/ecp/076/003/ecp12076003.pdf

[2] Bouissou M., Elqmvist H. Otter M. and Benveniste A. (2014) Efficient Monte Carlo simulation of stochastic hybrid system. MODELICA’2014 Conference Lund, Sweden March 10-12

11. APPENDIX : Monte Carlo simulation integrated into MODELICA Dymola

In order to simulate models with stochastic comportments, we choose to use the Monte-Carlo method. This means we will launch a great number of times the "same" simulation, only changing the seed of our random number generator. To do this great number of simulations with some efficiency, we took advantage of the recent SimulateMultiResultsModel() function in Dymola. This function was originally designed to launch several times the same simulation while modifying the value of a parameter, and store the corresponding trajectories of the asked variables. In our case, since the seed for our random number generator is automatically changing each time, we have no parameter to modify between each simulation.

The user gives in parameters to our function MC_function() the path of the model to simulate, the number of requested simulations, the simulation parameters, the name of the studied variable(s) and the requested indicators. For the indicators, we choose to allow the computation of the mean trajectory, the minimum values, the maximum values, two fractiles (customizable percentages) and the end-value. These indicators are enabled with Booleans.

Computing the exact fractiles would require a too great number of operations. Indeed, to compute it on N simulations, you would need a magnitude of N^2 comparisons. Since the Monte-Carlo method is based on a great number of simulations, this would not be acceptable. To avoid this, we decided to compute an estimation of the fractile. For this, we used the work presented in *Quantile Optimization for Heavy-Tailed Distributions Using Asymmetric Signum Functions* from Jae Ho Kim and Warren B. Powell, Princeton. According to this paper, the α -fractile of X is the limit Y of the sequence:

$$Y_n = Y_{n-1} - \gamma_{n-1} * sgn_\alpha(Y_{n-1} - X_n)$$

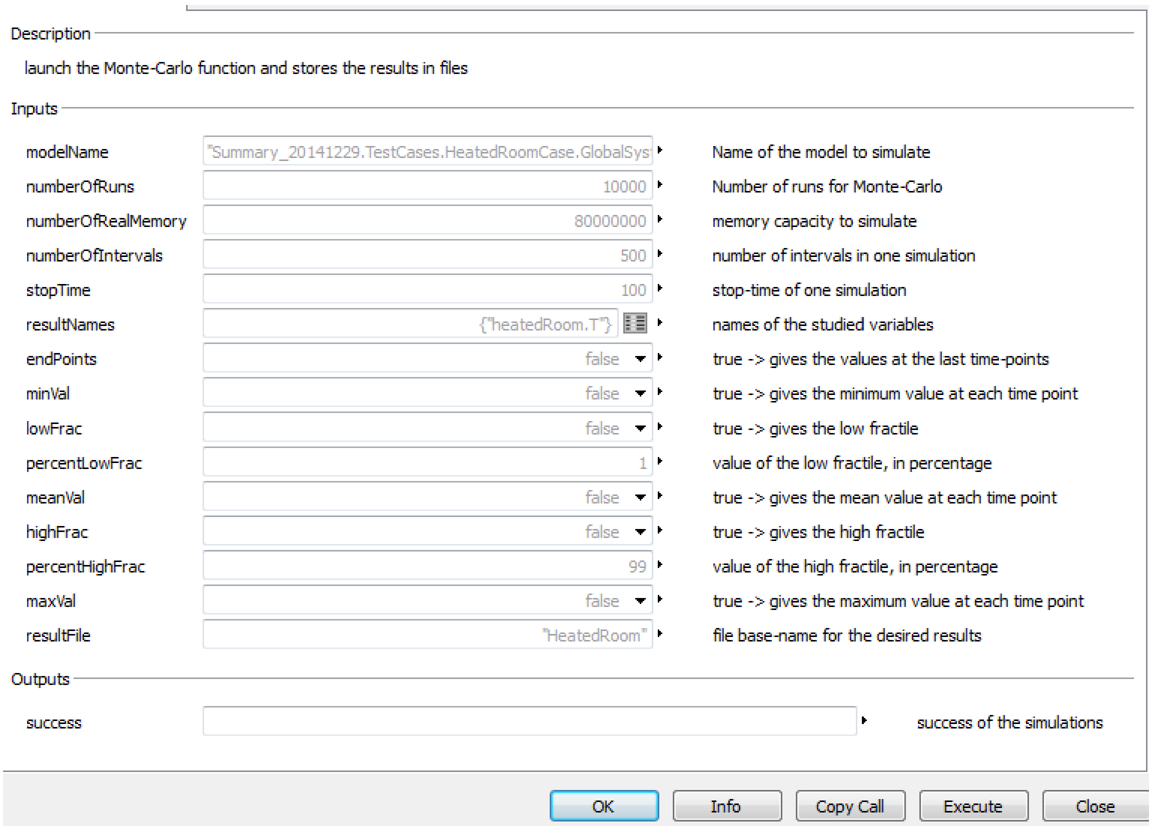
$$where\ sgn_\alpha(u) = \begin{cases} 1 - \alpha\ if\ u \geq 0 \\ -\alpha\ if\ u < 0 \end{cases}$$

$$and\ \gamma_n\ verifies:$$

$$\sum^{\infty} \gamma_n = \infty \quad \sum^{\infty} (\gamma_n)^2 < \infty$$

For the initialization Y0 and the sequence γ_n , we chose to first sort the 100 first values. We then take the value of rank α for Y0, we put sigma = 25value+75value/2*75value as a scaling factor, and we put γ_n , = sigma/n^(2/3).

Using this algorithm, we managed to have a number of operations proportional to the number N of simulations, instead of N^2.



New "MC function" integrated in the MODELICA library to do Monte Carlo simulation

In our function, we first do the simulations (with the simulateMultiResultsModel() function), then we compute the indicators with the results of the simulation, depending of the requested indicators. In case the combination size of the model and number of simulations would be too big for the physical memory, the user can also input some memory usage limitations in the parameter of the function. The simulations and indicator computations are then separated into batches of acceptable sizes, to be run one after another and thus prevent any memory saturation.