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# Study of the Operational Safety of An Electrical Installation with a View to Improving its Architecture: The Case of the Suction Fans At the Kansoko Mine

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## ABSTRACT

The quality of electrical power has become a very important aspect in industry today, in that critical equipment that operates 24 hours a day needs an uninterrupted supply, free from any impurities. This is the case for the ventilation fans used in underground mines around the world. A malfunction, stoppage or breakdown would automatically put the lives of the miners at risk.

This article focuses on the operational safety of the electrical circuit for the fans at the Kansoko mine in the Democratic Republic of Congo and proposes an improvement to the existing circuit. A detailed approach to the methodology of operational safety is given, followed by an overview of the installation of the existing circuit.

We then present our study on the operational safety of this installation based on the FMECA method and use the Fault Tree professional tool to simulate the circuit to understand its behavior in the event of any failure.

**Keywords**: electrical energy, operational safety, FMECA, Fault Tree professional tool, fan

## INTRODUCTION

In industry, as in the service sector, the quality of the power supply is increasingly important. The loss of a power supply is always annoying, but it can be very detrimental, for example, to information processing systems (IT - control command); it can even be catastrophic for certain processes and, in some cases, endanger human life.

An underground mine is a typical example of the risks posed by prolonged power cuts to operations and to the lives of many people. The smooth running of activities within the mine is intimately linked to several vital operations, including ventilation. Both the machines and the workers in the mine need air to carry out their assigned tasks. The fans in an underground mine are therefore priority receivers, as a failure in their power supply circuit would compromise the smooth operation of the machines and endanger the lives of the many workers in the mine.

Having spent a month in the Kansoko underground mine during our academic placement at KAMOA COPPER SA, we had to work on the electrical supply to the suction fans of a vacuum ventilation system. These are divided into two groups of four and three fans located at two different points in the mine, each supplied by a substation.

In view of the importance of the fans in the vacuum ventilation system at the Kansoko mine, a study of their operational safety was required. This is the purpose of this work entitled "Study of the operational safety of an electrical installation with a view to improving its architecture (case of the suction fans at the Kansoko mine)". He will identify the undesirable events likely to cause a loss of power to these fans and then quantify the probability of occurrence of a simultaneous loss of power to the fans of each of the two groups. It will then propose solutions to improve the operational safety of the two circuits.

Divided into three chapters, the first will present the methodology of the operational safety studies, the second will present the electrical installation studied and the third will deal with the operational safety study of the installation itself.

## I. METHODOLOGY FOR SAFETY STUDIES OF ELECTRICAL INSTALLATIONS

### I.1 GENERAL POINTS

Safety covers safety, reliability, availability and maintainability. Safety imperatives initially imposed safety studies on high-risk applications: rail and air transport, nuclear power plants. If we add to this the imperatives of reliability, availability and maintainability, many other fields are concerned. Demands on electricity quality have increased.

Given the considerable improvement in methods and equipment, users are now entitled to demand a high level of availability. To achieve this objective with justified confidence, safety studies are necessary. They enable us to optimize the architecture of the electrical network, the control and command system and the maintenance policy.

They also enable the right solutions to be chosen to achieve the desired level of availability at the best possible cost. Often, the study can be limited to a key point in the installation, which accounts for most of the overall unavailability. They generally involve classifying receivers or systems according to their level of sensitivity.

A distinction is made between

- receivers that can be shut down for long periods of time: up to 1 hour (non-priority),
- receivers which can be shut down for a few minutes (priority),  receivers which must be restarted after a few seconds (essential),  receivers which cannot be shut down at all (vital).

### I.2 SAFETY STUDIES

### I.2.1 DEFINITIONS OF SAFETY-RELATED TERMS

Before presenting power system reliability studies, it is useful to recall a few particularities of the definitions of terms used by reliability specialists. Even if everyone knows the general meaning of the words: reliable, available, maintenance, safety, these terms, when used by reliability specialists, take on a specific meaning (Logiaco, 1999).

- FMEA (Failure Mode and Effects Analysis): This is used to study the influence of component failures on the system.

- Dysfunctional analysis: Based on functional analysis, this is the analysis of system malfunctions (in practice, synonymous with "safety study").
- Availability: Probability of an entity being able to perform a required function under given conditions at a given time t; it is noted A(t).
- Dreaded event: System failure that must be analyzed to prove that the user can have justified confidence in the system. This system failure is a quality-of-service metric.
- Reliability: Probability that an entity can perform a required function, under given conditions, during a given time interval [t1, t2]; written as R(t1, t2).
- Maintainability: Probability that a given maintenance operation can be carried out during a given time interval [t1, t2].
- MDT (Mean Down Time): Mean time during which the system is unavailable. It includes the time taken to detect the fault, the time taken for the maintenance department to travel, the time taken to supply the faulty equipment and the repair time.
- Model: Graphical representation of the combination of failures found during the M.A.D.E. and their maintenance process.
- MTBF (Mean Time Between Failure) : Mean time between two failures of a repairable system.
- MTTF (Mean Time To Failure): Mean time to first failure.
- MTTR (Mean Time To Repair): Mean Time To Repair.
- MUT (Mean Up Time): Mean uptime after repair.
- Feedback: Operational reliability data collected during equipment failures in operation.
- Safety: Probability of avoiding an event with dangerous consequences.
- Dependability: Dependability is a generic concept that measures the quality of service delivered by a system in such a way that the user has justified confidence in it. Justified confidence is obtained through qualitative and quantitative analyses of the various properties of the service delivered by the system. These different properties are based on the probabilistic values defined below.
- Failure rate: Probability that an entity will lose its ability to perform a function during the interval [t, t+dt], knowing that it has not failed between [0, t]; it is noted λ.
- The repair rate μ(t) is introduced in a similar way to the failure rate. It is the inverse of the MTTR.
- Equivalent failure rate: Probability that a system will lose its ability to perform a function during the interval [t, t+dt], knowing that it has not failed between [0, t]; it is denoted λeq.

### I.2.2 FIELD OF APPLICATION

The studies are carried out on all types of electrical networks, from low voltage to high voltage, and on their protection and control systems.

## I.3 PROCEDURE FOR STUDIES

Whatever the need expressed by the designer or operator of an electrical installation, the safety study comprises the following phases:

1. expression and analysis of the need
2. functional analysis of the system
3. failure mode analysis
4. modelling
5. calculation or assessment of safety criteria.

