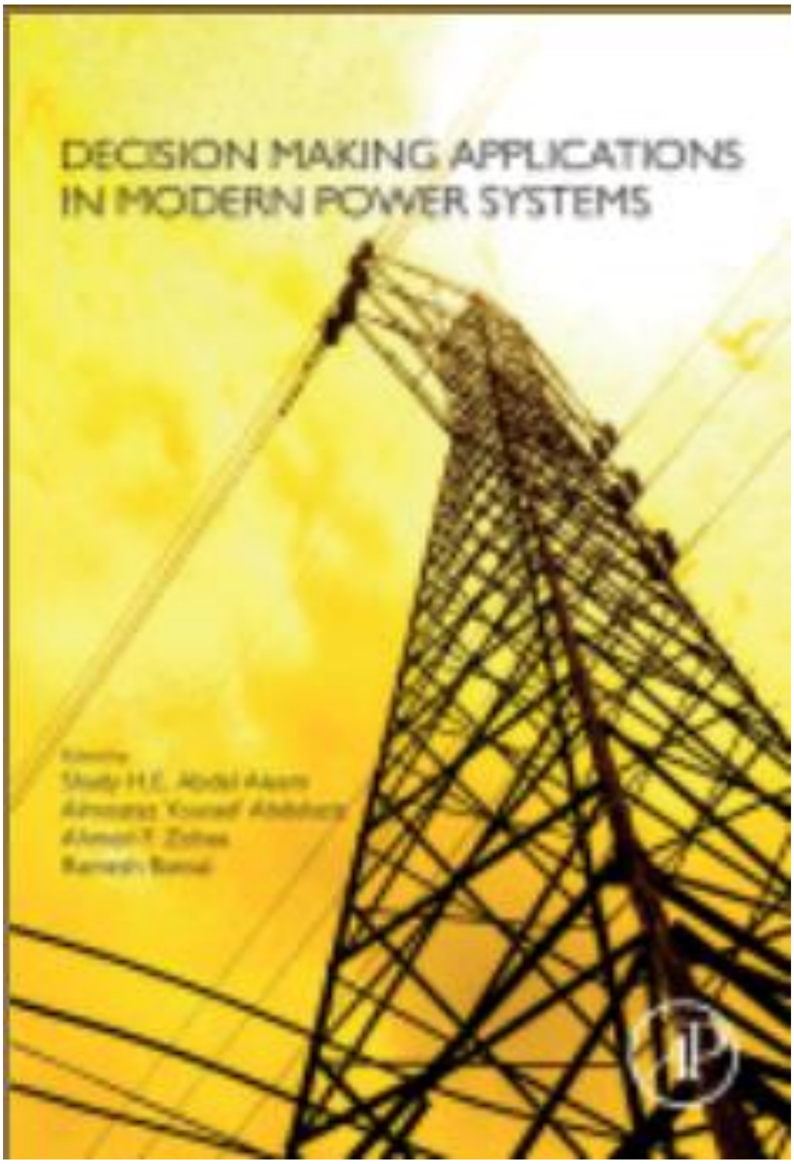

DECISION MAKING APPLICATIONS
IN MODERN POWER SYSTEMS

Chapter 13

# Maintenance management with application of computational intelligence generating a decision support system for the load dispatch in power plants

**Milton Fonseca Júnior[1], Jandecy Cabral Leite[2], Tirso Lorenzo Reyes Carvajal[2], Manoel Henrique Reis Nascimento[2], Jorge de Almeida Brito Júnior[2] and Carlos Alberto Oliveira Freitas[2]**

*[1]Mauá Generation Department, Generation Eletrobras Amazonas GT Manaus, Amazonas, Brazil, [2]Research Department, Institute of Technology and Education Galileo of Amazon - ITEGAM, Manaus, AM, Brazil*

## 13.1 Introduction

Most of the Brazilian thermoelectric parks remain completely closed for months whenever the hydrological situation is favorable. As in recent time, average hydroelectric generation has been 90% of its generation capacity for the system [1], idleness has prevailed in the thermal park as the plants can only be activated when the hydroelectric reservoirs go below 50% of their maximum volume. The contrasting fact with respect to those of other countries is striking. In most of the countries, combined-cycle coal or gas-fired power plants typically do not experience long-term idleness; instead, they operate at the base level of the system, being dispatched almost continuously. On the other hand, thermals that are used in other electrical systems for the generation of tip, with daily activation or at least in good part of the working days, such as open or thermal cycle gas engines with motors, in Brazil can remain idle for long, because they are not necessary in normal or favorable hydrologic situations.

