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Assessment of Industrial Risks Related to Steam Production in a Thermal Production Service: Case of the Ouaga North of Burkina Faso Thermal Production Service

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Abstract

In this work, we have focused on the risks emanating from the steam production process in a thermal production department with a view to reducing the occurrence of unwanted events. The practical aspect of this study is to ensure the well-being of production actors and the surrounding population. Subsequently, we opted for fault tree analysis and HAZOP, which are tools for studying the probabilities of occurrence of unwanted events in the operation of industrial thermal installations. In addition, in the process of steam production, it emerges that pressure and temperature remain the most important parameters to monitor in order to reduce the risks associated with chemicals but especially with steam circuits.

Keywords

Fault Tree, Evaluation, HAZOP, Industrial Risk, Steam

1. Introduction

The production of steam intended for the sterilization of certain agro-food [1] [2] products and biomedical materials, as well as for the superheating of Heavy Fuel Oil [3] [4], is not without risk. Since said vapor is produced at high temperatures and pressures.

Steam production facilities use water that has undergone specific treatment. This allows the water to have a higher quality recommended in the steam production process. The treatment confers recommended properties and requires much more care. The overheating of the Heavy Fuel Oil with the help of steam gives it a higher quality that is to say makes it lighter. This allows it easy to use in thermal power stations by a changeover with Distillate Diesel Oil [3] [4].

The risks emanating from steam production are chemical and physical in nature, given that overheating or sterilization process employed is natural convection. This convection process is a transfer of coolant.

The objective of this work is the analysis of these different risks which require prevention [5] [6]. This analysis will allow perfect control of the steam production system at full load, in this case, the various parameters such as temperature and pressure.

2. Materials and Methods

The materials entering the water treatment namely the Diaposime B117 and the salt (NaCl) are transferred continuously, from their respective supply tanks to the coils where they combine with the water to give the end product which is treated water.

According to the rule, the Diaposime B117 must always be greater than or equal to the NaCl introduced into the coils to avoid a risk of explosion. A complete design plan would include many other details such as the effects of pressure, reaction and reactant temperature, agitation, reaction time, compatibility of the Diaposime B117 pumps and NaCl, etc. …for the purposes of this study, they are ignored but they will be taken into account at the level of the fault tree. The part of the system retained for HAZOP review is the pipe from the Diaposime B117 supply tank to the boiler, including its transfer pump. The design intent for this part is to transfer, continuously, the Diaposime B117 from the reservoir to the coils, at a rate greater than that of NaCl. Based on the suggested elements, the design intent is illustrated in **Figure 1** below.

The quantity of Diaposime B117 must always be greater than that of NaCl to avoid any risk of explosion.

The guide words mentioned on the sheets as well as those proposed during the preparatory work are then applied in turn to each of the elements of the installation studied, and the results are recorded on the same HAZOP worksheets.

As an exception, the reporting method is used and only significant deviations are recorded. After analyzing each of the guide words for each of the equipment concerned in this part of the installation, another part, namely the NaCl transfer pipe is taken into account and the process is repeated. In addition, the risk analysis by HAZOP method will lead us to use suitable evaluations tables of the level of severity of the unwanted events as illustrated in **Table 1** and **Table 2**, and of the probabilities of occurrence of said events mentioned in **Table 3**.

Finally, all the different parts of the installation are examined in the same way and the results are recorded.

