The Natural Language Processing (NLP) Algorithm Integrated with FMECA Analysis Applied in the Maintenance Plans Development to Power Generation System Assets

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Abstract

Global electricity consumption has continued to grow rapidly. This growth of consumption shows that energy will be one of the major problems in the future. Maintenance of the energy supply is essential, as the interruption of this service leads to higher expenses, representing substantial monetary losses and even legal penalties for the power generation company (Azam et al,2021). Hydroelectricity is the basis of the Brazilian energy matrix. Therefore, it is clear the need to maintain the availability and operational reliability of hydroelectric plants, so as not to compromise the continuity and conformity (quality) of the electrical energy supply to the end consumer. Ensuring availability along with the reliability of hydroelectric plants can be maintained by employing appropriate maintenance policies that reduce the likelihood of failure or even eliminate its root causes, preventing failure from occurring. The aim of this paper is presenting a proposed smart maintenance system model that integrates Natural Language Processing (NLP) algorithm and FMECA (Failure Mode, Effects & Criticality Analysis) database automated by Power BI® for the development of consistent maintenance plans for hydrogenerators assets. This integrated innovative tool can identify the operational subsystem chronic failure modes supporting industrial managers to incorporate tasks aimed at strengthening and increasing the maintenance plan consistency in blocking failure modes before them occurrences. This work was applied to a case study in a 525 Kv transformer of a hydrogenerator unit type Francis to demonstrate its use and contribute to its understanding.

Keywords
Smart Maintenance System, NLP algorithm, FMECA, Consistent Maintenance Plans, Francis Hydrogenerator.

1. Introduction
Hydro generators are the main industrial assets in a hydroelectric power plant. The occurrence of failures in these hydro generators reduces efficiency and can stop the power generation. The unavailability of the power generation system demands costly maintenance actions for the reestablishment of assets and may incur in fines imposed by regulatory agencies, such as ANEEL (Brazilian Electrical Energy Regulatory Agency) in Brazil.

The availability and reliability of electrical energy generation systems can be maintained using appropriate maintenance policies, making it possible to anticipate failures and eliminate their causes. Thus, it is essential the adoption of assertive decisions on maintenance management that aim to develop an effective maintenance policy, ensuring high productivity levels while optimizing costs and resources.

The Brazilian hydroelectric sector (UHE) corresponds to most of the energy generating potential in the country. According to the National Electric Power Agency (ANEEL) the electric energy represents approximately 58.5% of the Brazilian energetic matrix, followed by Thermoelectrics (24.35%) and by Wind Energies (10.54%) (ANEEL 2021).

Industrial maintenance aims to maintain the availability of machines and equipment with adequate performance, so it needs to actively analyze machine failures and manufacturing facilities to directly act on the causes and modes of the failures, cutting them down or even completely.

The automation of the maintenance management decision making, applying different types of statistical analysis techniques and database science, aims to reduce the production costs of the electricity generation system and not to compromise the supply of electricity (system reliability guarantee). This research consists in the NLP algorithm application to structure a search system on textual information contained in Power generation assets FMECA failure analysis database. This smart system aims to assist engineers and industrial managers to develop consistent maintenance plans to block chronic failure modes in Hydroelectric Power Plants (HPPs).

The FMECA (Failure Mode Effects and Criticality Analysis) quality tool has an important application in industrial maintenance management, as it aims to analyze the causes of failures and their effects, directing the identification of effective preventive actions. The use of FMECA analysis has benefits for the maintenance plans development, but its textual information structure in spreadsheet format imposes a slowdown in searching and managing this information, making it difficult to maintenance policy construction.

With the constant increase in the data generated amount from machinery records and maintenance work orders, the industrial sectors need seek to apply new technologies from industry 4.0 to treat and structure database information and get better management process. The use of technologies, such as Big Data, can be applied to facilitate the data reading in order to generate concrete statistics to making decision maintenance process. This automatized management process presents in this new industrial era is denominate Smart Maintenance or Maintenance 4.0 (Lundgren et al. 2021).