In most cases you will need to do this several times:

- twice if the aim is to compare two diagrams,
- n times if the aim is to iteratively determine an architecture adapted to the requirement, considering technical and economic imperatives.

### I.3.1 EXPRESSION AND ANALYSIS OF REQUIREMENTS

In this stage, the client must specify the following points:

- What the study is about,
- The risk,
- The nature of the request (type of analysis),
- Formalization of requirements.

### I.3.2 FUNCTIONAL ANALYSIS OF THE SYSTEM

The functional analysis is a visual and textual description of the role of the network and/or its components.

This analysis results in two complementary descriptions of the network:

- a description, formalized by functional block diagrams, the aim of which is to present the architecture of the system and the functional links between the various elements of the system,
- a behavioral description, the aim of which is to describe the sequence of different possible states.

### I.3.3 ANALYSIS OF FAILURE MODES AND THEIR EFFECTS AND CRITICALITY

The purpose of this analysis is to provide:

1. The list of possible failure modes for each of the elements identified in the functional analysis,
2. Their causes of occurrence (a single cause is sufficient),
3. The consequences of these failures on the system (also known as single events),
4. The failure rate associated with each failure mode in a quantitative study.

The results are presented in tabular form. This analysis can be considered as the first step in modelling.

### I.3.4 MODELLING

Network malfunctions are represented by a model. The model is a graphical representation of the combinations of events determined by the analysis of the failure modes that contribute, for example, to the loss of power supply to certain receivers and their repair process. There are two main modelling methods: the combinatorial method and the combinatorial and sequential method.

### I.3.5 CALCULATIONS FOR ASSESSING SAFETY CRITERIA

#### I.3.5.1 Calculating the failure rate

The failure rate is generally determined by :

$$\frac{Number\ of\ failures}{Operating\ time\ in\ hours} \qquad (1)$$

The failure rate is usually expressed in terms of "failures per hour".

#### I.3.5.2 Determining MTBF and MTTR

There are many relationships between the quantities introduced. MTTF = 1/λ; and for a non-repairable system MTBF = MTTF (all failures are then first failures). This explains the classic formula widely used for (non-repairable) electronic components: MTBF = 1/ λ.

MTTR is the average repair time of a repairable component for a given failure mode.

## II. PRESENTATION OF THE STUDY FRAMEWORK

### II.1 GENERAL INFORMATION

The electrical installation which is the subject of our study is that which provides the power supply for the suction fans in the SD3 and RPD1 workings of the Kansoko mine. The purpose of these fans is to collect stale air from the various mine workings and convey it to the outside via a ventilation shaft.

### II.2 PRESENTATION OF THE KANSOKO MINE

The Kamoa-Kansoko project is located approximately 33 km as the crow flies to the west of the town of Kolwezi, capital of the Lualaba province, and 280 km as the crow flies to the west of Lubumbashi, in the south of the Democratic Republic of Congo (DRC). The coordinates are 10°46'S / longitude 25°15'E.

**Figure 1: Aerial view of the Kasonko mine**

### II.3 VENTILATION AT THE KANSOKO MINE

The ventilation circuit in the Kansoko mine is divided into two parts:

1. The main one which, thanks to blower fans placed at the mine entrance, sucks in air from outside the mine and sends it inside the mine thanks to pipes.
2. The secondary system, which transports the air from the main system to the various workings.

A vacuum ventilation project is currently underway; seven suction fans placed at two points in the mine (3 in RPD1 and 4 in SD3) will collect stale air and convey it to the outside via an air shaft. The fans are driven by 136 kW three-phase asynchronous motors. These motors have a nominal voltage of 550 V and are supplied delta connected. By changing their star connection, they can be operated at 1000V. It is these fans, or more precisely the three-phase asynchronous motors that drive them, that will be the focus of this work.

### II.3.1 ELECTRICAL CONTROL OF FAN MOTORS

The fans are electrically controlled by control cabinets containing a power circuit and a control circuit. A disconnecting circuit breaker is located at the input of the circuit and a contactor is used to control the fan. It should be noted that the circuit-breaker only performs the isolation function. An UMC 100 controller protects the motor. Various parameters are entered on this controller, including :

- The rated current,
- The high current protection threshold,
- The differential protection,
- Cooling time,
- Maximum number of starts.

Various measuring devices (tp and ti) are connected to the UMC 100, enabling it to pick up information relating to the operation of the motor, i.e. the current and voltage at its terminals. Using this information, the controller can provide effective protection for the motor.

Figure 2: fan control panel

## II.4. RPD1 FAN POWER SUPPLY CIRCUIT

An 11/1kV substation located in RP17 supplies power to the three fans. 4x35 mm2 armored cables supply the fans. The motors of fans 1 and 2 are protected by the same circuit breaker.

### II.4.1 ELECTRICAL CIRCUIT DIAGRAM

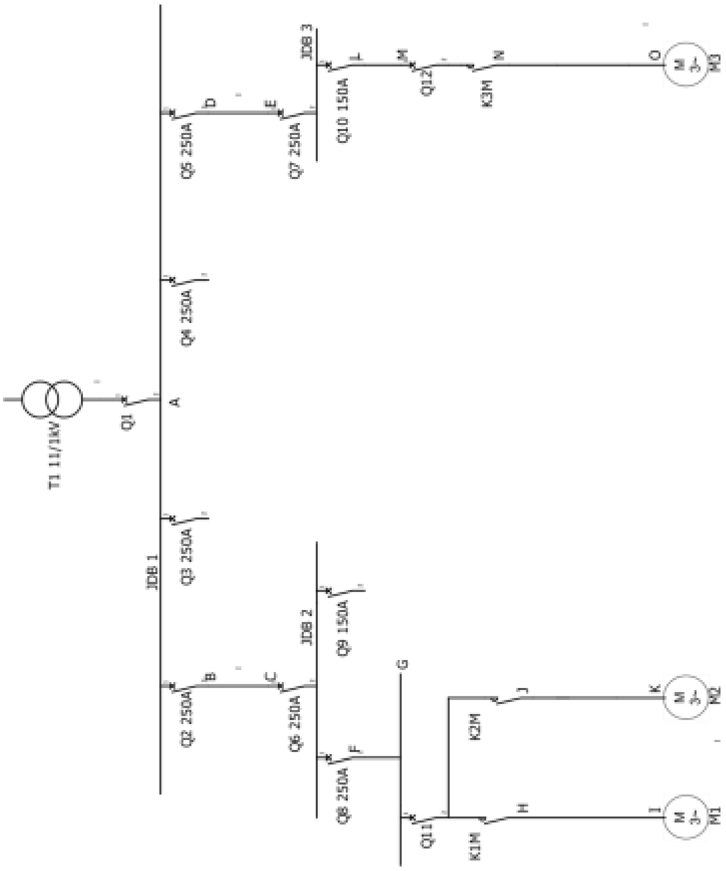

Figure 3: rpd1 motor power supply diagram

## II.5 POWER SUPPLY CIRCUIT FOR SD3 FANS

The four fans are powered from the 11/1kV substation in block 2. Four 4x35mm2 armored cables run from this substation to supply the four fans via the control cabinets located next to the substation. Two 250A circuit breakers in the substation each protect two feeders to the fans.