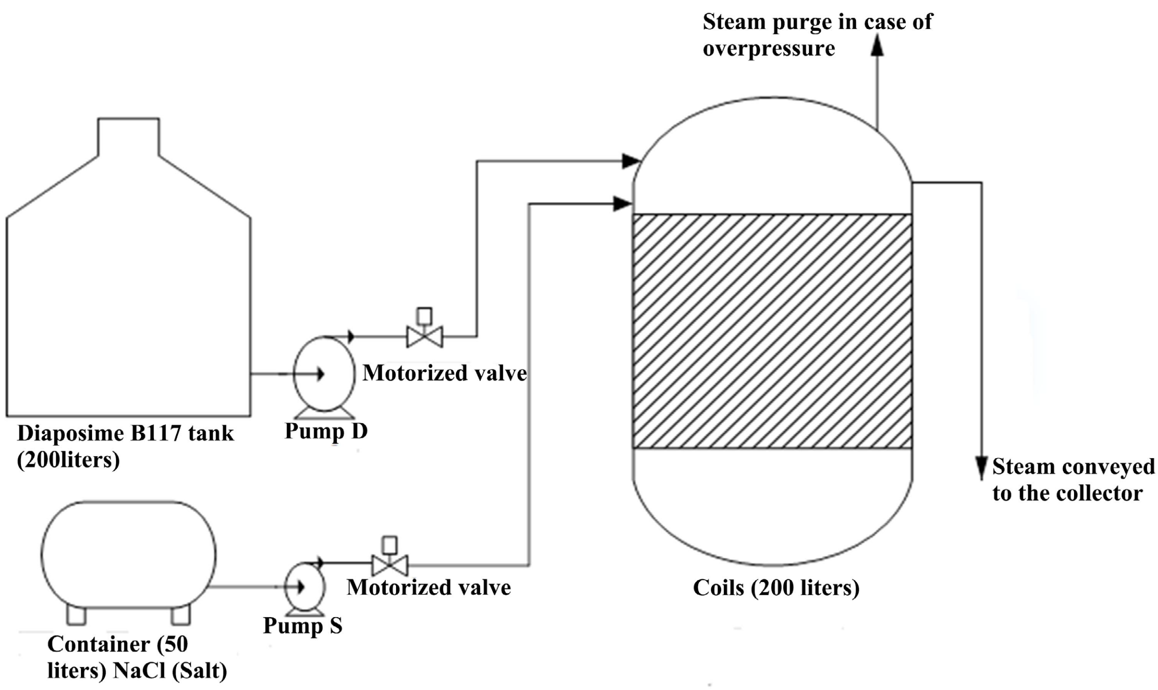

Figure 1. Automatic water treatment device.

Table 1. Severity level (G) of unwanted events (HAZOP).

Levels	Coefficients	Definitions
Minor consequences	1	- The tank will exceed the fill limit; - Presence of impurities.
Significant consequences	2	- Possible reduction in yield; - The product will contain far too many diaposime B117.
Critical or serious consequences	3	- No flow of diaposime B117 in the coils; - Explosion.
Catastrophic consequences	4	- Contamination of the supply tank by reflux of the reaction material; - Insufficient net positive section, possible turbulence and risk of explosion and inadequate flow.
External catastrophic consequences	5	- Environmental contamination; - Explosion or risk of explosion.

Probability of occurrence (P):

Let "Ω" be the universe of contingencies, that is of cases are likely to occur. We have 15 contingencies (HAZOP worksheets Tables 5-8) grouped into 6 events. That is:

- A: "Acceptable situation/Over";
- B: "Unacceptable situation/In addition to";
- C: "Unacceptable situation/Do not do";
- D: "Unacceptable situation/Other than";

- E: "Unacceptable situation/Less than";
- F: "Unacceptable situation/Inverse".

From the above, the cardinals of the various events are therefore recorded in the table of probabilities of occurrence.

Optimal operation of the boiler/steam circuit assembly of the various generating sets of the Ouaga Nord Thermal Production Department requires a reduction in the risks that may occur [5]-[10]. A graphical representation of the combinations of possible system failures that lead to the dysfunctions of interest.

In addition, this leads us to the analysis of the architecture through a qualitative and/or quantitative analysis [5] [6]:

- The research for weak points in the network;
- Research into the impact of the maintenance policy on its performance;
- The study of the cost performance compromise by comparisons of architecture and maintenance policy.

Table 2. Severity level of unwanted events.

Levels	Coefficients	Definitions
Minor consequences	1	- No personal injury; - Discomfort at work; - Destruction of property that does not jeopardize the integrity of the system.
Significant consequences	2	- Slight injury or limited intoxication of individuals by a low-toxic product; - Contamination of the order of the permissible annual dose; - Destruction of equipment resulting in system shutdown; - Exposure to high level nuisances (noise, vibration, etc.).
Critical or serious consequences	3	- One or more individuals injured or intoxication limited by a toxic product; - Contamination by a dose resulting in medical treatment; - Pollution of the environment by a weakly toxic product or a small quantity of a toxic product; - Irreversible loss of important information.
Internal catastrophic consequences	4	- Several people were seriously injured or dead; - Environmental pollution by significant or repeated emission of a very toxic product; - Complete destruction of the system.
External catastrophic consequences	5	Same as above except that the environmental impacts of the system are very significant.

