DEVELOPMENT OF METHODOLOGY FOR THE DETERMINATION OF CRITICALITY AND FAILURES ANALISYS IN COMPONENTS OF POWER GENERATION SYSTEMS

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Abstract. *This paper shows the development and results of the implementation of a methodology for the determination of the critical components and the failure analysis in systems for generating electricity. The case study method was entitled "Cycle of Routines" in thermoelectric power plants diesel engine – TPP, where they were identified, analyzed, systematized, classified, standardized and parametrized the systems and subsystems of generation, forming the basis for structured knowledge, which allowed the completion of adjustments in programs to maintain them. This study was motivated by the need to identify the TPP critical points, characterizing and quantifying the most common operational faults while suggesting procedures to solve them. This methodology was developed and implemented in current diesel TPPs in the north region of Brazil. The results of the implementation of the "Cycle of Routines" caused an increase in the operational reliability of the generating units – GUs and an overall reduction in the operation and maintenance over time. This method refers to a more comprehensive management approach called "Cycle of Routines for Process Systems Improvement and Power Generation", which aims at the development and implementation of a systematic management and planning of activities, maintenance operation, and the monitoring and diagnosis of the TPP generating units. This methodology uses artificial intelligence elements such as Fuzzy logic, genetic algorithms and neural networks As results of the implementation of this methodology, was obteined a redution in operating costs by 20%, as well as the number of outages at 15%.*

Keywords*: criticality; power generation; maintenance and operation; smart system; artificial intelligence;*

1. INTRODUCTION

The State of Pará, located in the northernmost of Brazil, is consists of 143 small cities and villages. Of these, 38 villages are served by TPPs in isolated systems. Some cities have their head offices connected with the national electricity system; however, many places are still not served by electric power. The state utility is responsible for the generation of energy, with a total of 165 genset, in 2008 (Santos, *et. al.*, 2010).

In TPPs operating in the public service it is necessary to reduce the electricity generation costs, making TTPs more efficient. This involves the effective control of all power generation operating parameters - as the fuel consumption of GUs, prevention and investigation of system and equipment failures, and the genset maintenance planning. Such task must be conducted taking into account that the performance degradation of those components causes an increase in the consumption of parts necessary to keep a plant operating, such as fuel, filters and lubricant oil, among others, to produce the same amount of electricity as would a system in perfect condition. Moreover, maintenance represents cost, as interventions in TPPs represent an average cost of 5 to 15 % of the system's investment per year (Jelen, *et. al.*, 1983).

The effective generation unit system diagnosis should allow the installation of individual management in order to reach the causes of operational failure so the reduction in performance can be detected and located and therefore the anomalies corrected. This way, any intervention can be more precise, avoiding the practice of corrective maintenance not scheduled (Santos, *et. al.*, 2009).

The control of information from the energy generation leads to reasonable economy, as it facilitates the costs assessment of possible corrective actions unforeseen, or emergencies in the TPPs, allowing the identification of the components and/or systems responsible for the loss of income or the causes of failures in the genset. Due to strict control, the TPPs now result in savings with the reduction of the plant's fuel consumption. In addition to the knowledge of generating sets current operating conditions, in combination with the cost of maintenance, it is necessary to define parameters to decide when to intervene in a generating unit.

This study proposes a methodology for the detection of the group anomalies or deficiencies responsible for the loss of efficiency of generation system, indicating the components of the gensets and proposing actions to be taken. It also demonstrates a methodology to determine the critical points, i.e., the criticality of the generation system. In this paper the case study was developed in TPPs with diesel genset.

2. METHODOLOGY CYCLE OF ROUTINE FOR THE IMPROVEMENT OF ELECTRICAL POWER GENERATION SYSTEMS

This methodology has the general objective of the computerization of the activities of maintenance, operation, monitoring and supervision on power plants, using an expert system for developing, managing, organizing, planning and evaluation of activities aiming at developing diagnostic and prognostic operating conditions of the components of power plants.