Generally, the maintenance actives history data and machinery operating parameters are collected from informal records and texts information, which are executed by operators and/or maintainers workers. This makes it difficult to apply a strictly quantitative analysis. However, it is possible to apply Natural Language Processing (NLP) with algorithms systematically built to obtain better search results to texts database with fast performance and reliability.

1.1 Objectives

The aim of this paper is presenting a proposed smart system model that integrates Machine Learning NLP algorithm and FMECA analysis automatized by Power-BI® for the development of consistency maintenance plans for hydrogenerators assets. This integrated innovative tool can identify the operational subsystem chronic failure modes supporting industrial managers to incorporate tasks aimed at strengthening and increasing the maintenance plan consistency in blocking failure modes before them occurrences. This approach was applied to a maintenance case study in a 525 Kv three-phase transformer which is part of a hydrogenerator unit type Francis to demonstrate its use and contribute to its understanding.

2. Literature Review

Maintenance management is an activity that allows the continuous and controlled process improvement with an optimal use of available resources and the critical operations or activities detection. An adequate maintenance management can ensure high productivity and machinery preservation (Belinelli 2012; Ding et al. 2014; EL Houda et al. 2021).

Hydro power plants (HPPs) require attention from the operation and maintenance teams due their operational unavailability can result in high unexpected spending. Therefore, it is necessary to structure a strong and adequate maintenance policy for the hydroelectric industrial assets. The aggregation of technologies present in Industry 4.0 allows the of decision-making processes optimization and agility to industrial maintenance, aiming at robust and effective decision-making (Rutagama 2019).

The industry 4.0 advent is considered as a natural transition process from traditional to modern manufacturing systems, evolving the maintenance management of industrial assets to the management model Smart Maintenance, which is defined as "an organizational design for the maintenance management of environments factories that have technologies universal digital (Lima and Polido 2021; Lundgren et al. 2020).

Industry 4.0 is compost of tools such as Big Data, Machine Learning, Internet of Things (IOT), Intelligence, Artificial Automation Systems, Physical Cybernetic Information Systems, Cloud Computing, Cyber Physical Systems (CPS), Augmented Reality, Additive Manufacturing, and others. An application of these technologies in maintenance management, it is possible obtain an effectively manage with higher level of reliability, robustness and mainly to prevent the failures modes (Poór et al. 2019; Bokrantz et al. 2020).

Finally, the most important and innovative part of this study is the tool developed with NPL algorithm integrated to FMECA database. This management smart system to assist engineers and industrial managers to planning the industrial assets maintenance better. The system developed is capable to identify chronic problems which affects the performance of the electrical energy generation system. Thus, helping structure effectives maintenance actions to mitigate these failures, ensuring availability and reliability in the hydro generator functions.

3. Methods

In this work, a smart system to assist for maintenance decision-making has been developed. The aim is to facilitate the development of the consistent maintenance plans to power generation systems components. The Figure 1 show the system functions.