With regard to the probability of occurrence of unwanted events, the rating grid is mentioned in **Table 3** below.

Table 3. Levels of probability of occurrence.

Levels	Coefficients(c)	Definitions
Very low	1	$p < 10^{-6}$ Once a year < p < 1 time per month
Low	2	$10^{-6} < p < 10^{-4}$ 1 time per month < p < 1 time per week
Medium	3	$10^{-4} < p < 10^{-2}$ 1 time per week < p < 1 time per day
Frequent	4	$10^{-3} < p < 10^{-1}$ 1 time per day < p < 1 time per hour
Very frequent	5	$10^{-1} < p$ p < 1 time per day

3. Results Anddiscussions

3.1. Risk Assessment of Chemical Components Used in Water Treatment by the HAZOP Method

The cardinal of the 15 contingencies is therefore: Card Ω = 15 (Table 4).

HAZOP Worksheets [3] [4] [5] [6]:

Table 4. Probabilities of occurrence of contingencies.

Events	Cardinals	Probabilities of occurrence
A	**Card A = 2**	$P(\text{A}) = \frac{\text{card A}}{\text{card } \Omega} = \frac{2}{15} = 0.133$
B	**Card B = 6**	$P(\text{B}) = \frac{\text{card B}}{\text{card } \Omega} = \frac{6}{15} = 0.4$
C	**Card C = 2**	$P(\text{C}) = \frac{\text{card C}}{\text{card } \Omega} = \frac{2}{15} = 0.133$
D	**Card D = 2**	$P(\text{D}) = \frac{\text{card D}}{\text{card } \Omega} = \frac{2}{15} = 0.133$
E	**Card E = 2**	$P(\text{E}) = \frac{\text{card E}}{\text{card } \Omega} = \frac{2}{15} = 0.133$
F	**Card F = 1**	$P(\text{F}) = \frac{\text{card F}}{\text{card } \Omega} = \frac{1}{15} = 0.067$

The quantification of the various failures was carried out with the collaboration of the other members of the team namely: SIRIMA Madjoyogo Herve (SMH), Chief Operating Officer (CE); Head of the Laboratory (CL); Head of Electrical Maintenance Division (CDME); Head of Mechanical Maintenance Division (CDMM); Charged with the CMMS (CG). The perfect demonstration of these analyzes is illustrated in Tables 5-8 below.

Table 5. HAZOP worksheets 1/4.

Title of the study: Water treatment process	Worksheets: 1/4
Drawing N°:	Date: 26/05/2021
Line-up: SMH, CE, CL, CDME, CDMM, CG,	Meeting date: 20/05/2021
Considered part: Transfer duct of supply tank from Diaposime to coils	
Material: Diaposime B117	
Source: Diaposime B117 Tank	Activity: Transfer continuously at a rate greater than that of NaCl Destination: Streamers
Operating parameters: Pressure and temperature	

N°	Word guide	Element	Deviation	Causes	Consequences	Barriers security	G	P	R	Events	Correctives action	Resp.
1	Do not do	Diaposime B117 (D)	No Diaposime B117	Empty supply tank	No flow of D in the coils. Explosion	None apparent	5	0.133	0.665	Unacceptable situation	Plan the installation for the B117 diaphragm tank of a low level alarm. As well as a low threshold trigger for shutting down the NaCl (Salt) pump.	CL, CE
2	Do not do	flow D > flow Salt (S)	No transfer takes place	Pump D stopped, duct clogged	Explosion	None apparent	5	0.133	0.665	Unacceptable situation	Flow measurement of material D, as well as a low level alarm and triggering of the S pump in case of low flow	CDME, CDMM, CE
3	More than	Material D	Material tank D full	Filling the tank from a tank, so that the ability is insufficient.	The tank is going exceed the limit filling	None apparent	2	0.133	0.266	Acceptable situation	Anticipate an alarm high level if not determined previously	CL

Table 6. HAZOP Worksheets 2/4.