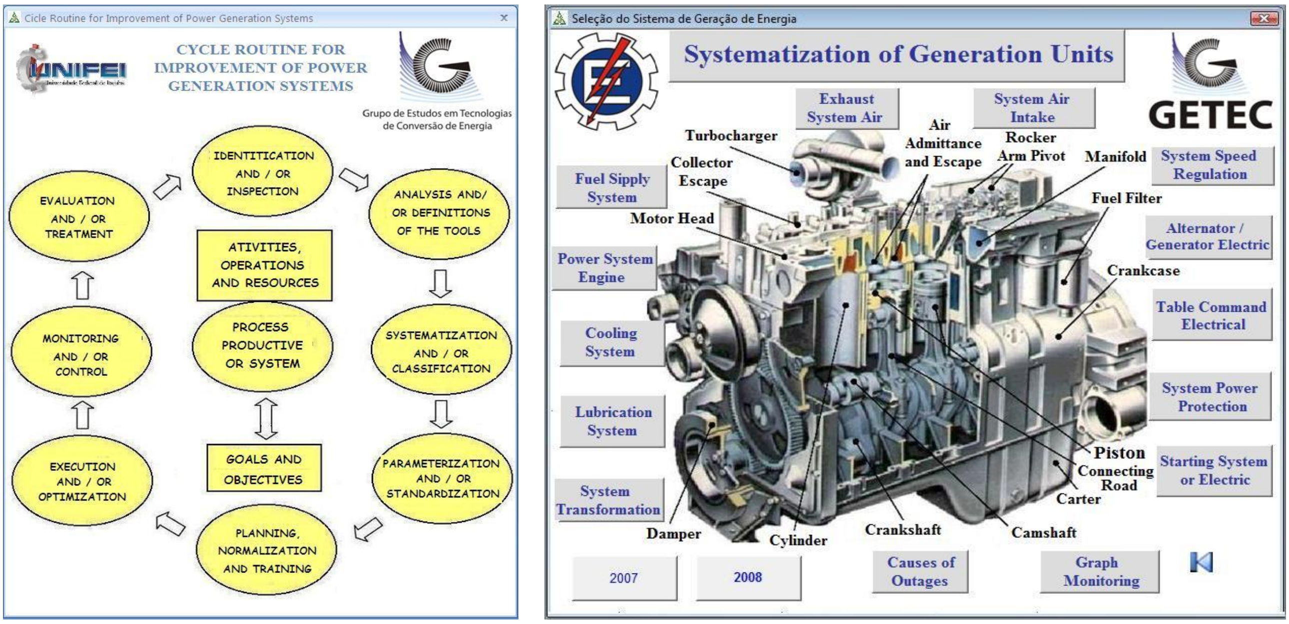
The cycle of routines was developed as a methodology to obtain the database for the application of electric power generation systems making use of artificial intelligence tools, besides management and administrative elements, as Reliability Centered Maintenance – RCM, methods of systems and processes administration, as 5S, Total Productive Maintenance – TPM, six sigma, etc., besides reliability engineering. (Santos, *et. al.*, 2010)

The cycle basic functionality is the identification, attendance, control, evaluation and treatment of the tasks and the planned activities; the systems and processes' operation and maintenance and the use of the resources (personal, material and financial), according to the objectives and goals defined by the company.

Besides the general objective the methodology requires the development of the following specific objectives for the generation system, that is:

- Identify and evaluate the needs generation systems;
- Evaluate the methods and procedures implemented or used by the system of power generation;
- Systematization and classification of systems of the gensets and their auxiliary components;
- Develop a methodology for analysis and fault diagnosis of systems and components;
- Identify and apply performance indicators and continuity in generating systems;
- Subsidize decisions based on the standards, procedures and tools with the use of expert systems;
- Develop methodology to determine the critical components of the generation system
- Build a knowledge base and prepare diagnostic and prognostic generation systems.

The methodology "Cycle of Routines", which some screens as shown in Figures 1(a) and 1(b), was developed in the Java programming language, using parts of a hybrid expert system of artificial intelligence consisting of a knowledge base, inference machine (engine) and User Interface.



(a) (b)

Figure 1. Screens of Cycle of Routines software: (a) Initial screen with activities and (b) Systematization screen.

Figure 1 (a) above shows the initial screen of functions of the Cycle of Routines software, where seek the sequence of tasks in this methodology. Figure 1 (b) shows the screen to systematize the components of a generating unit, whereby it is possible to register each of the components of a GU so that they can be part of the program's knowledge base.

The knowledge base combines the facts declarative knowledge used in databases, with procedures or standards for the development of tasks and/or activities, aimed at providing support for conclusive decisions, based on human reasoning, for the solution of problems or events in the generation system (Santos, *et. al.*, 2009).

2.1. Cycle of Routines General Characteristics

Figure 1 shows, for those involved in the processes, the general objectives and goals of the productive process or system, for each task and/or activity, where the activities, operations, resources and evaluation of the development will be defined;

The cycle should be initiated with the first four tasks in the second semester of every year, in order to serve as reference and database, to facilitate the elaboration and to be included in the following year organization's financial planning. That is an important step in the gathering of the database to be created;

2.2. Cycle of Routine Activities

According to Figure 1 (a) and Table 1 shows a summary of the Cycle of Routine tasks and activities:

Table 1. Tasks and activities of the cycle of routines.