### II.5.1 ELECTRICAL CIRCUIT DIAGRAM

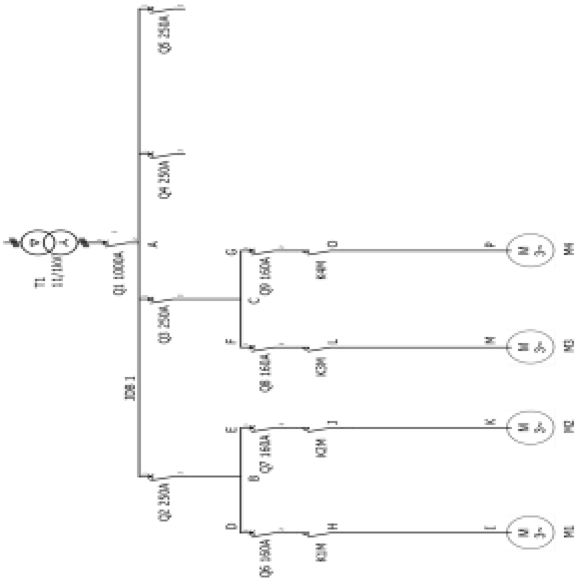

Figure 4: SD3 fan power supply circuit diagram

## III. STUDY OF THE OPERATIONAL SAFETY OF THE TWO INSTALLATIONS

### III.1 PARAMETERS OF THE STUDY

This study will determine the failure rate of each of the two power supply circuits to estimate the degree of confidence to be placed in them respectively. As one set of fans cannot be used as a back-up in the event of a problem on the second circuit, the study of the operational safety of one of the supply circuits will be carried out independently of the second. Although the two installations include other receivers, including numerous pumps, the study will only focus on the fan motors; only the elements likely to affect the correct operation of their supply circuit will be considered.

### III.2 SUPPLY CIRCUIT FOR RPD1 FANS

### III.2.1 RECEIVER CLASSIFICATION

The fans in this circuit are classified as priority receivers.

### III.2.2 FUNCTIONAL ANALYSIS

The three fans are designed to operate all at the same time if mining activities are taking place in the mine. They are only shut down during mining operations, when all personnel are evacuated from the mine and all machines are shut down to avoid any incidents. The most common faults on this circuit are cable insulation faults and short circuits. Protective equipment is therefore very much in demand and must be highly reliable.

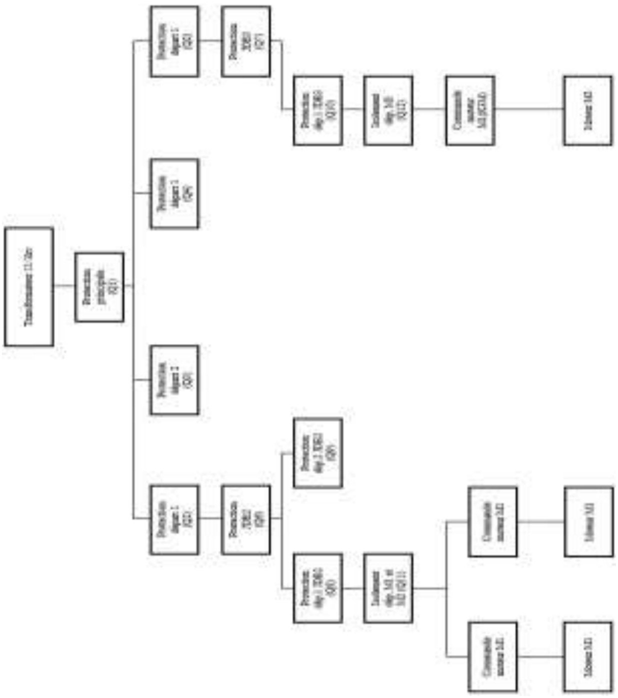

**Figure 5: Block diagram of the RPD1 power supply circuit**

On the previous page shows the circuit, specifying the role of each of its components. The circuit has no redundancy, which means that in the event of an event (work or breakdown, for example) that affects the power supply to the fans, they are unavailable until the power is available again. The block diagram in figure 10 describes the function of each component in the circuit.

### III.2.3 ANALYSIS OF FAILURE MODES AND THEIR EFFECTS

There are many failures that could be avoided by proper dimensioning of the various components. During our visit to the Kansoko mine, we noted that many failures, particularly those involving protective equipment, were linked to design faults.

Ainsi effectuons des calculs de vérification dans le but de nous assurer que les éléments de ce circuit ne sont pas défaillants par leur dimensionnement. Ces calculs porteront sur les différents critères pris en compte lors du dimensionnement d'un équipement principalement le pouvoir de coupure et le courant nominal des charges. Les résultats de ces calculs seront d'une grande utilité pour la détermination des taux de défaillance des éléments du circuit lors de l'élaboration du tableau de l'analyse des modes de défaillance et de leurs effets.

#### III.2.3.1 CALCULATIONS TO VERIFY COMPONENT SIZING

**a. Rated current**

Determining the rated current of each motor

$$I_N = \frac{P}{\sqrt{3}.U.Cos\rho} = \frac{132\ 000}{\sqrt{3}.1000.0,93} = 81,95\ A$$

1) **M2**

$$I_N = \frac{P}{\sqrt{3}.U.Cos\rho} = \frac{126\ 000}{\sqrt{3}.1000.0,93} = 78,22\ A$$

**b. Breaking capacity**

The breaking capacity of a circuit-breaker corresponds to the theoretical maximum current to be broken by a circuit-breaker. For a three-phase installation, it corresponds to the three-phase short-circuit current. For each circuit-breaker, it is calculated assuming the fault is just at the circuit-breaker output.