Title of the study: Water treatment process	Worksheets: 2/4
Drawing N°:	Date: 26/05/2021
Line-up: CE, CL, CDME, CDMM, CG, SMH	Meeting date: 20/05/2021
Party considered: Transfer duct from the supply tank of the diaposime to the boilers	
Material: Diaposime B117	
Source: Diaposime B117 tank	Activity: Transfer continuously at a rate greater than that of NaCl Destination: Streamers
Operating parameters: Pressure, temperature and flow	

N°	word-guide	Element	Deviation	Causes	Consequences	Barriers security	G	P	R	Events	Correctives action	Resp
4	More than	Diaposime transfer B117	Excess transfer. Increased flow of diaposime B117.	Incorrect sizing of the pump. Installation of a bad pump.	Reduction possible performance. The product contain way too much of B117 diaposime.	Nothingness	2	0.133	0.266	Acceptable situation	Check the flows and the characteristics of the pump during commissioning. Review the setting procedure in use	CDME

Continued

5	Less	Diaposime B117	Less diaposime B117	Low level in The reservoir	Suction head positive net insufficient. turbulence possible and risk explosion Inadequate flow	Nothingness	4	0.133	0.532	Unacceptable situation	Low level alarm in the tank Idem 1	CL, CE
6	Less	Diaposime Transfer Rate < NaCl Transfer Rate	Decrease of the flow of diaposime B117.	Pipe partially clogged, leaking, pump no performance, etc.	The tank is going exceed the limit filling	None apparent	4	0.133	0.532	Unacceptable situation	Idem 2	CE, CDMM

Table 7. HAZOP Worksheets 3/4.

Title of the study: Water treatment process	Worksheets: 3/4
Drawing N˚:	Date: 26/05/2021
Line-up: CE, CL, CDME, CDMM, CG, SMH	Meeting date: 20/05/2021
Party considered: Transfer duct from the supply tank of the diaposime to the boilers	
Material: Diaposime B117	
Source: Diaposime B117 tank	Activity: Transfer continuously at a rate greater than that of NaCl Destination: Streamers
Operating parameters: Pressure, temperature and flow	

N˚	Word guide	Element	Deviation	Causes	Consequences	Barriers security	G	P	R	Events	Corrective action	Resp
7	In addition to	Diaposime B117	In addition to D, a other fluid is also present in the tank supply.	procurement of tank contaminated	Unknown	Verification and analysis content from all feed tank before unloading in the supply tank.	4	0.4	1.6	Unacceptable situation	Check the procedure of operation	CL
8	In addition to	Diaposime transfer	In addition to the Diaposime transfer, something is passes: corrosion, erosion, crystallization or decomposition	Low level in The reservoir	Suction head positive net insufficient. turbulence possible and risk explosion Inadequate flow	Nothingness	4	0.4	1.6	Unacceptable situation	Idem 5	CL
						Nothingness	4	0.4	1.6	Unacceptable situation	Idem 5	
						Nothingness	4	0.4	1.6	Unacceptable situation	Idem 5	
						Nothingness	4	0.4	1.6	Unacceptable situation	Idem 5	
9	In addition to	Destination streamers	In addition to destination of the coils External leaks	Leak in the led, the valve or the seal mechanics of the pump	Contamination of the environment. Risk of explosion	Use a code or of a standard approved for the Pipelines	4	0.4	1.6	Unacceptable situation	Position the flowmeter for the release as close as possible coils	CE, CDM M

The risk R as well as the probability of occurrence P of event B being very high, then there is a need to pay more attention to the equipment which is likely to suffer the harmful consequences in the event of the occurrence of event B (Figure 2).

Table 8. HAZOP Worksheets 4/4.

Title of the study: Water treatment process	Worksheets: 4/4
Drawing N˚:	Date: 26/05/2021
Line-up: CE, CL, CDME, CDMM, CG, SMH	Meeting date: 20/05/2021
Party considered: Transfer duct from the supply tank of the diaposime to the boilers	
Material: Diaposime B117	
Source: Diaposime B117 tank	Activity: Transfer continuously at a rate greater than that of NaCl Destination: Streamers
Operating parameters: Pressure, temperature and flow	

