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RESEARCH ARTICLE

STUDY OF HTA DISTRIBUTION NETWORK RELIABILITYIN NIAMEYCITY

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Abstract

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With the growth of demand for electrical energy, electrical networks are nowadays subjected to very high loads, sometimes beyond their capacity. This leads to their malfunction and their inability to meet expectations. But given the importance of electricity in our lives, this disruption cannot be tolerated for long, which leads distribution operators to implement maintenance programs to ensure continuity of service. However, these measures, although extremely important, are time consuming, costly and sometimes do not provide complete satisfaction, resulting in the absence of electricity to consumers. The study of reliability of medium voltage distribution network in Niamey allowed us to analyze the performance indices of latter. Indeed, we based ourselves on the number of incidents (opening of HV outlets) and their duration while taking into account the origin of the associated disturbances. In the light of this analysis, the reliability of lines is close to 95% only for a period of one (1) hour (h) and is almost zero beyond 100 hours of operation. As for maintainability, it is only guaranteed within a period of 10 hours after the occurrence of incident on network.

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Introduction:-

Electricity networks represent significant investments made by utilities to ensure quality and continuity of power supply to customers.

The basic goal of all power generation is to meet energy demand of consumer at the lowest possible cost, while maintaining acceptable levels of power quality and continuity. From generation to distribution, power system is subject to many events such as accidents, random component failures, increasing power outages due to weather, and increased system risk due to aging assets. These events are unpredictable, but they can be taken into account to decide the level of distribution the system should survive, on the other hand the power system is a complex system from an operational and infrastructure point of view. Despite this; it must provide customers with a continuous and reliable power supply. [1].

This reliability can be defined, in a general way, as the probability of a device performing an expected function during the expected period under the operating conditions. The concept of power system reliability is extremely broad and covers all aspects of the system's ability to meet customer requirements [2].

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This article presents the concept of reliability and more specifically the notions of reliability. It describes reliability indicators, calculation models and reliability laws. The application of the reliability laws on the Nigelec operating data has allowed to obtain the results of the analysis of the medium voltage distribution network of Niameycity.

Concept of operational reliability

Dependability is the set of abilities of a device allowing it to fulfill its function at the right time during the expected duration, without damage to itself and its environment. Reliability is one of the components of dependability. It is defined as the science of failures [3; 4].

Operational safety comprises four quantities:

1. reliability, which measures the continuity of service;
2. maintainability, which is the ability of a device to be maintained or restored in a state in which it can accomplish its mission;
3. availability, which is the ability of a device to be in working order under the given conditions;
4. safety, which is the absence of catastrophic events for the environment.

The relationship between these four quantities is shown in the following figure:

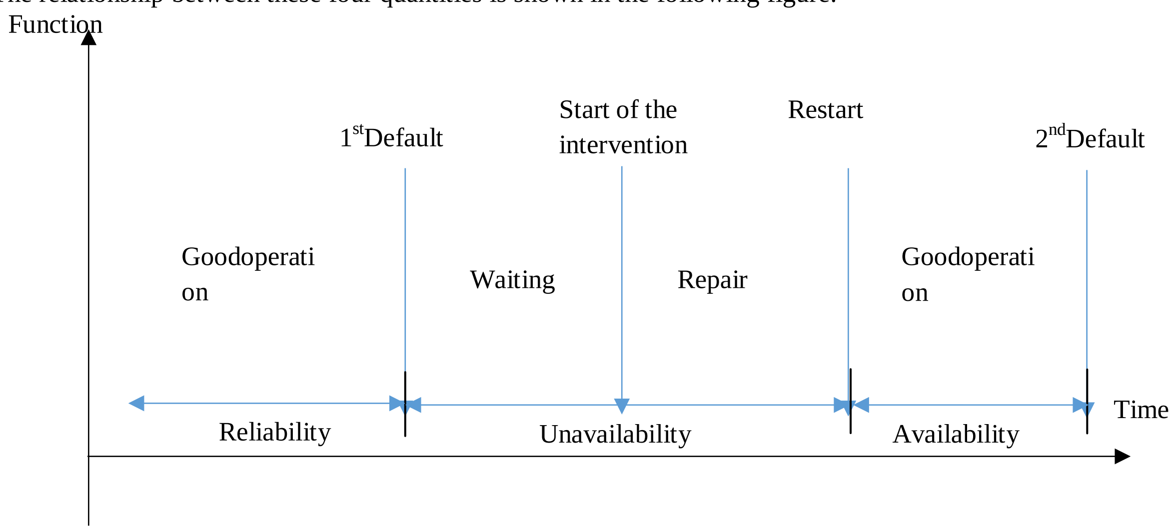

Figure 1:- Dependability as a function of time [3; 4].

Waiting is the time to detect the failure.

The operational safety of a system is based on the use of several combined means:

1. Fault prevention, which minimizes the occurrence of faults in the system;
2. Fault tolerance allows the system to accomplish its mission despite the presence of faults;
3. Fault elimination reduces the number and severity of faults;
4. Fault prediction, which is used to estimate the presence, future rate and possible consequences of faults [6].

Reliability of an electrical system

The definition of reliability, applied to the power system, becomes its ability to satisfy the demand for electricity of all customers of the system, in quality and quantity. That is, the demand must be met in the required quantity, with frequency and voltage remaining atacceptable values. The reliability of a power system is measured not by continuity of service, but rather by service interruptions. Several indices can be used:

1. the frequency and average duration of temporary interruptions;
2. the frequency and average duration of prolonged interruptions;
3. the energy not served in a given time interval;
4. the power cut;
5. the number of transgressions of acceptable frequency and voltage limits ....

Determining the reliability of a system requires first knowing the reliability law (or failure law) of each component involved in the system.

Reliability indicators

Failure rate

A failure is the alteration or the cessation of the ability of an assembly to perform its required function(s) with the performances defined in the technical specifications

The failure rate or damage rate characterizes the rate of change of reliability over time.

$$\lambda = \frac{\text{total number of failures during service}}{\text{total duration of good working order}} \quad (1)$$

The total time in service is the difference between the total time in service and the duration of failures.

The failure rate λ can be constant or variable over time with gradual change without discontinuity.

For the majority of industrial products, the variations of λ (t) over time (the so-called bathtub curve) presents three typical zones [2].

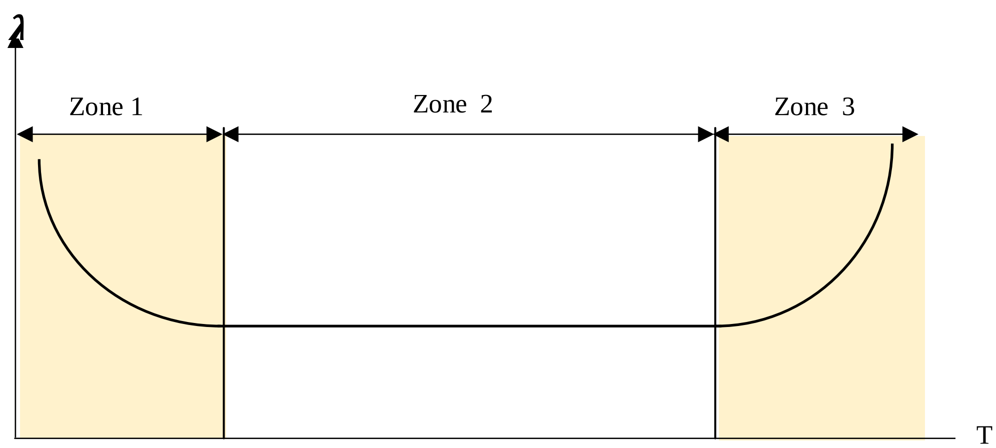

Figure 2:- Failure curve (bathtub curve) [2].

Zone 1: Youth period

This is the period of early or youthful failure, it is the beginning of the life of the product and the failures are said to be youthful. The failure rate decreases rapidly over time.