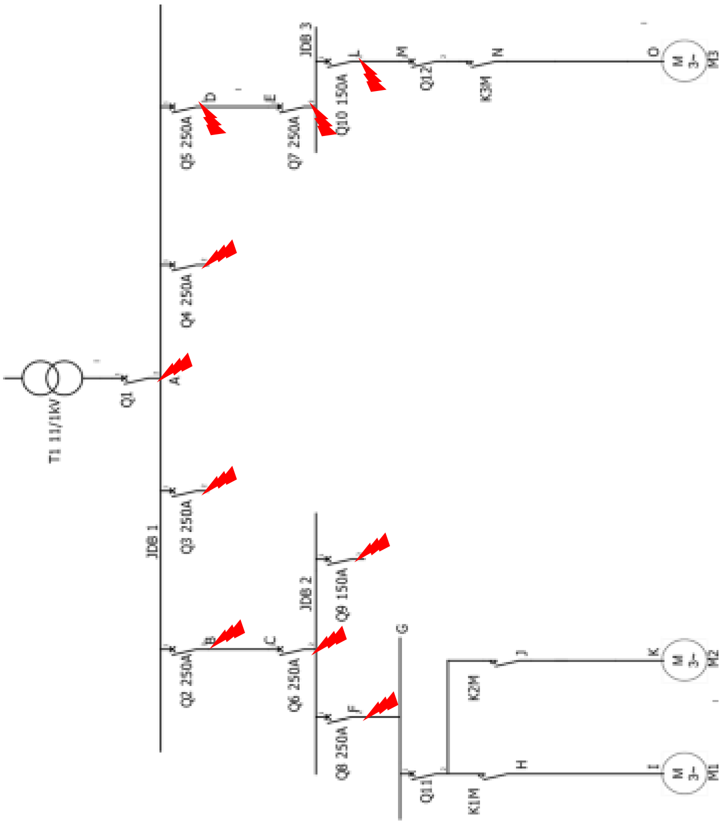

**Figure 6: RPD1 short-circuit current calculation points**

As Q11 and Q12 do not provide protection, there is no need to calculate their pdc.

**sCalculation assumptions**

1. Busbar impedance neglected
2. Circuit breaker reactance neglected
3. Linear reactance of three-phase cables XL= 0.08 mΩ/m
4. Upstream network reactance neglected. This results in a calculation error of approximately 5%. (Metz-noblat, Dumas and Poulin, 2005).

**Table III.1: Impedance calculations for RPD1 circuit elements**

| **Element** | **R, X** | **Formulas** | **Calculations** | **Results** |
|---|---|---|---|---|
| Transformer T1 | $X_T$ | $X_T \simeq Z_T = \frac{Ucc}{100}\frac{U^2}{S_N}$ | $X_T \simeq Z_T = \frac{5,64}{100}\frac{1000^2}{800\ 000}$ | 0,0705 Ω |
| | $R_T$ | $R_T = 0,2\ Z_T$ | $R_T = 0,2.0,\ 0705$ | 0,0141 Ω |
| B-C connection | XBC | $X_{BC} = l_{BC}.0,\ 08.10^{-3}$ | $X_{BC} = 40.0,\ 08.10^{-3}$ | 0,0032 Ω |
| | RBC | $RBC = l_{BC}.R_L$ | $R_{BC} = 40.0,\ 268.10^{-3}$ | 0,01072 Ω |
| D-E connection | XDE | $X_{DE} = l_{DE}.0,\ 08.10^{-3}$ | $X_{BC} = 40.0,\ 08.10^{-3}$ | 0,0032 Ω |
| | RDE | $RDE = l_{DE}.R_L$ | $R_{BC} = 40.0,\ 268.10^{-3}$ | 0,01072 Ω |

**Short-circuit current in A**

ZA $= \sqrt{R_T^2 + X_T^2} = \sqrt{0,0141^2 + 0,0705^2} = 0,0719$ Ω

$I_{CCA} = \frac{U}{\sqrt{3}.Z_A} = \frac{1000}{\sqrt{3}.0,0719} =$ 8029,906 A or 8,029 kA

**Short-circuit current at the output of circuit-breakers connected to JDB1**

JDB1 impedance neglected ICCA = ICCB = ICCD = 8.029 kA

**Short-circuit current at JDB2**

$R_{jdb2} = R_T + R_{BC} = 0,0141+0,01072 = 0,02482$ Ω

$X_{jdb2} = X_T + X_{BC} = 0,0705+0,0032 = 0,0737$ Ω

Zjdb2 $= \sqrt{R_{jdb2}^2 + X_{jdb2}^2} = \sqrt{0,02482^2 + 0,0737^2} = 0,07778$ Ω

$I_{CCjdb2} = \frac{U}{\sqrt{3}.Z_{jdb2}} = \frac{1000}{\sqrt{3}.0,07778} = 7422,86$ A or 7,422 kA

**Short-circuit current at the output of circuit-breakers connected to JDB2**

Since the impedance of JDB2 is neglected, the output currents of the circuit breakers connected to it are equal to ICCjdb2.

**Short-circuit current at JDB3**

Connections B-C and D-E are identical; they have the same length and the same cable cross-section, so Zjdb2 = Zjdb3 and therefore ICCjdb2 = ICCjdb3 = 7.422 kA.

The same applies to all the circuit-breakers connected to the JDB3, as its impedance is neglected.

### III.2.3.2 Interpretation of the results of the verification calculations

The comparison of the characteristics of the circuit elements presented in the tables in the previous chapter with the calculated values shows that all the circuit elements have been correctly sized and consequently that none of them has failed by design. Thus, the probability of occurrence of failure modes linked to inadequate sizing is zero.

### III.2.3.3 Establishing the analysis of failure modes and their effects

Determining the failure rate requires knowledge of the feedback data from use of the various components of the circuit, and for this it is necessary to contact their manufacturer. For this purpose, we were only able to obtain feedback data from ABB contactors (see Appendix 3). Faced with the difficulty of obtaining data on the other components, we opted to use two widely used and recognized data collections in the electrotechnical field, namely RAC NPRD97 for the various circuit breakers and IEEE STD 493 for the transformer.

The connecting cables are often the victims of attacks by mining machinery, at a rate of once every 7 months. This gives us a failure rate of 2.32. 10-4. If the cable is attacked, there is a 50% chance of a short-circuit and a 50% chance of an insulation fault.