N˚	Word guide	Element	Deviation	Causes	Consequences	Barriers security	G	P	R	Events	Corrective action	Resp
10	Inverted	Transfer Diaposime B117	Inversion of the direction of flow. The treated water flows from the coils to the tank supply	Pressure in the coils superior to the pressure evacuation the pump	Contamination of tank supply by reflux material from reaction	None apparent	3	0.067	0.201	Unacceptable situation	Provide installing a check valve in driving	CE
11	Other than	Diaposime B117	Other than Diaposime B117. Material other that the Diaposime B117 in the tank supply	Bad material in the tank supply	unknown Function of material	Controls and analyzes of the nature of content of the tanker before unloading	4	0.133	0.532	Acceptable situation		CE, CL
12	Other than	Reactor of destination	External leak Nothing happens to boilers	Conduct break	Contamination of the environment and risk of explosion	Integrity of pipelines	4	0.133	0.532	Acceptable situation	Specify that the detector flow proposed is enough fast to release to avoid a explosion	CDME, CDMM

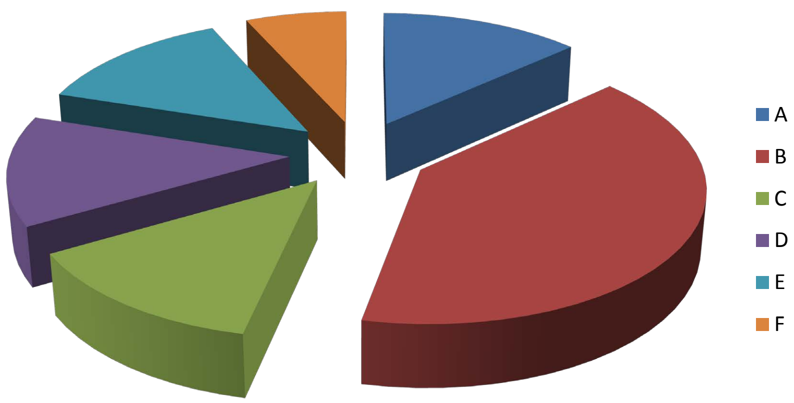

Figure 2. Sectors of interpretation of the probabilities of occurrence.

Then the importance will be given to the equipment which is likely to undergo the harmful effects of events A, C, D, E (Table 4).

Finally, it is the turn of the equipment that will suffer failures in case the occurrence of event F. It should be noted that the analysis was carried out on the boilers of a single thermal power station, in particular that of BWSC & MAN, in order to extrapolate it to the other thermal power stations.

3.2. Evaluation of the Operating Reliability of the Existing System by the Fault Tree

The determination and quantification of the various failures were carried out with the collaboration of technicians from the thermal production department (Table 9).

Table 9. Components of the failure tree.

Landmarks	Designations	Levels
A	Lack of feed water in the coils	Very low
B	Unavailability of boilers for maintenance	Frequent
C	Drilled Steam Rails	Medium
D	Runs exploded	Very low
E	Steam Balloon Feeding Pumps	Medium
F	Faulty backup pump	Low
G	Pierced Coils	Low
H	Pumps supplying defective coils	Low
I	Steam vapor balloon	Very low
J	B117 diaphragm pump failed	Very low
K	Pump NaCl (salt) failed	Very low
L	Abnormal value of pressure	Frequent
M	Abnormal temperature value	Frequent
N	Lack of feed water in the steam flask	Low
O	Unavailability due to short circuit feedback (high pressure alarm)	Medium
P	Defective contactor (high pressure alarm)	Medium
Q	Failed High Pressure Alarm	Frequent
R	Unavailability due to short circuit feedback (high temperature alarm)	Medium
S	Defective contactor (high temperature alarm)	Medium
T	Fail high temperature alarm	Frequent

The different scenarios (Scenes) (Figure 3) are: Scenes 1 “A, N, I, E, F”; Scene 2 “A, H”; Scene 3 “A, G”; Scene 4 “B”; Scene 5 “C”; Scene 6 “D, M, R, S, T”; Scene 7 “D, L, O, P, Q”; Scene 8 “D, J”; Scene 9 “D, K”.

This fault tree is a general overview of the faults likely to occur on the boilers/steam circuits of each SPTN generator set.