Zone 2: Useful life

This is the zone of maturity or full activity of the product for which the failure rate is approximately constant. It is also the area of unpredictable failures occurring in a random way. In probability studies, the reliability law adopted in this zone is the exponential distribution.

Zone 3: Aging period

This is the period of failure by aging. It is the period of end of life of the product characterized by failures due to age or wear of components. The failure rate increases rapidly with time, due to the degradation of the material. The reliability laws adapted to this area are the normal law, gamma, log-normal...

Mean Time Between Failures (MTBF)

The MTBF is often translated as "Mean Time Between Failure" but represents the average time between two failures of a system. In other words, it corresponds to the expectation of the lifetime t.

Physically the MTBF can be expressed as the ratio of times.

$$\mathbf{MTBF} = \frac{\text{sum of operating times between failures}}{\text{number of interventions with immobilization}} \quad (2)$$

If λ is constant then we have :MTBF= $\frac{1}{\lambda}$ (3)

By definition, the MTBF is the average life of the system.

Repair rate μ(t)

The repair rate indicates the ability of a device to be repaired. It isobtained by the relation (4):

$$\mu(t) = \frac{1}{MTTR} \quad (4)$$

In the case where this rate is constant, we have the maintainability function which is given by the relation (5):

$(t) = 1 - e^{-\mu t}$(5)

Mean Time To Repair

The Mean Time To Repair is the average time to repair. It is the average of the technical repair times. It is given by the relationship (6):

$$MTTR = \int_0^{\infty}[1 - M(t)]dt = \frac{1}{\mu} \quad (6)$$

The Mean Up Time

The Mean Up Time (MUT) is the average running time after repair. We have:

$$MTBF = MTTR + MUT \quad (7)$$

Mean Down Time

The Mean Down Time (MDT) is the average duration of unavailability. It includes the phases of detection of the failure, repair and return to service.

Probability laws of reliability

Several laws are used in the calculation of the reliability of systems among which the exponential law used in this paper.

The exponential law has many applications in the field of engineering, in particular in the study of equipment reliability [2]. It also has various applications in the study of expectation phenomena, such as:

1. the useful life of an electronic component ;
2. the time between two consecutive arrivals at an automatic teller machine ;
3. the time between two consecutive failures of a computer system;
4. the service time at a factory spare parts counter...

In a general way the exponential distribution is given by the expression (8):

$$f(x) = \begin{cases} 0 \; si x < 0 \\ \frac{1}{\beta} e^{\frac{-x}{\beta}} x \geq 0 \end{cases} \quad (8)$$

The distribution function is given by the following expression:

$$F(x) = \int_0^x f(t)dt = \int_0^x \frac{1}{\beta} e^{\frac{-t}{\beta}} dt \quad (9)$$

$$F(x) = \begin{cases} 0 \; si x < 0 \\ 1 - e^{\frac{-x}{\beta}} x \geq 0 \end{cases} \quad (10)$$