**Table III.2: Failure mode and criticality analysis table**

| Element | Function | Failure modes | Causes | λ | Effects |
|---|---|---|---|---|---|
| Circuit breaker Q1 | Protection | Untimely opening | low setting | $2,01.10^{-8}$ | Loss of power supply of the 3 fans |
| | | No opening in | Faulty release | $2,68.10^{-}$ | Destruction of T1 |

| | | | | | |
|---|---|---|---|---|---|
| | | case of default | mechanism | 8 | |
| | | | Low breaking capacity | 0 | |
| Circuit breakers Q2, Q3,<br>Q4 et Q5 | Protection | No opening in case of default | Setting current too low | $2,01.10^{-8}$ | Loss of power supply of the respective downstream receivers t M1 and M2 for Q2 and M3 for Q5 |
| | | No opening in case of default | Faulty release mechanism | $2,68.10^{-8}$ | Opening of Q1 and loss of<br>power supply<br>to the entire circuit, including all fans |

**Table III.2: Failure mode and criticality analysis table (continued)**

| | | | | | |
|---|---|---|---|---|---|
| Circuit breaker Q2, Q3,<br>Q4 et Q5 | Protection | | Low breaking capacity | 0 | |
| Circuit breaker Q8 et Q9 | Protection | Untimely opening | Setting current too low | $2,01.10^{-8}$ | Loss of power to downstream receivers including<br>M1 and M2 |
| | | No opening in case of default | Faulty release mechanism | $2,68.10^{-8}$ | Opening of Q6 and loss of power supply<br>to all<br>receivers connected to JDB2 including M1 and M2<br>Low voltage |
| | | | Low breaking capacity | 0 | |
| Q10 | Protection | Untimely opening | Setting current too low | $2,01.10^{-8}$ | Loss of power to M3 |
| | | No opening in case of default | Faulty release mechanism | $2,68.10^{-8}$ | Opening of Q7 and loss of power supply of all receivers connected to the JDB3, including M1 |
| | | | Low breaking capacity | 0 | |
| Contactors K1M, K2M et K3M | order | Untimely opening | Inadequate setting of umc 100. | $2,01.10^{-8}$ | Loss of power<br>to controlled motors |
| | | Non fermeture | No closure | 1,83. | Loss of power |

| | | | | | |
|---|---|---|---|---|---|
| | | | | $10^{-6}$ | to controlled motors |

**Table III.2: Failure mode and criticality analysis table (continued)**

| | | | | | |
|---|---|---|---|---|---|
| Cables | connection | Insulation fault | Assault of mining engins | 1,16.$10^{-4}$ | Triggering of upstream protections and loss of power supply to downstream receivers |
| | | Short circuit | Assault of mining engins | 1,16.$10^{-4}$ | Triggering |
| TransformerT1 | Lowering device MT-BT | Cooling system shutdown | Cooling system failure | 4,2.$10^{-10}$ | of upstream protections and loss of |

### III.2.3 MODELLING

The fault tree is the tool used for modelling. Consideration of all faults when drawing up the fault tree would make it very cumbersome, flooding it unnecessarily with details of very low probability. We will therefore only consider failures whose rate of occurrence is greater than 10-6.

For repairable cable failures, we set the MTTR at 1.5 hours. Except for the low setting, all the failure rates associated with circuit breakers and contactors are non-repairable. To facilitate the calculations, we will use fault tree modelling software called ‘Fault Tree’ . All that is required is to draw the fault tree and specify the probability of the events at the base of the tree. Figure 13 shows the fault tree for the circuit under study. The variables TR and λ represent respectively the failure rate associated with each failure and MTTR for repairable components.

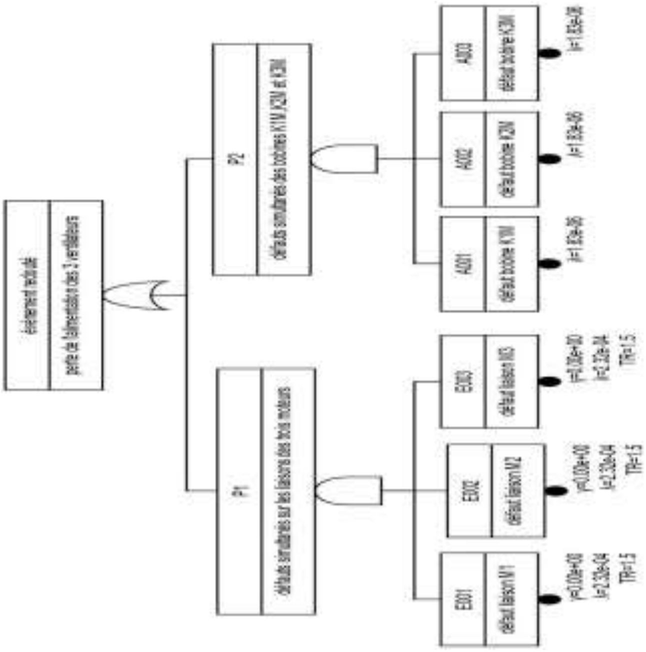

**Figure 7: RPD1 fan supply circuit fault tree**

### III.2.4 SAFETY CALCULATIONS

The Fault Tree tool can be used to perform the necessary safety calculations; using the information gathered from the fault tree, it will determine the equivalent failure rate of the system and its MTBF. The results of the Fault Tree simulation are as follows:

- System failure rate: 4.85. 10-12
- MTBF: 2.06. 1011 hours
- Number of failures per year: 4.25.10-8

### III.2.5 INTERPRETATION OF SAFETY CALCULATION RESULTS AND RECOMMENDATIONS

The mean time between failures (MTBF) that could lead to the simultaneous loss of power to the three fans is very high: 2.06. 1011 hours, which brings the number of failures of this type per year to 4.25.10-8. In view of these figures, the installation displays a high level of reliability. However, it is also important to consider the hours during which the transformer will be unavailable for maintenance. IEEE STD 493 sets the maintenance downtime for this type of transformer at around 6 hours/year. 6 hours during which none of the four fans will be powered. Given the small size of the mine, this condition could be tolerated for the time being, but in the future, with the constant expansion of the mine, this type of event will be less and less tolerable.

To overcome this problem, it would be preferable to separate the power sources for the three fans by, for example, supplying one of them from another transformer other than the one at RP17, as shown in Figure 14 on the following page. For the moment, it is difficult to envisage this solution because none of the transformers other than RP17 is close enough to the fans; in the future, with the expansion of the mine and the possible installation of new substations, it will be imperative to consider this solution.