Tasks / Activities	Description
Identification and/or Inspection	To continuously identify the process needs, deficiencies and/or events for projects in operation and new projects, as well as problems to be corrected, frequent types of failures, subsystem components with critical levels of wear, improved procedures, environmental conditions etc. In this activity it is important to know the company's internal and external drawbacks for the development of the current process.
Analysis and/or Definition of the tools	Analyzes the need to verify all the aspects involved in the solution, defining the management tools (software) to be used in each subsystem of the process.
Systemization and/or Classification	The use of management principles and artificial intelligence tolls is divided into systems and subsystems coming to the elements. Soon after, it performs the encoding operation and the classification of all the components and types of faults, aimed at their identification as maintenance items.
Parameterization and/or Standardization	The objective of this task is the analysis of the operating conditions and the achievement of operating parameters for the equipment that makes up a system through commissioning test, followed by the study of the standardization of the components and consumable items in order to reduce costs and standardize maintenance.
Planning, normalization and training	This step refers to the settings and details of the activities to be implemented in order to achieve the company's objectives and goals. Plans are drawn up for the activities, the physical and financial schedules, standards and operational procedures.
Execution and/or Optimization	These activities are aimed at processing the plan developed and studied with efficiency and effectiveness, while evaluating all canonicals which can contribute to the process evaluation or improvement.
Monitoring and/or Control	This phase aims at checking if the implementation/optimizations are being conducted efficiently and effectively in relation to what was planned, that is, if the activities being developed are enabling the objectives and targets.
Evaluation and/or Treatment	Along with the assessment of the productive process and the efficiency of the Cycle of Routines, a treatment process risk is carried out, to obtain crucial information about the potential loss of the generating units and the damages likely to occur in the generation system, enabling equipments insurance contracts.

Source: Santos, *et. al.*, 2009.

3. APPLICATION OF THE CYCLE IN THE NORTH REGION OF BRAZIL

The use of the Cycle of Routines in 15 TPPs utility in Pará started in the second half of 2002 with the participation of the maintenance team of Centrais Elétricas do Pará S. A. – CELPA. The other state TPPs are controlled by outsourced companies. The initial work was the removal of the gensets operating conditions and the gathering of the information distributed in the following technical tasks and activities:

3.1. Identification and/or Inspection

Considering that the generation of power plants in the utility, is a 24-hour public service, one of the events identified as critical, and which should be dealt with, is the TPPs outage total number.

The monitoring of energy outage began in 2003, when all kinds of systems interruptions were registered, that is all or part of the mill, those lasting more than three minutes, including the reclosers on feeders and plants, planned maintenance and weather conditions, among others. This period had the initial target of up to three outages per year at each power plant.

A requirement of the Brazilian National Agency of Electric Energy – ANEEL, demanded the creation of a system in which all the outages that occurred in state plants should be informed to the concessionaire operational department on a daily basis, informing the sector responsible for the data processing and the transfer of information to regulatory agencies. This way enabling the follow up of the causes of anomalies and the creation of the knowledge base for the

Cycle of Routines. Figure 2 shows the outage monitoring occurred in the TPPs system alone from 2003 to 2009 emphasizing the participation of the generating companies.

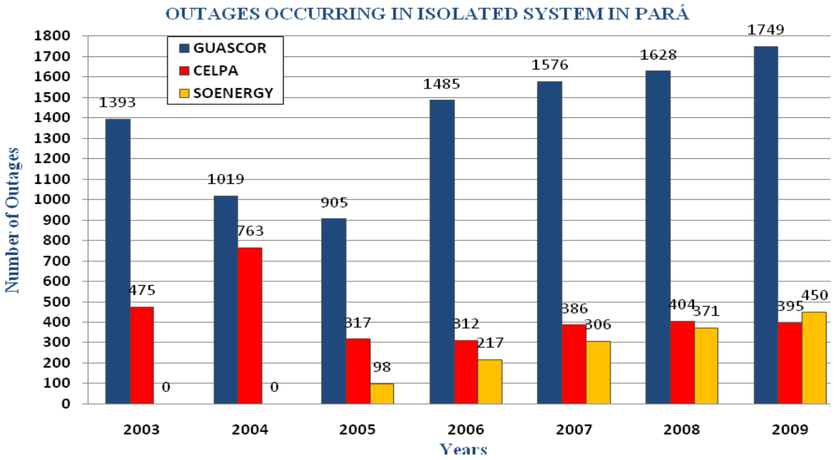


Figure 2. Outages occurred in isolated system in the State of Pará during 2003 and 2008.

Figure 2 shows that, over the years, there's a tendency to stabilize with slight increase in the number of outages occurred in power plants managed by the utility of the state, in red (CELPA), depending on the implementation of methodology in TTPs from 2003, while the subcontractors, in blue (GUASCOR) and orange (SOENERGY) for the same monitoring period, there was a strong trend of increased occurrences of outages.

3.2. Analysis and/or Definition of the Tools

The adopted management tool was the Integrated System of Maintenance – SIM, the application of maintenance administration used by the utility for the service orders control (opening and closing) and as database of maintenance items; however some adaptation was necessary and the configuration of the information was increased so that the application could be used for the electric power generation.

The goal to the CELPA deployment cycle was the reduction and control of outages occurred in the TPPs utility and, in absolute numbers, interventions were below three outages per month per plant in 2008, as dynamic system interruptions may occur during outages scheduled for maintenance, and so on.

3.3. Systemization and/or Classification

This activity was developed from the inventory information held in the utility plants do Pará, formed a large database, whose elements were coded and registered in the knowledge base of cycle routines software, including its subsystems, peripherals and accessories, being that the division had the following order: general and auxiliary systems, engine systems, generator systems, systems control panel; system of substation of power plant, systems of civil structures, security systems, external components, etc.