With $\frac{1}{\beta}$ =λ(failure or breakdown rate) and β =MTBF

The mathematical expectation is E (X) = β

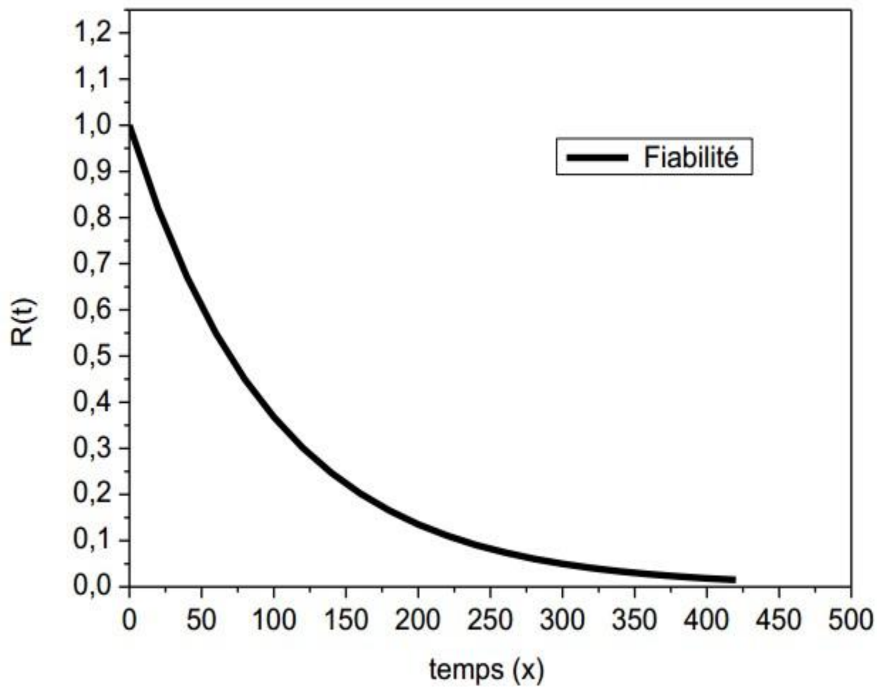

Figure 3:- Theoretical curve of the reliability law of the exponential law [5].

Most natural phenomena are subject to the aging process. There are phenomena where there is no aging or wear. These are generally accidental phenomena. For these phenomena, the probability, for an object to be still alive or not to fail before a given time knowing that the object is in good condition at a time t, does not depend on t. For example, for a crystal glass, the probability of being broken within five years does not depend on its date of manufacture or its age. By definition, a lifetime is said to be wear-free if the probability of survival at time t does not depend on t.

Its reliability function is :

$$R(t) = e^{-\lambda t} \quad (11)$$

The probability of failure is:

$$F(t) = 1 - e^{-\lambda t} \quad (12)$$

The probability density of parameter X is written:

$f(t) = \lambda e^{-\lambda}$(13)

Where λ is the intensity

Reliability models based on the random failure rate are the most commonly used

Assumptions:

1. the failure rate λ(t) is independent of the age of the system;
2. for the system operating on demand, the failure at the nth demand is independent of those at the n-1 demand ;
3. for the system operating continuously, this represents a constant λ(t).

To characterize the lifetime and highlight the notion of aging, the exponential law is used to approximate the distribution of failure times.

The random variables describing a wear-free lifetime all follow an exponential law. The law of a totally random phenomenon can be modeled by an exponential function.

Application of the exponential law on reliability to the MV network of the city of Niamey
Diagnosis of incidents on the MV network of the city of Niamey
Presentation of incident data

The Niger Electricity Company (NIGELEC) is responsible for energy distribution in Niger. The river area (Dosso, Tillabéry and Niamey regions) is mainly supplied by Nigerian transmission networks.

The data used are those of the operation of the HTA network of the city of Niamey during the period from January 1, 2019 to June 30, 2021, i.e. three years. These data contain the following information:

1. the departures concerned ;
2. description of the incidents;
3. the duration of the outage;
4. the power cut ;
5. the undistributed energy;
6. the type of feeder according to whether it is overhead or underground.

Analysis of incidents on the network

The incidents that have occurred on the network have various causes, the analysis of these incidents allows us to classify them into five categories which are:

1. AL: Absence of 132 kV line or power limitation;
2. PD: Outgoing feeder disturbance;
3. PP : Generation disturbance;
4. PR : Network disturbances;
5. TR: Work or SRMERD Intervention.

Table 1:- Statistics on disturbances on the electrical network in the city of Niamey in 2019.

Nature Disturbance	**Number of openings**	**Percentage (%)**
AL	58	26,98
PD	39	18,14
PP	01	0,47
PR	112	52,09
TR	23	10,70

Table 1:- Statistics on disturbances on the electrical network in the city of Niamey in 2020.

Nature Disturbance	**Number of openings**	**Percentage (%)**
AL	45	20,93
PD	66	30,70
PP	71	33,02
PR	14	6,51
TR	19	8,84

Table 1:- Statistics on disturbances on the electrical network in the city of Niamey in 2021 (1st semester).