It is necessary to ensure the supply of electricity to consumers within standards of continuity and reliability. Although the lack of investments in the industry causes the loss of product quality, the excessive investment makes the product very costly, which discourages its consumption [2,3].

**Decision Making Applications in Modern Power Systems. DOI: https://doi.org/10.1016/B978-0-12-816445-7.00013-X**

One of the most important aspects to sustain the quality and reliability of the electric power supply is to be able to perform an optimal load dispatch [2,4]. The great majority of the works presented in the literature develop the load dispatch of the thermal plants, considering that all the engines of the plant have a favorable technical state, but this is not always the case, so in this chapter, a method is presented for the predispatch of load that takes into account the technical state of the plant's motors through diagnosis and making use of fuzzy logic.

The development of a computational tool to support the decision of cargo dispatch according to the operating conditions of the engines and generators of thermal plants is proposed, which are classified in relation to the probabilities of failure by a fuzzy system developed in this chapter, from indicators obtained from lubricant oil analysis, vibration analysis, and thermography of power generation equipment. The study is based on the principle of operation and operational conditions of the equipment to be dispatched for the generation in a thermal plant, besides its particularities as specific consumption and the quality of pollutants sent by each equipment.

## 13.2 Maintenance systems and their application in thermoelectric plants

The ability of a generation source to meet an energy demand can be influenced by unexpected units of power generating units. The tests were even more advanced to repair preventive maintenance measures but were not revised in the 1990s with maintenance and maintenance work on engines and generators.

In recent times, condition-based maintenance (CBM) has been introduced in industrial systems to preventively maintain the right equipment at the right time relative to its current "operating condition." The good state of operation of a generator can be represented mainly by conventional indicators, such as oil temperature, harmonic data, and vibration. Monitoring the motors/generators and their diagnosis is also important so that the dispatch of cargo does not have unexpected interruptions.

Most energy generation unit–scheduling packages are considered preventive maintenance schedules for units over an operational planning period of 1 or 2 years in order to defray the operating total, while meeting the requirements—system power and maintenance restrictions. This process consists of verifying the generating units that must be stopped from production. The generating units should be regularly examined for safety. It is important for a failure in a power generating unit that can be used in the machines. Therefore the fixation and the key point are used in the proposed methodology. The issue is addressed as an optimization problem. The model is developed by determining the objective function, which is a net power reserve of the unit [5].

They point out that CBM is a strategy that collects and evaluates information in real time and recommends maintenance decisions based on the current condition of the system. Since the last decade research on CBM has been growing rapidly due to the considerable development of computer-enabled monitoring technologies. Research studies have proven that CBM, if properly planned, can be effective in improving the reliability of equipment at reduced costs [6].

It presents an algorithm for deciding preferences in maintenance activities for power supply sections of distribution systems. A component measure of importance, known as a diagnostic importance factor (DIF), was used for this purpose. A methodology was developed to calculate a weighted cumulative DIF for each feed section, which represents a quantitatively relative significance for the prioritization of maintenance activities. The developed methodology includes the distributed generation effect and the loads. It was implemented in two distribution systems, so that, at the end, sorted lists of feed sections for maintenance activities are obtained [7].

CBM is an increasingly applicable policy in the competitive market that acts as a means of improving the reliability and efficiency of equipment. Not only does maintenance have a close relationship with security, but its costs also make the issue even more attractive to researchers [8].

Proper maintenance can increase the company's productivity and increase its value in the market. The main study provided a robust model that can strategically evaluate important available technologies and may exclude outdated and/or inappropriate technologies. There are many researches in this field in which the number of models has been proposed, such as the maintenance management system, maintenance performance measurement, and maintenance performance indicators, but the details of the effectiveness of the predictive maintenance indicator, specifically based on maintenance and conditions with maintenance and management requirements using the analytical hierarchy process, are hardly available in the literature [9].

Basically, the process consists of monitoring parameters that characterize the state of operation of the equipment. The methods employed involve techniques and procedures for measuring, monitoring, and analyzing these parameters. It can be related as oil analysis, ferrography, thermography, and vibration analysis.

Motor operation data in conjunction with vibration, oil, and temperature analysis data are collected periodically at the plant and are used in an integrated way to feed a fuzzy rule−based system, which returns the predispatch scheduling of the plant for the period of interest, taking into account the state of operation of the machines, Fig. 13.1.

Thermal power plants consist of a set of mechanical and electrical systems that require constant monitoring of energy production. The data obtained through the monitoring actions are necessary in the operation, maintenance, and evaluation of the performance of the plants. For this purpose, it is often called distributed control systems (DCS).