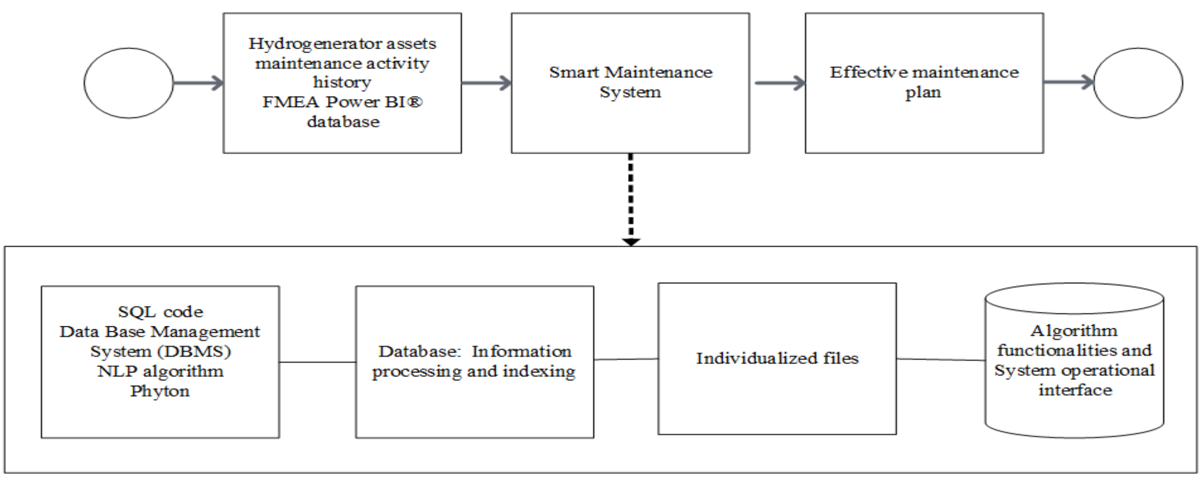

Figure 1. Smart Maintenance System NLP algorithm structure

4. Data Collection

In this paper, the PLN tool was applied to a maintenance planning case study to demonstrate its use and contribute to its understanding. The research then proposes a qualitative approach, since it will be based on the analysis of textual data, of an applied nature, with the development of practical knowledge to a specific problem. A hydrogenerator unit type Francis was selected for this purpose. Hydroelectric plants are of great importance in Brazil due to the predominance of this type of energy in its energy matrix. The Figure 2 show the hydrogenerator functional tree highlighting the Elevator Transformer main components used in this study.