Nature Disturbance	**Number of openings**	**Percentage (%)**
AL	27	20
PD	31	23
PP	42	32
PR	23	17
TR	10	8

Calculation of the reliability indicators:

case of the HTA lines supplying the North feeder for the year 2019

$$MTTR = \frac{\mathbf{T}}{\mathbf{N}}$$

With T= total duration of outages and N= total number of outages

$$MTTR = \frac{361.9167\,heures}{290} = 1.26868 \text{ h/outage}$$

The repair rate $\mu = \frac{1}{MTTR} = \frac{1}{1.26868}$ = 0.78822 interventions/h

The failure rate $\lambda = \frac{N}{T}$.
where N is the number of outages and MTBF is the mean time between failures
$\lambda = \frac{290}{(8760 - 367.917)}$ =0.03456 outages per hour.
The mean time of good functioning between two successive outages
MTBF = $\frac{1}{\lambda} = \frac{1}{0.03446}$ = 28.938 hours
The availability of the feeder D = $\frac{\mu}{\lambda+\mu} = \frac{0.78822}{0.03456 + 0.78822}$*100 = 96%
The reliability R(t) is obtained through the relation :
R(t) = $e^{-\lambda t}$, t the time in hours.
for t =1h and λ=0.03456, we find R(t) = 0.96 or 96%.

Calculation of the maintainability of the MV network lines
The maintainability is expressed as:

M(t) = 1 - $e^{-\mu t}$

For t = 1h,
M(t) = 1- $e^{-0.78822}$ = 0.5453, or 54.53%.

For t = 10h
M(t) =1-$e^{-0.78822*10}$=1 or 100%, so all network faults have a probability of being detected and the system restored within ten hours of the failure.

These results allowed us to draw the curves of variation of the reliability and maintainability of the North departure (overhead line) of the distribution network of the city of Niamey as a function of time for the years 2019 and 2020.

Reliability and maintainability curves for the Campus Filles feeder, which is an underground line, are also plotted against time for the year 2020.