The obsolescence of this equipment (DCS) increases the risks of unavailability of the generating units, mainly in thermoelectric plants, with a high degree of mechanical wear, due to the high temperatures and the chemical agents used for the production of electric energy [10].

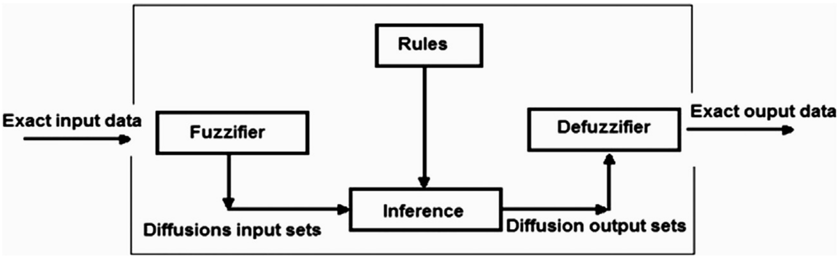
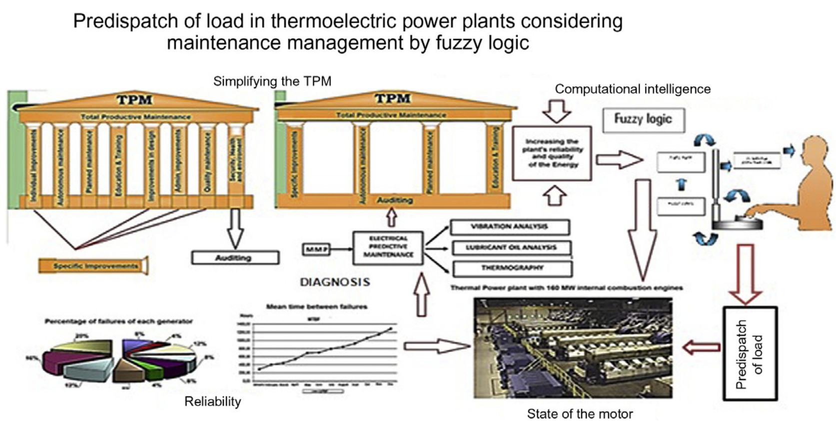



**FIGURE 13.1** System based on fuzzy logic.

MTBF (mean time between failures) or mean period between failures is a value assigned to a particular device or a device to describe its reliability. This assigned value indicates when a device failure may occur. The higher this index, the greater the reliability of the equipment, and, consequently, the maintenance will be evaluated in efficiency issues.

The average mean time for repair (MTTR) is a measure on the basis of repairable item maintenance. It represents that the average time required to repair a component failure or mathematically expressed equipment is the corrective maintenance.

Oil analysis: The initial purpose of oil analysis for a lubricated assembly or a hydraulic system is to economize by optimizing the intervals between the exchanges. As the analyses carried out resulted in indicators that report on the wear of the lubricated components, the second objective of this process became the defect control for predictive maintenance [11].




Methodology.

- In the upper left, you can see the simplification of the eight pillars of the total productive maintenance (TPM), for four pillars.
- The left-center part shows the diagnostic activities that allow one to know the technical state of the motors, to know whether or not they can be used in the predispatch of load.

- In the lower left, we show the reliability analyses, which together with the diagnosis allow us to know when it is possible for each motor to fail to consider it in the predispatch of load.
- The right part shows the application of the fuzzy logic, to perform the predispatch of load, according to the fuzzy rules that meet the technical state of the engines.

## 13.3 Fragments used for implantation end methodology TPM program

This study presents a new solution proposal, which includes the predispatch of load focused on the operational conditions of the machines using computational intelligence, specifically fuzzy logic. Such an implementation is characterized by incorporating some innovations, such as good maintenance management through TPM program for decision-making, considering performance indicators of the generating units with respect to vibration, lubricating oil, temperature, being it possible to say if the generating unit will operate and maintain reliability or will get into maintenance due to poorly diagnosed performance.