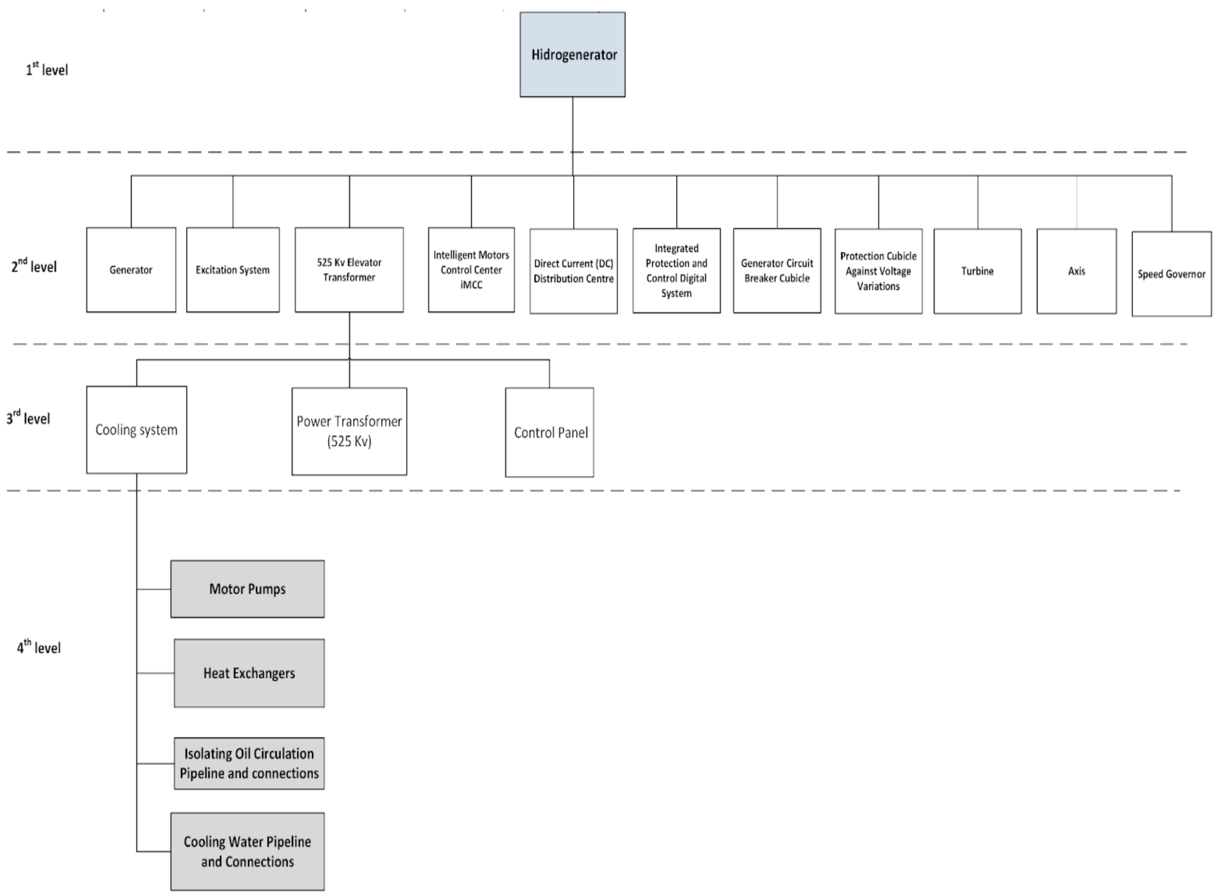

Figure 2. 525 Kv Power Transformer System Functional Tree (FT)

The purpose of a Functional Tree (FT) is to structure, in a logical and hierarchical way, the interdependence between the different components of a system, to expose how each one performs its functions. The elevator transformer object of the study has 308 components in its structure, which are distributed in seven subsystems, which are: Transformer Cooling system (34 components), Control panel (60 components), Oil-preservation system (43 components), Active part of the transformer (18 components), 525 Kv transformer Bushings (72 components), Transformer Protection and Control system (7 components) and Terminal board panel (74 components).

The smart maintenance system was applied to transformer cooling system whose function is to cool of the water and insulating oil circuit. This subsystem consists of motor pumps, heat exchangers and water and oil pipelines.

4.1 Automated Power-BI® FMECA Maintenance Database

The 525 Kv Transformer Cooling system database was used in this case study to development an adequate maintenance plans for assets. This database was automated applied the Power BI® tool, aiming to facilitate the data visualization and search as: failure mode, component type, TAG, cause, effect, and preventive actions. Figure 3 shows the FMECA Power-BI database.