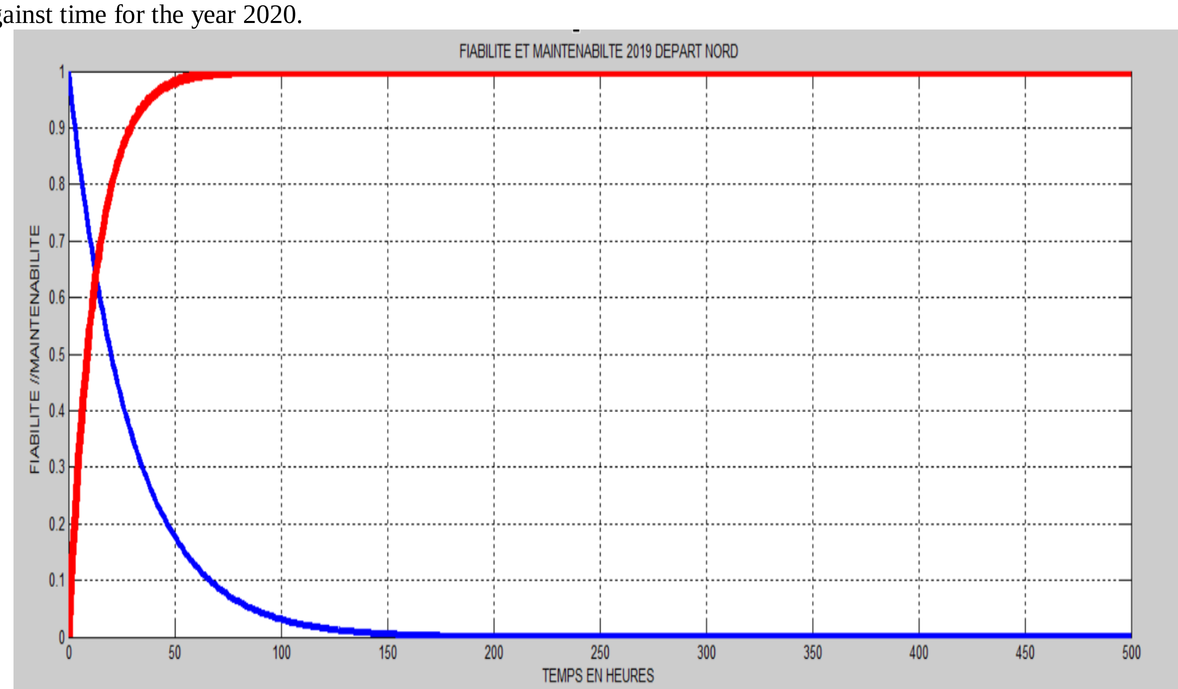

Figure 4:- Reliability and Maintainability North 2019.

We can see that reliability decreases with time while maintainability increases with time. This shows that it is possible to reduce intervention times while remaining within the rules of the art.

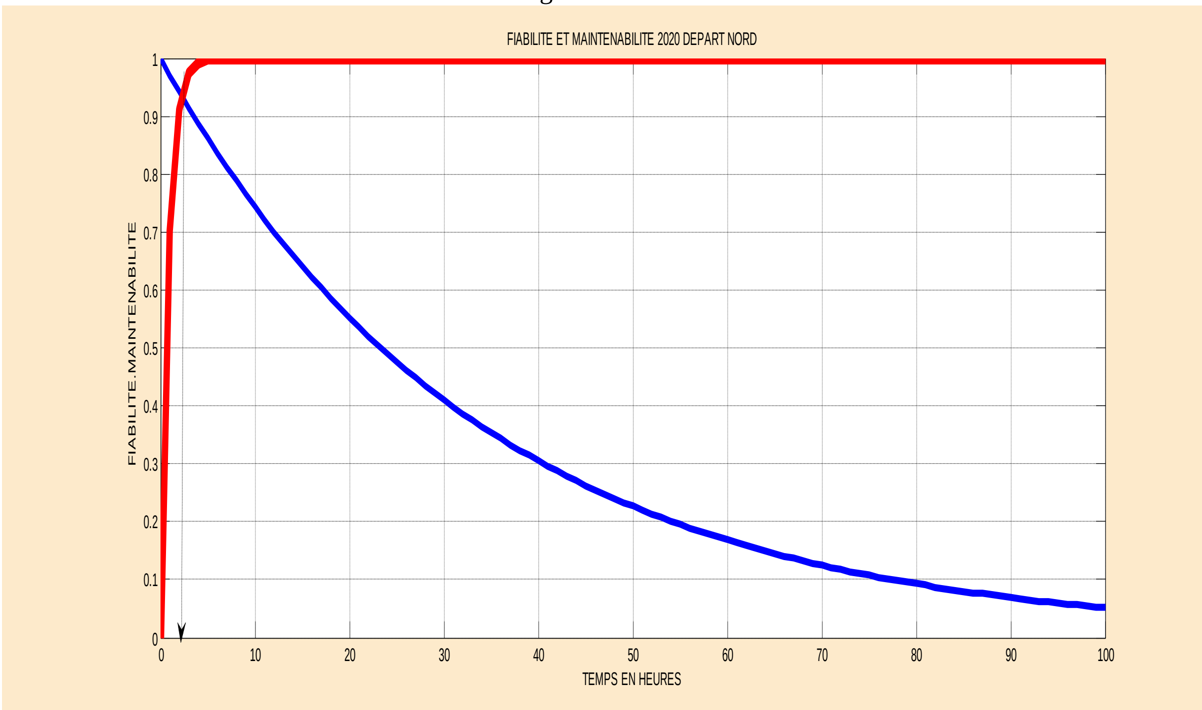

Figure 5:- Reliability and maintainability 2020 northbound.