1. *Pilar of specific improvements* (*Recommended group*: Coordinators of ME, MA (Plant Managers), MP and SMA):
   *Purpose*: To maximize the overall efficiency of the equipment and the operation through the analysis and elimination of operational losses (Table 13.1).
2. *Automatic maintenance pillar* (*Recommended group*: Managers, Supervisors and Operators of each Plant):
   *Objective*: To enable operators to keep their workplaces clean, organized, inspecting their equipment, following operating procedures, lubricating, identifying abnormalities, labeling and attempting to eliminate hard-to-reach places and sources of dirt (Table 13.2).
3. *Planned maintenance pillar* (*Recommended group*: PM Coordinator, Service Managers and Supervisors and each Plant):
   *Objective*: To create a maintenance management corporate model for all engines and auxiliary equipment of the plants and external clients to optimize interventions and reduce maintenance costs, ensuring the performance of auxiliary engines and equipment (Table 13.3).
4. *Pillar of education and training* (*Recommended group*: This pillar is corporate and only depends on HR):
   *Objective*: To support the other pillars, analyzing the qualification of participants and the need for training. Responsible for communication, TPM disclosure, event planning, compliance with the Basic Program Guidelines to facilitate documentation, reduction of dissemination costs and support materials (Table 13.4).

**TABLE 13.1 Pillar of specific improvements.**

| **Pillar of specific improvements** | | **Evaluation/progress/ criteria** |
|---|---|---|
| **Evaluation/progress/ criteria** | **Background/objective** | **Expected condition** |
| 1. Elaborate complete and detailed flow of the operation, identifying the various auxiliary engines and equipment, their respective priorities and main risks. Note the current conditions so that you can compare after the improvements implemented | To increase the knowledge of the whole operation and to standardize the knowledge of the participants of the working group, using the tools of quality | Working group formed, operational flow completed in a clear and didactic way, equipment, priorities and main risks identified and being known by all participants |
| 2. Identify the generation capacities in megawatt (MW) of each engine/ plant—standard and real—and the current losses of the operation, quantifying through the Pareto chart | Identify the distortions between the actual and expected (standard or standard) of each engine/ plant. Identify fuel and lubricant/engine/plant consumptions, knowing the performance of each one to be able to act on improvements | Motors, auxiliary equipment, and operations identified with their nominal and actual capacities<br>Criterion to analyze and identify the main losses of the operation, stratify and classify graphically in A, B, and C (Pareto) |
| 3. Investigate losses in detail according to the priority grades I, II, III of the chart, presenting alternatives for reducing or eliminating current losses found for later comparison | Allow to identify the fundamental causes of each selected loss, the actual operating conditions of each motor/auxiliary equipment (clearances, paint, leaks, instrumentation, working environment conditions, qualification of operators, necessary and available tools, etc.) | Use of the Analysis and Problem Solving Method (APSM) tools to analyze and solve identified losses. PDCA, fishbone, 5W2H<br>Methodology being used to investigate and eliminate losses |
| 4. Prepare detailed action plan for the chosen losses and develop a schedule of activities, following the APSM methodology | Organize the various activities necessary to eliminate identified losses, in order of priority (from highest to lowest) and investment (from lowest to highest) | Plan of Action prepared by the working group with actions, responsible, deadlines and progress of the activities chosen in the item above, through the APSM tools<br>Put the action plan into practice and compare the results before and after |

(*Continued*)

**TABLE 13.1 (Continued)**

| Pillar of specific improvements | | Evaluation/progress/ criteria |
|---|---|---|
| **Evaluation/progress/ criteria** | **Background/objective** | **Expected condition** |
| 5. Standardize operational procedures, ensuring that engines and auxiliary equipment are operated within the required conditions of pressure, temperature, speed, rpm, etc. | After achieving the expected results, standardize the procedures that should be followed by all operators | Interim operational standard completed and being used by the operators in each engine and auxiliary equipment |
| 6. Analyze the existing operational reports and make the necessary modifications to improve the quality of the annotated information, including maintenance stops by motor or auxiliary equipment, lack of spare parts, labor problems, transportation, etc. | Improving the quality of information to assist in the investigation of losses and their eliminations | Performance of the operation/motor and auxiliary equipment being evaluated by comparing the indicators and objectives defined for each engine/plant. Information of the operational reports being provided with quality and accompanied by the managers, supervisors, and operators. No data distortion |

Members of the audit pillar checklist should meet monthly to discuss the MTBF goals and the monthly MTTR and other activities corresponding to the Maintenance Management Program (Table 13.5).

## 13.4 Predictive maintenance using computational (fuzzy logic) decision support tool in preload dispatch

An application of fuzzy logic is justified by the ability to anticipate the possibilities of making the predispatch time of the load on the operational tasks of the equipment.

This study deals with the application of fuzzy logic to load dispatch, but with a particularity that is to perform said predispatch of load taking into account the technical state of the engines, evaluated by different variables related to maintenance. In the first part the development of the fuzzy rules and of the whole procedure of inference is exposed, and in the second part, all the tests to evaluate the maintenance and the technical state of the motors.