The codification of the subsystems elements of electric power generation, in other words, the formation of their chromosomes, genetic operators of uniform type were used, following rules shown in Figure 3: (Santos, *et. al.*, 2009)

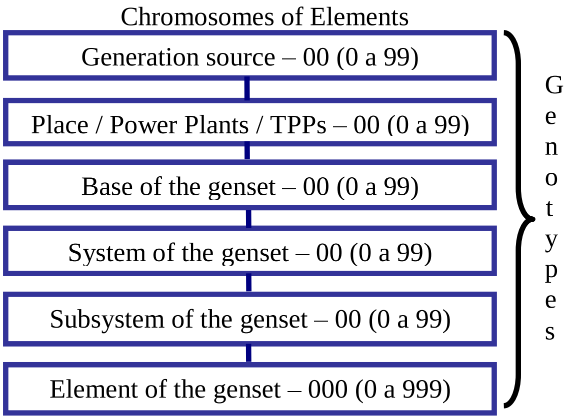


Figure 3. Formation of the chromosomes of the elements used in the Cycle of Routines.

Each element that composes the generating system received an operational genetic code, as shown in Figure 3, so that their identification in the system was possible in a faster and efficient way and without duplicities. Examples of those codes are: 01.11.02.01.03.02.100, where the type of energy generation is represented by 01, the generation place is codified with the number 11, a generating unit in the base 02, a component of the generation system codified as 01, a generation system codified as 03, a subsystem generation codified as 02 and an element of a subsystem codified as 100.

Each element of the coding system received a classification value of initial criticality C_{EQ} to facilitate its monitoring when in operation. This value was adjusted to obtain the generating sets operational history, with values ranging between 01 and 10, as shown in Table 2.

Table 2. Classification of the system critical elements.

C_{EQ}	Description
10	Very critical element, the system **stops** for a long time (more than one month) if it is not working properly and rely on scheduled or corrective maintenance to restore it;
9	Very critical element, the system **stops** for a long time (more than two weeks) if it is not working properly and rely on scheduled or corrective maintenance to restore it;
8	Very critical element, the system **stops** for a long time (more than a week) if it is not working properly and maintenance is scheduled for its restoration;
7	Very critical element, the system **stops** for a long time (more than three days) if it is not working properly and corrective maintenance is scheduled for its restoration;
6	Very critical element, the system **stops** for a mean time (more than one day) if it is not working properly but corrective maintenance is not scheduled for its restoration;
5	Critical element, the system **stops** for a mean time (more than twelve hours) if it is not working properly but corrective maintenance is not scheduled for its restoration;
4	Critical element, the system **stops** for a time average (over four hours) it is not working properly and corrective maintenance is not scheduled for its restoration;
3	Necessary, the system **stops** for a short time (more than an hour) if it is not working properly but corrective maintenance is not scheduled for its restoration;
2	Necessary, the system **does not stop**, or is operating with restrictions, for a few days until the scheduled corrective maintenance is performed and components are replaced;
1	Necessary, the system **does not stop**, or is operating with restrictions, for a few hours until it is held on scheduled or corrective maintenance while there is a shutdown for the replacement of components;

Source: Santos, *et. al.*, 2009.

Using the principles of RCM and based on all the historical causes of anomalies or outages, they were grouped into major categories and/or representative causes, such as: Fuel system; Power system; Cooling system; System air intake; Lubrication system, Ventilation air system; Starting or electric system; protection system; Speed regulation system, damage to the generator; Control system framework or electrical control panel; Transformation system (the power plant substation); Unavailability of generation; Failed operation (operations and timing); Storms / animals in the substation; Scheduled maintenance; Ignored cause; Stability failure/urban distribution network failure.

In the method Cycle of Routines all occurrences that prevent the system normal function are registered in the software knowledge base where the diagnosis of the genset operating conditions are made, including the generation unit operational time regarding maintenance which provides subsidies to the maintenance anticipation or delay.

Immediately after the anomalies have been detected and reported, maintenance requests, and later maintenance orders, are placed. However, services that can only be made after a pre-planning, to prevent the execution of corrective maintenance, are not scheduled as they may represent a high maintenance and operational cost, except in cases of emergency.

It was developed a specialist perceptron (binary classifier) the methodology for "Cycle of routines", as shown in the diagram in Figure 4 (Rosenblatt, 1958). The process begins when an anomaly that occurs in the system are automatically generated service orders - OS, which presents the information in normal operation and maintenance plan of the generating unit, followed by an analysis of the power plant. Comparisons are made with the conditions regarding testing of receipt or commissioning of existing equipment in the knowledge base of the program.

The diagnosis of the occurrence and the best suggestions to repair the anomalies are shown to the system operator, who analyzes the results and sets the actions to be taken. The choices made by the person responsible for the maintenance will be part of the program knowledge base and, therefore, will be made available for other cases (Santos, *et. al.*, 2009)

At this stage, fuzzy logic routines are used, as the fuzzyfication to determine the equipment criticality from relational base with all the elements that make up the systems and subsystems of the generating energy.