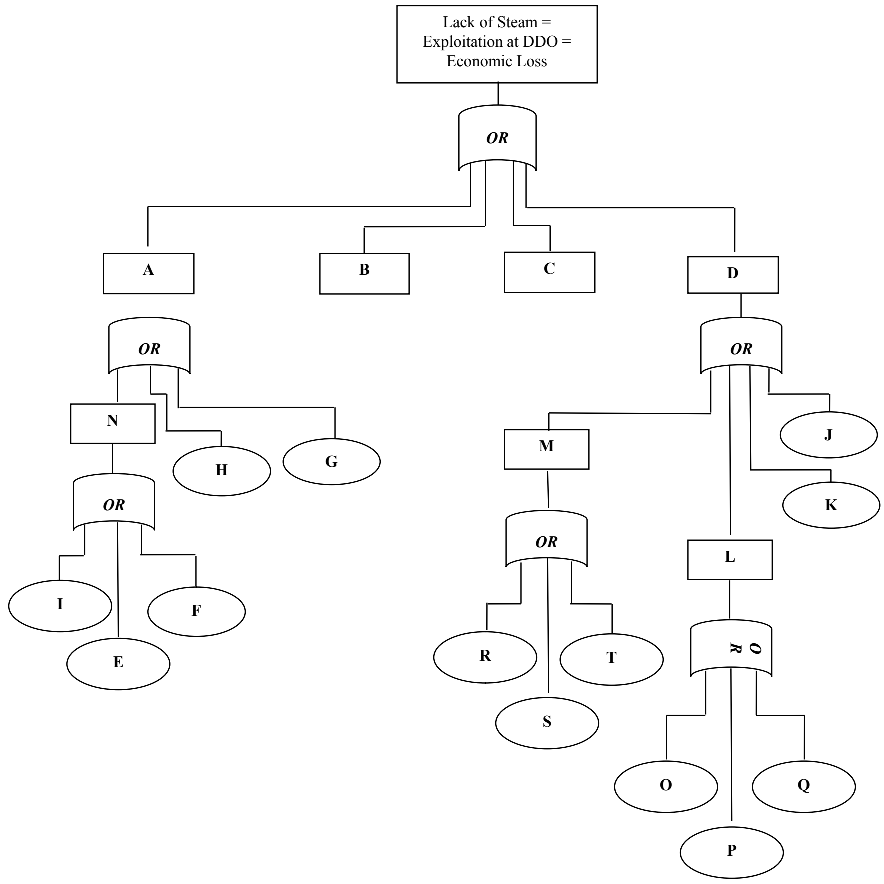

Figure 3. Fault tree.

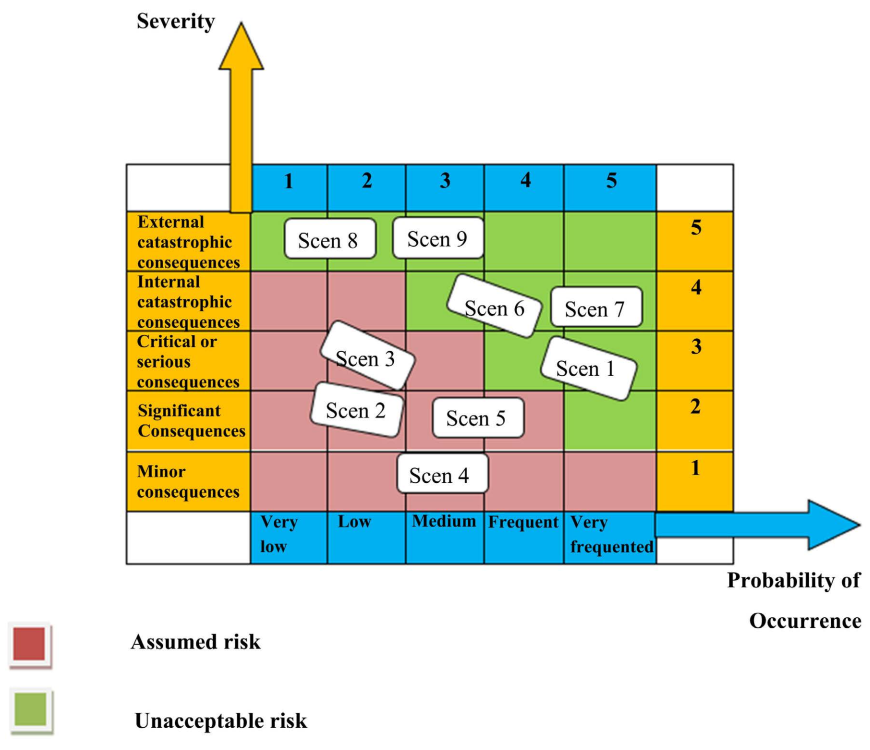

Figure 4. Risk estimation.