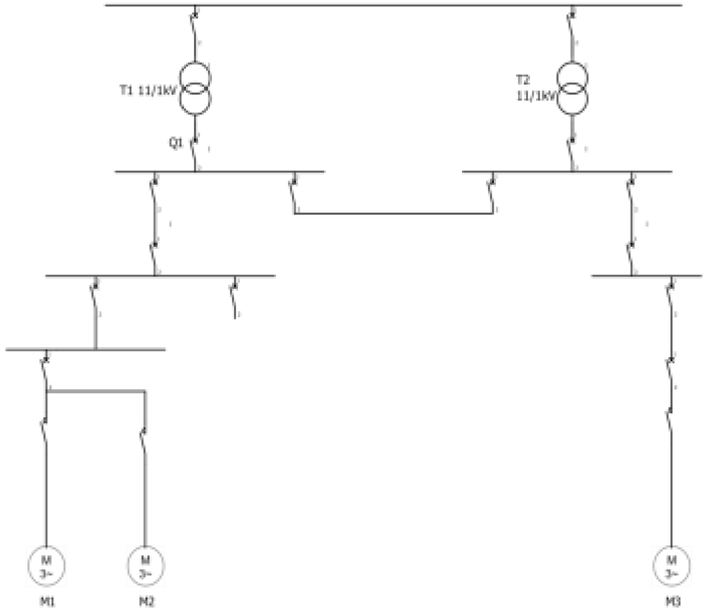

**Figure 8: Proposed power supply architecture for RPD1 fans**

## III.3 POWER SUPPLY CIRCUIT FOR SD3 FANS

### III.3.1 RECEIVER CLASSIFICATION

In view of their importance, the fans in this circuit are classified as priority receivers.

### III.3.2 FUNCTIONAL ANALYSIS

The operation of this circuit is like that of RPD1. The four fans are supposed to operate at the same time and, since there is no redundancy, the system is unavailable if repair work is being carried out on it. Figure 15 on the next page shows the circuit and the role played by each of its components.

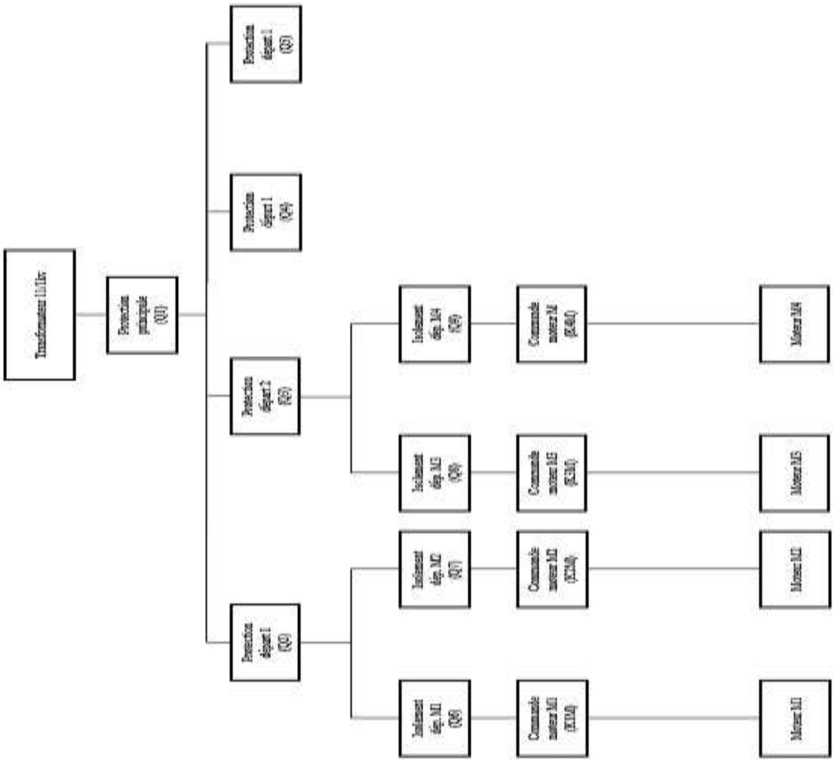

**Figure 9: Block diagram of SD3 fan power supply circuit**

### III.3.3 ANALYSIS OF FAILURE MODES AND THEIR EFFECTS

As we did for the previous circuit, we will carry out verification calculations to ensure that the circuit components are correctly sized. These calculations will also make it possible to calculate the failure rates of certain failures linked to certain elements.

#### III.3.3.1 Component sizing verification calculations

**a. Rated current**

Determining the rated current of each motor

$$I_N = \frac{P}{\sqrt{3}.U.Cos\rho} = \frac{132\ 000}{\sqrt{3}.1000.0,93} = 81,95\ A$$

**b. Breaking capacity**

Since Q6, Q7, Q8 and Q9 do not perform the protection function, it is not necessary to calculate their pdc. The calculation of the short-circuit currents is therefore reduced to the calculation of the short-circuit currents at the output of the circuit-breakers connected to the JDB1. This is shown in Figure 15.

**Calculation assumptions**

The calculation assumptions are the same as for the previous circuit, i.e.:

1. Busbar impedance neglected
2. Circuit breaker reactance neglected

3. Linear reactance of three-phase cables XL= 0.08 mΩ/m
4. Upstream network reactance neglected. This results in an error of approximately 5%. (Metz-noblat, Dumas and Poulin, 2005).

Figure 10 on the following page shows the calculation points for short-circuit currents.

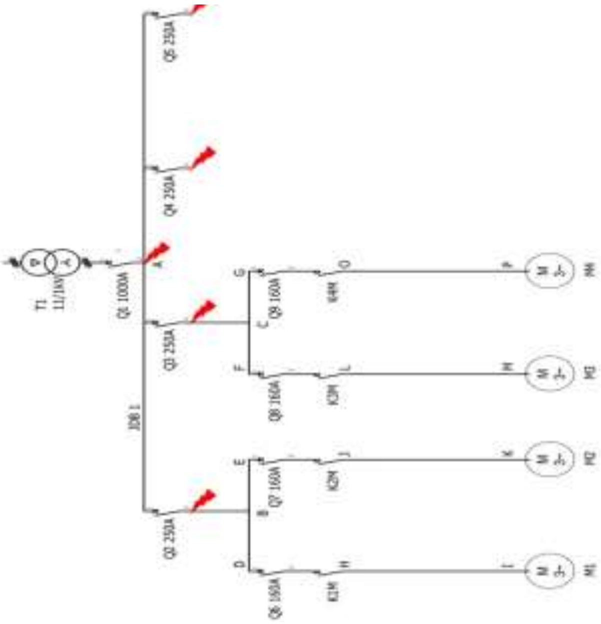

**Figure 10: Calculation points for the short-circuit currents of the SD3 fan supply circuit**

With the impedance of the busbar and that of Q1 neglected, the short-circuit current of all the circuit-breakers connected to JDB1 is reduced to the short-circuit current at the output of transformer T1. Let's determine XT and RT

$$X_T \simeq Z_T = \frac{Ucc}{100}\frac{U^2}{S_N} = \frac{5{,}57}{100}\frac{1000^2}{800\,000} = 0{,}0696\ \Omega$$