The Fuzzy inference based on the Mamdani technique, aims at the detection of the most critical components of the generation. An example of inference using the cycle has the following logic: (Haykin, 1999)

Yk = If (And (E_n = "is an element of a GU, where there have been instances of interruption caused by E_n"); Then, compare the operating conditions of the element with the I_{CO}, considering the H_X and C_{EQn}; So perform the specific maintenance procedures to repair the anomaly caused by E_n and, register the solution on the database by function f(YK));

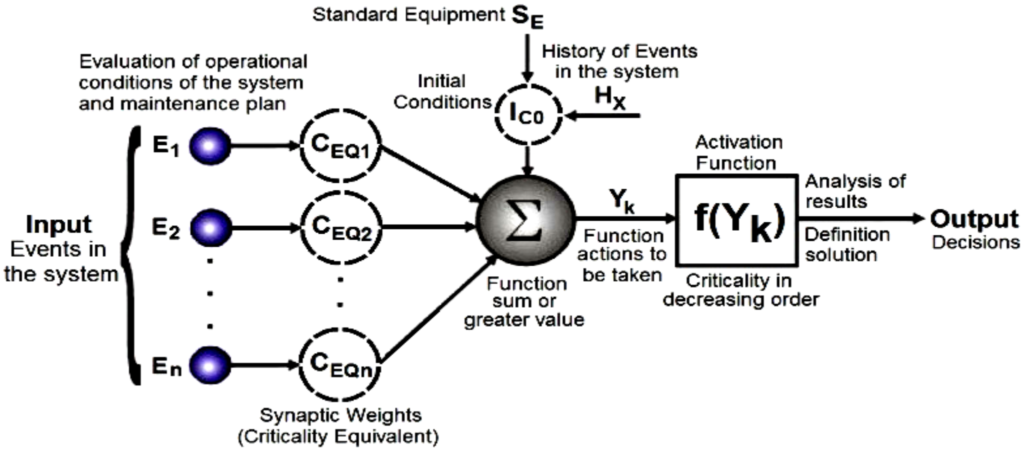


Figure 4. Scheme of the methodology developed for decision-making using artificial intelligence hybrid tools.

The result is the actions of defuzzyfication in the form of Fuzzy f(Yk), as shown in Figure 4, for the implementation of a set of maintenance actions, operational and administrative components and elements of the electric power generation in order to ensure the continuity of the electricity supply service to the local community in the shortest time possible.

Based on the Fuzzy historical events that occurred in the generating units of thermal power plants, grouped in categories and according to the "Cycle of Routines" software knowledge base, we can achieve the training of a neural network for each category of events, aiming at the prognostic of the generation system and the plans adjustment for the maintenance of the generating units.

3.4. Parameterization and/or Standardization

Due to the characteristics of the plants generating groups, their operational conditions, and the state regional distances, tests for machine reception were accomplished, where parameters were created and defined according to the operational strips of each generating unit and their frequency limits, potential factor, tension, generation current and distribution.

In this same accomplished task we can achieve the standardization of the following items:

- Means of communication and types of information and documents to be reviewed by the generation unit maintenance team;
- Gensets maintenance plans, defining the maintenance accomplishment per hour and per type of machine manufacturer and load classification;
- An electric generator maintenance plan, as well as a command and transformer board were created, with their respective inspection procedures; Consumable elements were periodically changed;
- Basic listings for revisions of generating groups;

With the increase of the useful lifecycle and the standardization of the consumable elements periodical changes, it was possible to reduce operational costs, see Table 3, achieving cost reduction with several filters, addictive for radiator and lubricating oil in comparison with the year 2008.

In Table 3 a comparison was accomplished adopting the 2008 unitary current values of each consumable element, and, an average 08:00-hour daily operation was considered for small load motors, a 12:00-hour operation for medium load and a 16:00-hour operation for great load.

Table 3. Cost reduction of the consumable elements of the thermoelectric power plants of Pará.

Elements	**2002**		**2008**		**Difference X U$ 1000**
	Unit (*)	**Annual Cost U$ X 1000**	**Unit (*)**	**Annual Cost U$ X 1000**	
Filters	7827	5,361.68	4390	1,811.99	3,549.69
Addictive for radiator (**)	1521	53.46	254	2.51	50,95
Lubricating oil (drums)	658	1,106.46	278	562.36	544.10

(*) The units refer to the numbers of filters used in the motors and the 200 liters drums of lubricating oil.
(* *) The addictive for radiator, in liters, was used in the engine cooling system in substitution to water filters, which were eliminated from the GUs;

Source: Santos, *et. al.*, 2010.

As a result, the process for the determination of parameters and standardization generated a significant reduction of maintenance cost from 2002 to 2008, according to Table 4.

Table 4. Maintenance average cost of generating units.