By analyzing the fault tree, we realize that the interconnection of the vapor circuits would reduce the effects of the probability of occurrence of the "Lack of vapor" event. If the event occurs, this reduction in effects is achieved by transferring steam from a generator set in operation to the generator set whose boiler is failing.

The estimation of the various risks leads us to carry out their sizing according to the types of risk, namely the "Assumed risk" and the "Unacceptable risk" as illustrated in Figure 4.

In addition, we carry out the risk calculations as shown in Table 10 below.

Table 10. Risks Calculation.

Landmarks	Probability (P)	Severity (G)	Risks (R) $R = P \times G$
A	9.01×10^{-3}	2	18.02×10^{-3}
B	4×10^{-2}	1	4×10^{-2}
C	3×10^{-3}	3	9×10^{-3}
D	93×10^{-3}	5	465×10^{-3}
E	3×10^{-3}	1	3×10^{-3}
F	2×10^{-3}	2	4×10^{-3}
G	2×10^{-3}	5	10×10^{-3}
H	2×10^{-3}	4	8×10^{-3}
I	1×10^{-5}	4	4×10^{-5}
J	1×10^{-4}	5	5×10^{-4}
K	1×10^{-4}	5	5×10^{-4}
L	46×10^{-3}	2	92×10^{-3}
M	46×10^{-3}	2	92×10^{-3}
N	5.01×10^{-3}	2	10.01×10^{-3}
O	3×10^{-3}	2	6×10^{-3}
P	3×10^{-3}	2	6×10^{-3}
Q	4×10^{-2}	2	8×10^{-2}
R	3×10^{-3}	2	6×10^{-3}
S	3×10^{-3}	2	6×10^{-3}
T	4×10^{-2}	2	8×10^{-2}

Note that the probability of occurrence P is obtained by multiplying the coefficient of level c by the probability p between an interval ($P = p \times c$). Confers table of the level of probability of occurrence. From the foregoing it follows that:

$$R = P \times G = p \times c \times G$$

The events N, A, M, L, D being respectively the unions of the following sets of events: {I, E, F}; {N, H, G}; {R, S, T}; {O, P, Q}; {L, M, J, K}.

The respective gravities of the events N, A, M, L, D are not deduced respectively from the sets of events mentioned above but directly on the table of the level of severity of the undesired events.

Then their probabilities are deduced from the following formulas:

$$P(\mathrm{N}) = P(\mathrm{I}) + P(\mathrm{E}) + P(\mathrm{F});$$

$$P(\mathrm{A}) = P(\mathrm{N}) + P(\mathrm{H}) + P(\mathrm{G});$$

$$P(\mathrm{M}) = P(\mathrm{R}) + P(\mathrm{S}) + P(\mathrm{T});$$

$$P(\mathrm{L}) = P(\mathrm{O}) + P(\mathrm{P}) + P(\mathrm{Q});$$

$$P(\mathrm{D}) = P(\mathrm{L}) + P(\mathrm{M}) + P(\mathrm{J}) + P(\mathrm{K});$$

The probability P that there is a lack of steam is therefore given by the following formula:

$$P = P(\mathrm{A}) + P(\mathrm{B}) + P(\mathrm{C}) + P(\mathrm{D})$$

$$P = 18.02\times10^{-3} + 4\times10^{-2} + 9\times10^{-3} + 465\times10^{-3}$$

$$P = 532.02\times10^{-3}$$

As the probability P is very high, there is therefore a need to interconnect the boilers of the generator sets of the various thermal power stations of the SPTN. It should be noted that the analysis was carried out on the boilers of a single generator set in particular that of BWSC & MAN, in order to extend it to the other boilers.

4. Conclusions

The risk analysis presented in this work is a considerable contribution to controlling the management of industrial risks in the steam production process, with a view to optimizing the probability of occurrence of unwanted events.

This study allowed us to look for the possible causes of derivatives of the various operating parameters as well as to determine the possible consequences and risks, a practice of identifying dangers and operational problems adopted by many industries.

In addition, the risk assessment in the thermal production process has enabled us to easily realize that the number of incidents can be reduced. We can also save on time losses due to various unplanned shutdowns and a general overview of other components that may experience failures in the thermal production system.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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