$R_T = 0{,}2\ Z_T = 0{,}2.0{,}0696 = 0{,}01392\ \Omega$

$$ZA = \sqrt{R_T^2 + X_T^2} = \sqrt{0{,}0696^2 + 0{,}01392^2} = 0{,}071\ \Omega$$

$$I_{CCA} = \frac{U}{\sqrt{3}.Z_A} = \frac{1000}{\sqrt{3}.0{,}071} = 8131{,}69 \text{ A or } 8{,}131 \text{ kA}$$

### III.3.3.2 Interpretation of the calculation results

Comparison of the characteristics of the circuit elements with the calculated values shows that:

- Except for Q1, whose Pdc is 30 kA, all the circuit-breakers connected to JDB1 have too low a breaking capacity, i.e. 7kA (see table II.6). They cannot trip in the event of a fault on the circuit they are supposed to protect; they are therefore faulty by design. As a result, they cause selectivity problems because their failure to trip will cause Q1 to trip. The failure rate associated with non-tripping due to incorrect sizing is 1.
- Contactors K1M, K2M, K3M and K4M have a rated current greater than that of the motors they control (see table II.7). They can be used in complete safety.
- The various motor supply cables have a rated current higher than that of the motors (see table II.8). They can be used in complete safety.

### III.3.3.3 Drawing up the analysis of failure modes and their effects

As for the study of the previous circuit, we opted to use the RAC NPRD97 and IEEE STD 493 (see appendices 1 and 3). The link cables are often the victims of aggression from mining machinery at a rate of once every 6 months. This gives us a failure rate of 2.32. 10-4. 50% of cable attacks cause insulation faults and 50% short circuits. If the team in the mine is large enough, repairing an injured cable can take about an hour and a half. Except for failures due to incorrect adjustment, all circuit-breaker failures are non-repairable and systematically lead to replacement of the circuit-breaker.

**Table III.3: Failure mode and criticality analysis table**

| **Element** | **Function** | **Failure modes** | **Causes** | **λ** | **Effects** |
|---|---|---|---|---|---|
| Circuit breaker Q1 | Protection | Untimely opening | Low low setting | $2,01.10^{-8}$ | Loss of power supply of the 3 fans |
| | | No opening in case of default | Faulty release mechanism | $2,68.10^{-8}$ | Destruction of T1 |
| | | | Low breaking capacity | 0 | |
| Circuit breaker Q2, Q3, Q4 et Q5 | Protection | Untimely opening | Setting current too low | $2,01.10^{-8}$ | Loss of power to downstream receivers M1 and M2 for Q2, M3 and M4 for Q5 respectively |
| | | No opening in the event of a fault Q5 | Faulty release mechanism | $2,68.10^{-8}$ | Opening of Q1 and loss of power to the entire circuit, including all fans |
| | | | Low breaking capacity | 1 | |
| Q10 | protection | Untimely opening | Setting current too low | $2,01.10^{-8}$ | Loss of power to |

**Table III.3: Failure mode and criticality analysis table**

| | | | | | |
|---|---|---|---|---|---|
| Q10 | protection | No opening in case of default | No opening in the event of a fault Faulty release mechanism | 2,68. 10-8 | Opening of Q7 and loss of power to all receivers |
| | | | Low breaking capacity | 0 | connected to the |
| Contactorrs K1M, K2M | command | Low switching capacity | Inadequate setting of umc 100. | 2,01. 10-8 | Loss of power to controlled motors |

| | | | | | |
|---|---|---|---|---|---|
| et K3M | | Untimely opening | | | |
| | | No closure | contactor coil faulty | 1,83. 10-6 | Loss of power to controlled motors |
| Cables | Connection | Insulation fault | Attack on mining equipment | 1,16. 10-4 | Tripping of upstream protections and loss of power to downstream loads |
| | | Short circuit | Attack on mining equipment | 1,16. 10-4 | Tripping of upstream protections and loss of power to supplied loads |
| Transformer T1 | Lowering device MT-BT | Cooling system shutdown | Cooling system failure | 4,2. $10^{-10}$ | Destruction of windings and loss of power to the entire installation |

### III.3.3 MODELLING

As in the previous study, we will only consider faults with a rate of occurrence greater than 10-6 to simplify the tree and avoid flooding it with elements with a very low probability of occurrence. We will also neglect the possibility of all three contactor coils failing simultaneously, as the probability of such an event occurring is extremely low, on the order of 10-18. We will also use Analyst tree for modelling and safety calculations.

The tree in Figure 16 on the following page shows the fault tree for the SD3 fan power circuit. The variables TR and λ represent the MTTR of repairable components and the failure rate, respectively.

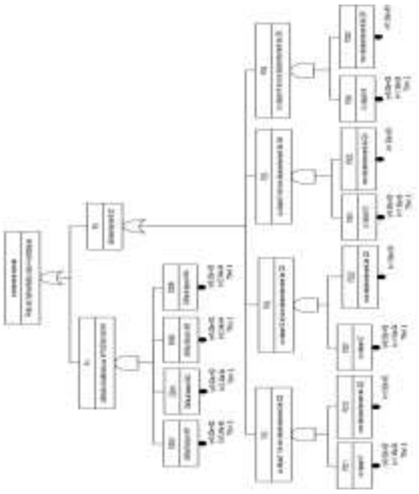

**Figure 11: Fault tree for the SD3 fan supply circuit**

### III.3.4 SAFETY CALCULATIONS

Modelling and analysis using Fault Tree gave the following results:

- System failure rate: 4.64.10-4
- MTBF: 2166
- Number of failures/years: 4.04

### III.2.5 INTERPRETATION OF SAFETY CALCULATION RESULTS AND RECOMMENDATIONS

The mean time between two failures that could lead to the loss of power to the four fans is very short, 2166 hours or around 90 days. The number of such failures per year is therefore 4. This is too many for a system that is supposed to ensure proper ventilation of the mine workings, especially as the 4 fans will remain without power for as long as the detection and repair work on the various cables and the replacement of the damaged circuit-breaker take. In the most unfavorable cases (work equipment not available, small maintenance team), this work could take much longer than expected. Replacing circuit breakers Q2, Q3, Q4 and Q5 with circuit breakers with sufficient breaking capacity will remedy this problem.