COST MEDIUM OF THE MAINTENANCE OF GENSETS (U$ / kWh)						
GUs	**2002**	**2003**	**2004**	**2005**	**2006**	**2007/2008**
Small	588.74	487.49	397.49	351,00	337,50	296.24
Medium	879.07	627.91	544.19	502.33	439,54	384,28

Source: Santos, *et. al.*, (2009).

The reduction was due to the standardization of the listings of materials used in the general and partial inspection and maintenance, and the use of specialized companies for the recovery of motor components in the services accomplished in the general and partial revisions of the GSs elements.

The determination of parameters and standards enabled the development of support studies, norms and procedures, aimed at plant operators and maintenance technicians, as a way of training and qualifying the technicians involved with the generation of energy.

During parameterization it was necessary to obtain the curve characteristics of the generating unit specific consumption (Lora, *et. al.*, 2004 and Conde, 2006), in order to define the generator optimum operational range. This curve was obtained by the testing and commissioning of GSs in 15 thermoelectric power plants, according to the Brazilian standards NBR 6376 (1985), NBR 8422 (1982) and NBR 5477 (1997). Figure 6 shows an example of the consumption curve obtained for a specific generating unit of the Cotijuba TPP, located near Belém, capital city of Pará.

In Figure 5, we observe that the operating range of this genset is between 60 and 70% of the nominal power installed. The analysis of the commissioning tests, together with the results of the oil analysis of the generating units, and the example in Figure 5, enabled to adjust the GUs operating ranges anticipating or delaying the maintenance of the generators.

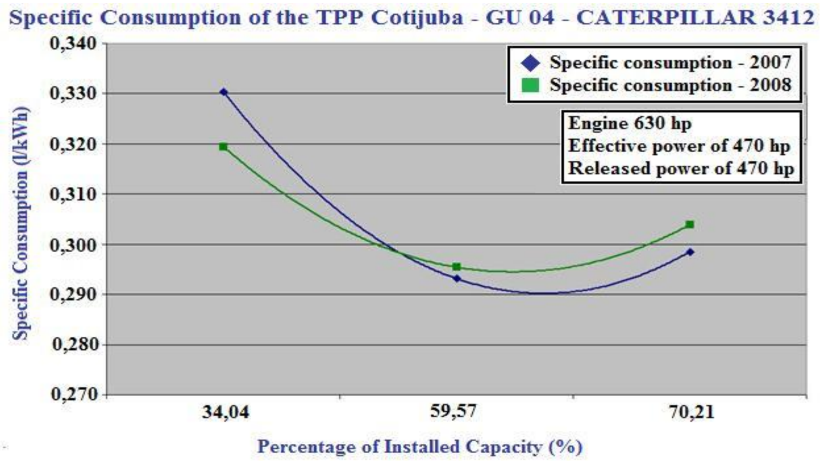


Figure 5. Curve of a specific consumption of the generating unit of the Cotijuba TPP.

In Figure 5 it is clear that there was an increase in consumption of specific generating unit UTE Cotijuba in two consecutive tests between overhauls. This variation was due to system operation, load modulation, the degradation of some components of the engine, among other factors, besides the high life of UDG. Through these factors was possible to simulate the cost benefit of reviews, reducing the costs of these operations.

3.5. Planning, normalization and training

From 2002 to 2004 trainings were provided to qualify the personnel involved with the operation of thermoelectric power plants. At the same time, some norms and procedures for the maintenance and operation of the TPPs were developed and approved by the CELPA technical management team, mainly those regarding the preservation of the environment, developed with the support of the CELPA environmental team (Santos, *et. al.*, 2009).

3.6. Execution and/or optimization

The implementation of the planning cycle occurred between the years 2004 and 2005 when it was in fact possible to complete the first phase of the method. In 2007 the activities were concentrated on the actions of the monitoring system and on the optimization of the elements of the generation system.

Despite all the efforts to reduce outages, including the use of SIM in TPPs, the great difficulty in obtaining accurate information on the causes of outages was a major problem to be solved. Lack of, or poor communication between engineers and maintenance operators was a major barrier to overcome, as in many cases, the operators had no knowledge of the causes of the deficiencies identified and depended on technical maintenance for identification. Several operational procedures were developed and implemented with a view to remediate this deficiency as part of the training offered to the power plant operators.

3.7. Monitoring and/or Control

The equipment operational criticality is intended to relate the possible deviations from the equipment operating conditions in the generator set, considering and quantifying the importance of the element in the system which it is part of. The criticality of the second term relates to the level of use of the element within the specified maintenance scheduled for the system, emphasizing the component lifecycle. The third item of criticality shows the influence of the malfunction of the element in the system, concerning the indicators of productivity in the generation system.

According to Santos, *et. al.* (2010) to determine the criticality of a component a Generation System – C_{COMP} performs the composition of this magnitude for three operating conditions: Operating the Equipment Criticality – C_{EQ}; time equivalent Criticality – $C_{EQTEMPO}$ and Criticality component in the system – C_{ES}.