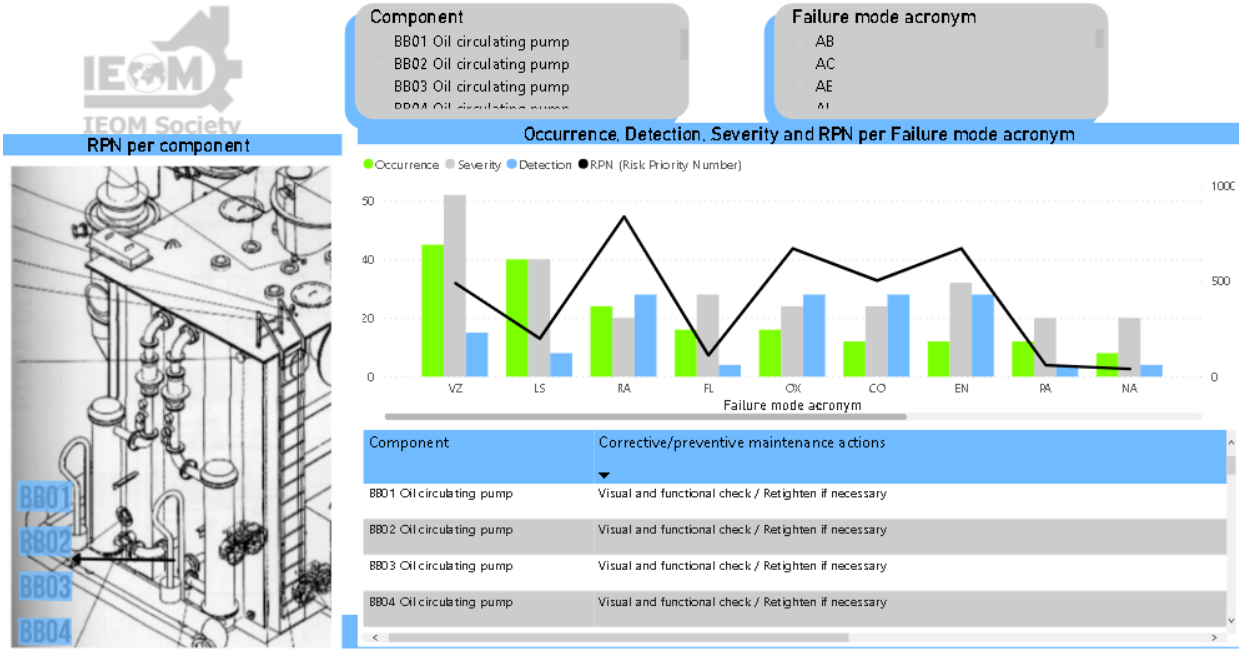

Figure 3. FMECA Power-BI database (Motor pumps analysis)

To develop the textual information searcher engine in the FMECA database was used the Structured Query Language (SQL) from a database management system MYSQL. The Snowflakes Schema dimensional data modeling, represented by Figure 4, was structured to relate the primary keys of each column with of the FMECA foreign keys.