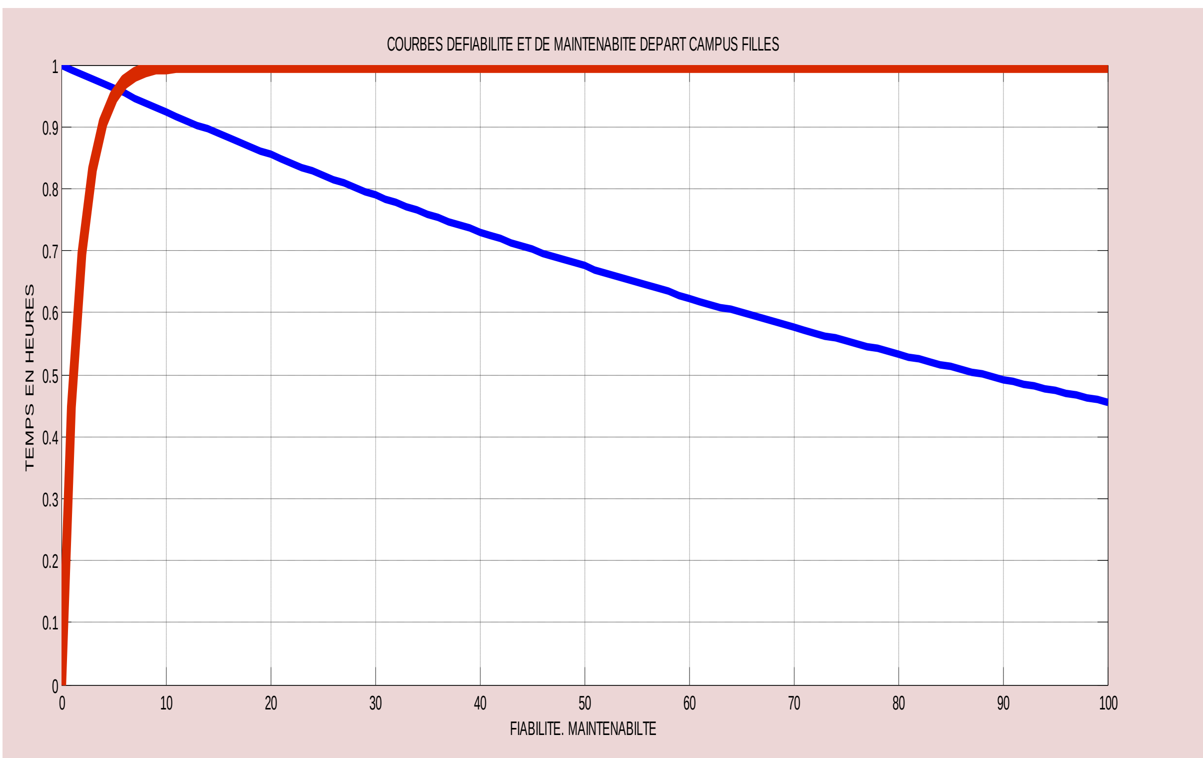

Figure 6:- Reliability and maintainability 2020 of the Girls' Campus departure.

We note a good maintainability on the Girls' Campus departure compared to the North departure. This is due to the fact that the North feeder, which is an overhead line, is influenced by weather phenomena that are not accessible to the Girls' Campus feeder, which is an underground line.

Conclusion:-

Reliability analysis in the field of electrical networks is a very important tool to characterize the behavior of equipment in the different phases of life, measure the impact of design changes on the integrity of this equipment, qualify a new product and improve its performance throughout their functions.

The results of the reliability assessment of the HTA network of the city of Niamey were presented.

However, it should be noted that these results must be improved. Indeed, the distribution network of Niamey has a complex structure and there is a lack of data on the components and equipment of the network. In addition, due to lack of data, we did not calculate reliability indices such as SAIDI (System Average Interruption Duration Index), SAIFI (System Average Interruption Frequency Index), CAIDI (Customer Average Interruption Duration Index), ENS (Energy Not Supplied).

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