The C_{EQ} is intended to relate the possible deviations from the operating condition of equipment in GUs, considering and quantifying the importance of the element to the system which he belongs. The second term of criticality, C_{QTEMPO}, relates the level of use of the element within the prescribed maintenance schedule for the system, emphasizing the life span of each element in the same and the third item, C_{ES}, seeks to reveal the influence of the malfunctioning component in the system, starting indicators of productivity and availability of the generation system. The composition of the critical components is calculated by Equation (1), and $\boldsymbol{\sigma}_S$ the standard deviation of measures:

$$C_{COMP} = C_{EQ} + C_{QTEMPO} + C_{ES} + D(\%) \pm \sigma_S, \qquad (1)$$

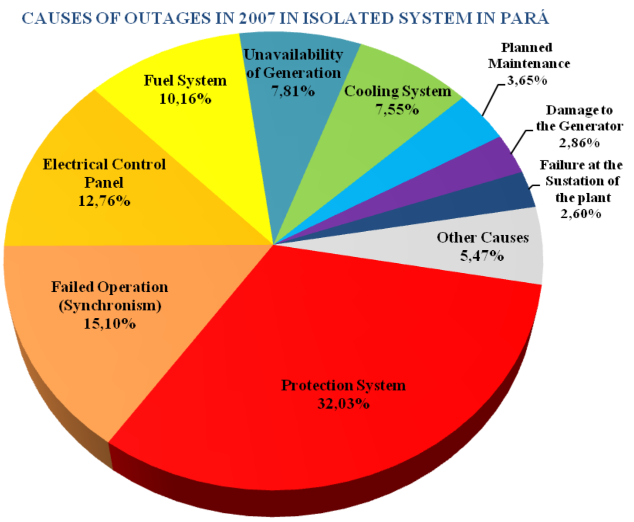
Thus, it was possible to separately evaluate the groups of power generators, determining the critical points of each one, and deciding on the actions to be taken to solve these problems.

All interruptions in the electric power supply that happened at the power plants were registered in the application “Cycle of Routines”, as well as all outages which occurred along the years 2003 and 2008, as can be seen in the graph of Figure 6, which shows outages in isolated system in 2008.

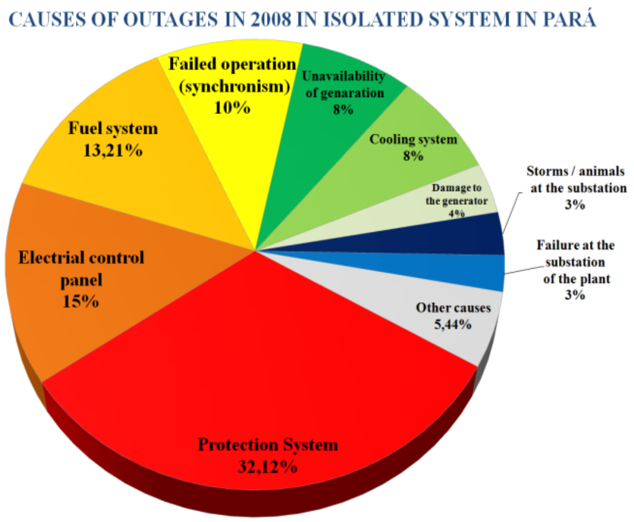
Throughout the deployment period of the method “Cycle of Routines”, the outages that occurred in the TPP were studied, therefore meetings with the engineering staff and mechanical and electrical coordinators were held in order to find a solution to the deficiencies.

The main focus of the meetings was the transfer of information from operational conditions of the generating units, with a view to adjust the maintenance plans or to schedule inspections in the gensets.

As the generation system is quite dynamic, it was observed that, despite the reduction in the number of occurrences of outages, each year new problems were in evidence, as the shows Figure 6, where it can be noted that in 2008 most outages were caused due to protection systems and failures in the command staff of the plant units.



(a)



(b)

Figure 6. Outages occurred in isolated systems of the State of Pará: (a) 2007; (b) 2008.

In 2007, Figure 6(a), the largest number of anomalies of the outages were caused due to failures in the protection system, failure in operation (synchronism), damage to components of the panels and tables of commands, system failures fuel supply engines, unavailability of generation.

In 2008, Figure 6(b), the greatest numbers of outages were due to failures in the protection system of power plant, the components of the panels and tables of commands, system failures fuel supply the engines, failures in the operation (synchronism).

Table 5 shows the identification of the most critical components of diesel power plants in the state of Pará, from 2004 to 2008, along with their genetic codes and component names, in addition to the diagnostic and prognostic problems and the suggested actions to be taken.

Table 5. Diagnoses and prognoses of the generating units of the isolated system.

	TTP	Genetic Code	Component	Diagnostic	Prognostic / Actions to be Taken
2005	Melgaço – GU 02	01.09.02.01.01.002	Radiator	Poor quality of the cooling water	Clogging of the radiator / water treatment and replacement water filter for additive radiator
2006	Bagre – GU 01	01.03.01.04.13.198	Exciter	Blown fuses static exciter control panel	Develop studies to increase the excitation current / Deployment of new static exciters in TTPs
2007	Cotijuba – GU – 04	01.07.04.08.14.259	Failure Operation	Difficulty of making the synchronism of the GUs	Conducting recycling training for staff of operators of power plants
2008	Jacareacanga – GU – 03	01.08.03.01.03.060	Solenoid Valve	Burning fuse equipment	Improper performance of the protection system / replacement of the solenoid valves by more robust and reliable in GUs

Source: Santos, *et. al.*, (2009).