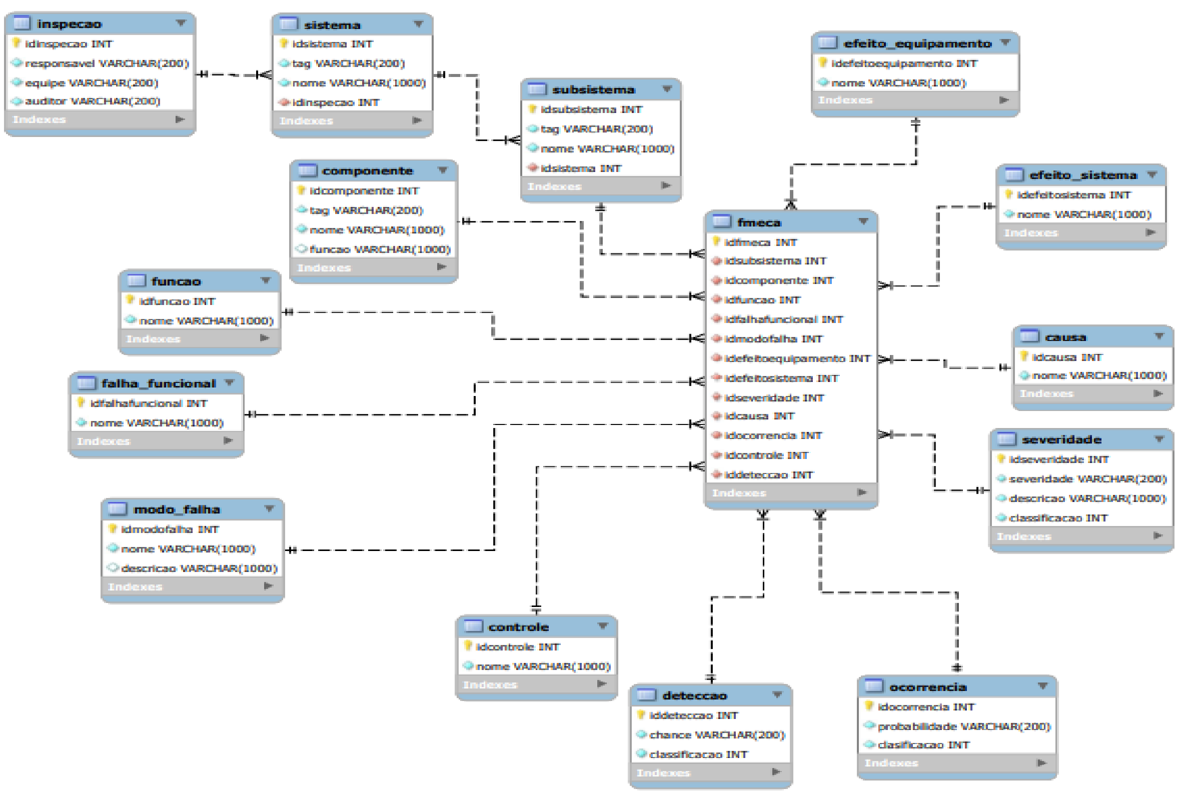

Figure 4. Dimensional data modeling of the FMECA database searcher.

5. Results and Discussion

5.1 PLN Search Algorithm

To build the Smart maintenance system, the Python programming language was used, due to its learning ease and use simplicity, compared to other programming language. The Spyder was the integrated development environment used, due to its principal focus on data processing and analysis. This smart system was developed aims of performing the queries return using of a specific word (keyword) and classified based on the failure mode frequency context.

To query a component, the algorithm functionality activated is the component ID return and its TAG from the component name insertion, as shown in Figure 5. This function is executed from the "searchid_bycompname" function request inserting the component name argument, either in single or double quotes.

```
def searchid_bycompname(compname):
    con = pymysql.connect(host='localhost', user ='root', passwd= senha, db='fmea')
    cursorid = con.cursor()
    cursorid.execute('select idcomponente, tag from componente where nome = %s', compname)
    if cursorid.rowcount > 0:
        retorno = cursorid.fetchall()
        print(retorno)
    else:
        print("component name not found")
    cursorid.close()
    con.close()
```

Figure 5. Algorithm search function by ID (component)

The function occurs from the database connection using the MYSQL library. This function establishes the cursor opening, which executes the code specified in the Data Base Management System (DBMS). If the query returns one row or more, the console shows the return in double format, as shown the Figure 6. Otherwise, if the component is not found, a warning is returned.

```
In [18]: searchid_forcompname('Moto bombas')
((1, '01004.1.1'),)
```

Figure 6. Result of the query using the 'Motor pump' argument.

Another query function established into the maintenance smart system is the search using the identifier (ID) or TAG as an argument, obtained as result the component name. All these functions demonstrated can be applied to obtain a deep knowledge of the component into the database with limited information inputs.

To realize queries using failure mode as argument, the activated functionality is the failure mode frequency query, inserting the search word in the format single or double quotes. This functionality can run it by requesting the "searchfreq_byfailure" function. The code detail is presented in Figure 7.

```
def searchfreq_byfailure(modofalha):
    conexao = pymysql.connect(host='localhost', user ='root', passwd= senha, db='fmea')
    cursorid = conexao.cursor()
    cursorid.execute('SELECT modo_falha.idmodofalha, modo_falha.nome as modo_falha, fmeca.idfmeca,
    comp = set()
    freq = set()

    for modo_falha in cursorid:
        comp.add(modo_falha[4])
        freq.add(modo_falha[2])

    print('\n Different components found: ', comp)
    print('\n Number of different components found: ', str(len(comp)))
    print('\n Frequency of occurrence of failure mode: ', len(freq))
    cursorid.close()
    conexao.close()
```