As with the previous circuit, transformer maintenance is also an important consideration. The entire installation is de-energized during maintenance, and IEEE STD 493 also sets the downtime for maintenance of this type of transformer at around 6 hours/year. As with the fans at RPD1, this type of problem may be tolerable for the time being, but it will not be tolerable in the future as the mine expands.

To remedy this problem, it would be preferable to vary the transformers supplying the different fans; two fans being supplied by a transformer other than the one in block 2. The new substation in SD3 can be used for this purpose. The fan power supply diagram would then be as shown in figure 18 on the following page.

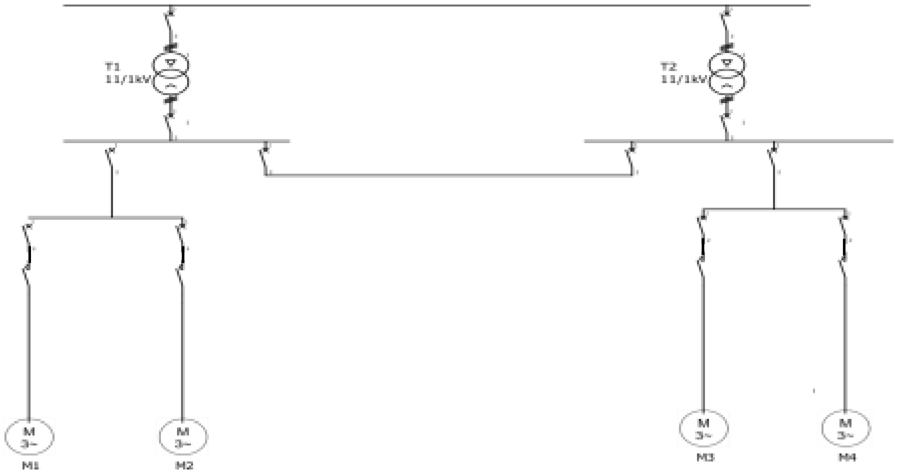

**Figure 12: Proposed power supply architecture for SD3 fans**

### CONCLUSION

The operational safety of an electrical installation is an essential aspect in today's industry. A loss of power to certain receivers could have a detrimental effect on production or even be life-threatening. Users of an electrical installation must therefore have justified confidence in their power supply circuit. Hence the need for safety studies to establish the degree of confidence to be placed in an electrical installation with a view to possible improvements. The present work is a study of the operational reliability of the power supply circuit for the fans of the vacuum ventilation system at the Kansoko mine, which are located at two points in the mine, SD3 and RP17. A loss of power to these fans would penalize operations and endanger the lives of mine workers; their power supply circuits must therefore have a very low failure rate, hence the importance of a study of their operational safety. To carry out this study, we first checked the design of the components of the two installations to ensure that they would not fail, considering their design. We then modelled the system using Fault Tree software, to determine the number of breakdowns per year for each of the two circuits. From this study, we detected four circuit-breakers in the power supply circuit for the fans located in SD3 that had too low a breaking capacity and were therefore faulty, and which would have to be replaced by suitable circuit-breakers. The study also showed that the reliability of the power supply circuit for a group of fans could be improved by a new architecture in which two substations share the power supply for the fans in a group. This solution can already be envisaged for the fan supply circuit in SD3, but not yet for those on the RPD1 side, as there is no substation close to these fans other than the one at RP17. We do not claim to have completed the work, and so we encourage those who have understood that the field of investigation is rich in interest. They will therefore be able to continue this study by, for example, sizing the new architecture that we have proposed and tackling certain points such as developing a better system maintenance policy.

## BIBLIOGRAPHY

### A. BOOKS

1. Faucher J., Pratique de l’AMDEC (2ème édition), Editeur Dunod, 17 juin 2009.
2. Chatelet E., Sûreté de fonctionnement : méthodes et outils de base. Université de technologie de Troyes edition, 2000.
3. Jardine. A. Maintenance, replacement and reliability, Pitman, Boston, MA, 1987.
4. Logiaco, S. (1999, Janvier). Etudes de sûreté des installations électriques.
5. MONCHY F., VERNIER J., (2010). *Maintenance : Méthodes et organisation* ($3^e$ edition). Paris, France : DUNOD
6. Faucher J., Pratique de l’AMDEC (2ème édition), Editeur Dunod, 17 juin 2009.
7. Jardine. A. Maintenance, replacement and reliability, Pitman, Boston, MA, 1987.
8. Cabau, E. (1999, Juin). Introduction à la conception de la sûreté. *Cahier technique* (144).
9. CEI-60812: Techniques d’analyse de la fiabilité du système – procédure d’analyse des modes de défaillance et de leurs effets, International Electrotechnical Commission standard, 2006.
10. CEI-61508: Functional safety of electrical/electronic/ programmable electronic safety-related systems, International Electrotechnical Commission standard, 2010.

### B. ARTICLES

1. Laprie. J-C, “Sûreté de fonctionnement des systèmes : concepts de base et terminologie”, Revue de l’Électricité et de l’Électronique (REE), (11), pp.95-105, novembre 2004.
2. Buzzatto J.L., Failure mode, effects and criticality analysis (FMECA) use in the Federal Aviation Administration (FAA) reusable launch vehicle (RLV) licensing process. Digital Avionics Systems Conference, 1999. Proceedings 18th. vol.2 10/24-29/1999. Location: St Louis, MO, USA.
3. IEEE 493,(2007). *Design of Reliable Industrial and Commercial Power Systems* . Consulté sur : 493-2007 - IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems | IEEE Standard | IEEE Xplore
4. Application of functional safety to electrical power equipment and systems in process industries

### C. WEBOGRAPHIE

1. https://tel.archives-ouvertes.fr/tel-00393077
2. www.installations-electriques.net/Divers/PDF/surete.pdf
3. www.schneider-electric.com

4. https://hal.univ-lorraine.fr/tel-01748700
5. www.industrie .gouv .fr /energie /electric /pdf /rte bilan 05- complet. pdf.