Considering the many outages in the thermoelectric generation system in the period studied, it was possible to identify all the causes of anomalies, obtaining, through the Cycle of Routines, the most critical components of each TPP, this ways allowing the establishment of diagnostic and prognostic operational measures through techniques such as: genetic algorithms for the identification of genotype anomalies in the genset; Fuzzy logic - as a valuable tool for the decision making, i.e., provision of parameters to help decide when to intervene in the GUs power plants, maintenance schedule anticipation or delay, and neural networks for the simulation of the possible failures that could occur in the system, as seen in Table 5.

The results in Table 5 and the graphs in Figure 6(a) and 6(b) were obtained from a careful investigation of the real causes of the outages, which required direct communication of the monitoring team with the team's methodology of operation of each one of the utility power plants in order to avoid diversion of evaluation of the causes of outages.

It is important to emphasize that for every detected anomaly in the thermoelectric plants, investigations were carried out in order to define their criticality and hence the priority of service, this process resulted from the planning of actions to remedy them.

3.8. Evaluation and/or treatment

In 2002 the CELPA plants average availability varied from 40 to 70%. In 2008 these values ranged from 75 to 98% due to the philosophy of maintaining plants in the so-called “cold reserve”, i.e., due to the TPP installed power, more machines were necessary, in case of breakage of the main machine, therefore the energy generation would be kept until the damaged machine could be repaired. Those actions were only possible for the standardization of the average time to accomplish maintenance services and to recover the machines.

The standardization, in combination with the increase of the power plants operational data, enabled the determination of the equipments, instruments and assets for the insurance coverage.

The Cycle still offered individual diagnoses of the power plants and the generating units for the groups of interruptions of energy supply which happened in the generation system so that it was possible to intervene proactively in the generation systems and to reduce such effects. The analyses result can be seen in the graphs of Figures 2 and 6.

According to the management process of the developed method, the treatment of anomalies is complemented by the prognosis of criticality, for each of the following management decisions to be taken: removal, reduction, retention or transfer of the risk and the criticality identified. (Santos, *et. al.*, 2010)

Considering the many outages in the thermoelectric generation system in the period studied, it was possible to identify all the causes of anomalies, obtaining, through the Cycle of Routines, the most critical components of each TPP, this ways allowing the establishment of diagnostic and prognostic operational measures through techniques such

as: genetic algorithms for the identification of genotype anomalies in the genset; Fuzzy logic - as a valuable tool for the decision making, i.e., provision of parameters to help decide when to intervene in the GUs power plants, maintenance schedule anticipation or delay, and neural networks for the simulation of the possible failures that could occur in the system, as seen in Table 5.

4. CONCLUSIONS

The methodology Cycle of Routines has been applied in TPPs that utilize biodiesel as fuel in the state of Pará, where the objectives and goals have been satisfactorily and efficiently achieved. The methodology applied enabled the monitoring of the performance parameters of the power generation, the identification of the causes of anomalies, the reduction of operational costs by 20 % (according to Tables 3 and 4) and the decrease in the number of outages by 15 % (as shown in Figure 2) per year in the electrical generation system of the state.

However, the need of a management change of the activities is intrinsic, that is, according to the six sigma method, it is necessary to reformulate the goals in order to keep up with the achieved results and to improve them, so that the electric power generation in the state of Pará is not interrupted, in other words, it is necessary to “rotate the cycle”.

It is stood out that the developed method was aimed at providing tools for the management decision making, because with the Cycle of Routines it was possible to evaluate and to optimize the CELPA generation of energy starting from the diagnoses of the system most critical elements, as seen in Table 5.

Through the realization of inventories and the development of procedures and standards beyond the analysis of specific consumption curves of the generating units, Figure 5, along with formation of the function of historical occurrence [f (Yk)], the classification of instances outages in categories of systems, Figures 6(a) and 6(b) and with the determination of critical points of each power plant, Table 5, it was possible to develop and simulate a range of diagnostic and prognostic for all possible anomalies that come to occur in power plants in order to solve them proactively.

The introduction of a system of hybrid artificial intelligence in the Cycle of Routines application method empowered the tool for the development of the tasks, enabling the decision making for the operation and maintenance of genset, making it more accurate, efficient and reducing the overall cost.

The next steps of this work is the implementation of the methodology Cycle of Routines in other energy generation sources, such as thermoelectric steam power plants, gas or combined cycle, in combination with the Fuzzy function for the report of occurrences, to perform the training of neural networks, to simulate the faults in the generation systems, enabling the knowledge of technical parameters to carry out preventive maintenance on the various elements of the system.

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