Figure 7. Frequency search function of the algorithm

The function occurs from the database connection using the MYSQL library. This this function establishes the cursor opening, which executes the code specified in the Data Base Management System (DBMS). The code aims to structure the relationship between the FMECA Power BI® database and the foreign keys with their primary keys aggregated. An important factor is the filtering command by inserting the "Where" argument, which is filled in by the function argument. The Figure 8 presents the FMECA database connection with Keywords system.

```
SELECT modo_falha.idmodofalha, modo_falha.nome as modo_falha, fmeca.idfmeca, componente.idcomponente,
componente.nome as componente, severidade.classificacao as severidade,
ocorrencia.clasificacao as ocorrencia, deteccao.classificacao as deteccao,
severidade.classificacao * ocorrencia.clasificacao * deteccao.classificacao as NPR
FROM fmeca
JOIN componente on fmeca.idcomponente = componente.idcomponente
JOIN modo_falha on fmeca.idmodofalha = modo_falha.idmodofalha
JOIN severidade on fmeca.idseveridade = severidade.idseveridade
JOIN ocorrencia on fmeca.idocorrencia = ocorrencia.idocorrencia
JOIN deteccao on fmeca.iddeteccao = deteccao.iddeteccao
Where modo_falha.nome = "fluxo ou vazão anormal"
```

Figure 8. SQL code of the frequency function

Subsequently, two variables assume empty commands. These commands are filled in by the query data at positions number four and number two respectively, referring to the component name and the FMECA database unique identifier. With both sets filled in, it is possible to present the components name with the failure mode, the subsystem different components quantity and frequency that appears the failure modes in the search, as showed in Figure 9.

```
In [49]: searchfreq_byfailure("fluxo ou vazao anormal")

 Different components found:  {'BOM-00198 Bomba (Bomba 1 de circulaÃ§Ã£o de Ã³leo do
trafo) ', 'BOM-00200 Bomba (Bomba 3 de circulaÃ§Ã£o de Ã³leo do trafo) ', 'BOM-00201
Bomba (Bomba 4 de circulaÃ§Ã£o de Ã³leo do trafo) ', 'BOM-00199 Bomba (Bomba 2 de
circulaÃ§Ã£o de Ã³leo do trafo) '}

 Number of different components found:  4

 Frequency of occurrence of failure mode:  16
```

Figure 9. Algorithm of the "searchfreq_byfailure" function query result using "abnormal flow or outflow"

This query, in a generalized way, returns the name of all components, the quantity of these components and the frequency of the failures modes aggregated to components. This information is fundamental for the maintenance plan construction process.

5.2 Development Maintenance Plan

The functions composted in the search system allow the maintenance plan construction based on the failure modes frequency and severity. A maintenance plan based on these variables is effective to identify the main and chronic failures that must be mitigated within an operating subsystem. The failure modes visual identification is achieved into the Smart maintenance system by the WordCloud library. Figure 10 shows the WordCloud obtained with the chronical failure modes present in the transformer cooling system.

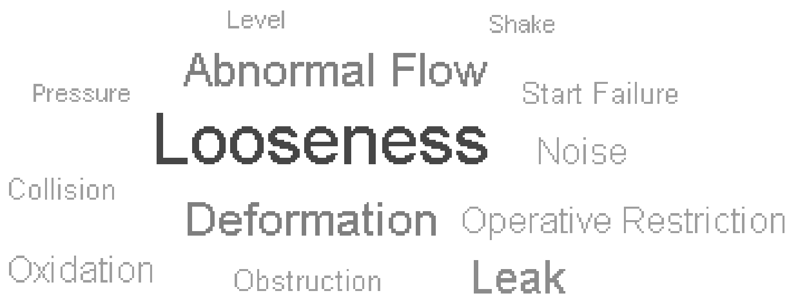

Figure 10. Chronic failure modes (WordCloud)

Ensure that the " Looseness" failure mode has a higher frequency among others Transformer Cooling system failures modes. Other failure modes such as " Leak", “Deformation” and "Abnormal flow" are also easily identified, making it easier to identify the most chronic failure modes that occur in this hydrogenerator subsystem.

The WordCloud resultant identifies in order of priority the most chronic failure modes, assisting in decision making process relating to the resources planning applied in maintenance tasks. This directs human, financial and material resources to execute priority the tasks that aimed at mitigating and/or eliminating those failure modes, which most affect operational performance. In addition, the identification of chronic failure modes facilitates the choice of employees training type, as well as the investment amount to parts, materials, and tools.

The maintenance plan development is carried out with the analysis of the information grouping around the failure modes, such as frequency and risk priority number (RPN). Figure 11 shows the table model returned with the “Looseness" argument researched.

<table>
<tr><th colspan="8">Preventive Plans Development Process</th></tr>
<tr><th>Failure Mode</th><th>Frequency of occurrence</th><th>TAG</th><th>Component</th><th>Severity</th><th>Occurrence</th><th>Detection</th><th>RPN (Risk Priority Number)</th></tr>
<tr><td rowspan="8">Looseness</td><td rowspan="8">24</td><td>01004.1.2.1</td><td>Heat exchanger TC-01</td><td rowspan="4">6</td><td rowspan="4">5</td><td rowspan="4">1</td><td rowspan="4">30</td></tr>
<tr><td>01004.1.2.2</td><td>Heat exchanger TC-02</td></tr>
<tr><td>01004.1.2.3</td><td>Heat exchanger TC-03</td></tr>
<tr><td>01004.1.2.4</td><td>Heat exchanger TC-04</td></tr>
<tr><td>01004.1.1.1</td><td>BB01 Oil circulating pump</td><td rowspan="4">4</td><td rowspan="4">5</td><td rowspan="4">1</td><td rowspan="4">20</td></tr>
<tr><td>01004.1.1.2</td><td>BB02 Oil circulating pump</td></tr>
<tr><td>01004.1.1.3</td><td>BB03 Oil circulating pump</td></tr>
<tr><td>01004.1.1.4</td><td>BB04 Oil circulating pump</td></tr>
</table>

Figure 11. Information grouping related to the “Looseness” failure mode

The information grouping of the failures modes components that affect the energy generation system operational performance, assist the engineers and managers to developed effectives maintenance plans to mitigate and/or solve these chronic maintenance problems. Equally assist the development of FMECA analysis process, standardizing terms to failure modes, effects, mechanisms, and preventive tasks. The maintenance tasks for the preventive plan assembly are inserted into the FMECA database automated by Power BI® that makes it easy the preventive plan joining/assembly and streamlines access to the maintenance tasks for execution.

6. Conclusion

Hydroelectricity is the basis of the Brazilian energy matrix. Therefore, it is clear the need to maintain the availability and operational reliability of hydroelectric plants, so as not to compromise the continuity and conformity (quality) of the electrical energy supply to the end consumer. Ensuring availability along with the reliability of hydroelectric plants can be maintained by employing appropriate maintenance policies that reduce the likelihood of failure or even eliminate its root causes, preventing failure from occurring.

This paper proposed an innovative and automated tool which contributes to ensuring the assertiveness in decision making to develop adequate preventive maintenance plans. This approach was applied to a maintenance case study of a 525Kv elevator transformer of a hydrogenerator unit type Francis to demonstrate its use and contribute to its understanding.

As a main result, the smart maintenance system development using NLP algorithm integrated with FMECA database assists in a consistent maintenance plan development, which aims to anticipate failures and eliminate their causes. Thus, it is possible to determine and prioritize assertively the maintenance actions, ensuring availability and reliability operational to the energy generation process. In addition, it enables better maintenance planning decision-making, directing pieces, material, human and financial resources to execute the exact maintenance actions that mitigate the chronic failure modes.

Consequently, it is expected that this study will contribute to researchers and professionals in the field of maintenance in improving decision making in industrial planning in electric energy generation systems. Thus, it is possible to determine and prioritize assertively the maintenance actions, ensuring availability and reliability operational to the energy generation process.

As opportunities for future work, the authors suggest determining the optimal time interval for performing the maintenance plan (replacing assets components or operational systems preventive/predictive inspection) and automatizing the maintenance tasks decision through the NLP algorithm applied to maintenance work orders database analysis.

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