**TABLE 13.2 Automatic maintenance pillar.**

| **Automatic maintenance pillar** | | **Valuation/progress/ criteria** |
|---|---|---|
| **Evaluation/progress/ criteria** | **Background/objective** | **Expected condition** |
| 1. Determine the procedure and how to identify abnormalities through labels. Determine labeling procedures, label types, and colors<br>2. Train participants to identify abnormalities of motors, auxiliary equipment, and work area through labeling | Eliminate abnormalities of motors, auxiliary equipment, installations, workplace, accumulated dirt, eliminate unused materials in the operation, visually identify the abnormal conditions that need to be repaired, maintain the ideal working conditions that meet industrial safety | At initial cleaning, operators and personnel involved must be trained to identify abnormalities in motors, auxiliary equipment, facilities, and workplaces through *stickers*<br>Areas, engines, auxiliary equipment, and facilities must be clean and maintained in this condition, no longer tolerating any signs of clutter and dirty locations. Use the 5 S's<br>Locations that are not meeting this requirement should at least be flagged and their future repair be included in a timely, responsible action plan |
| 3. Perform initial cleaning on all motors, auxiliary equipment and operating areas, determining ideal working conditions (no leakage, good flooring, motors, auxiliary equipment, and facilities, painted and corrosion-free, with necessary signaling, conditions security, etc.) | In this initial cleaning, the conditions of motors, auxiliary equipment, and installations such as loose bolts, lack of fixings and protections, damaged parts and temporary repairs, lack of signaling, etc., identified each with a label and providing the necessary repairs must be observed. The label must only be removed after approval of the service performed | |
| 4. Prepare planning/ schedule to carry out the necessary activities of removal of the labels placed in places that presented abnormalities | Monitor the activities performed and measure the results after the improvements implemented | After label placement, a control should be created indicating the type of problem, the number of labels placed and removed, and the areas involved in the abnormalities, such as maintenance, operation, safety, and environment. Identification, simple and objective control |

(*Continued*)

**TABLE 13.2 (Continued)**

| Automatic maintenance pillar | | Valuation/progress/ criteria |
|---|---|---|
| **Evaluation/progress/ criteria** | **Background/objective** | **Expected condition** |
| 5. Establish the basic conditions of engines, auxiliary equipment and facilities, workplaces, floors, walls, lighting, painting, signaling, temperatures, etc. | Ensure operation within the ideal standards required | Ideal conditions for motors, auxiliary equipment, signed installations and work areas, with industrial safety colors, nameplates, lighting, and cleaning |

**TABLE 13.3 Planned maintenance pillar.**

| Planned maintenance pillar | | Evaluation/progress |
|---|---|---|
| **Evaluation/progress/criteria** | **Background/ objective** | **Expected condition** |
| 1. Elaborate and approve methodology to prioritize engines, auxiliary equipment and facilities in A, B, and C and disclose to all Operation and maintenance management program (OMMP) coordinators. Determine form of identification and approve with the steering committee | Standardize how to prioritize engines, auxiliary equipment and facilities as the company needs, with a focus on *business* | Complete prioritization worksheet containing pertinent questions from the areas involved in the operation (operation, maintenance, engineering, safety, and environment) |
| 2. Determine how and when the meeting involving operation, engineering, maintenance, safety, and environment will be made to define all the engines, auxiliary equipment, and facilities of each plant in A, B, or C | Identify the company's *business* priorities to facilitate the deployment of a maintenance management model | Meeting to evaluate and classify in A, B, and C all engines, auxiliary equipment, and facilities of the company, marked or performed with the areas involved |

(*Continued*)

**TABLE 13.3 (Continued)**

| Planned maintenance pillar | | Evaluation/progress |
|---|---|---|
| **Evaluation/progress/criteria** | **Background/ objective** | **Expected condition** |
| 3. After completion, visually list and identify priorities A, B, or C to facilitate supervision | Facilitate service and decision in the most appropriate action to be taken, according to priority | All motors, auxiliary equipment, and facilities, classified in A, B, and C with the visual identification labels, according to the model approved and adopted by the company |
| 4. Identify the current state of each engine, auxiliary equipment, and installation, inspect/review and make necessary repairs to maintain in perfect operational conditions | Rescue the ideal operating conditions of engines, auxiliary equipment, and facilities, improving availability, reliability, and maintenance | Inspection/revision planning in engines, equipment, and facilities A to redeem desired conditions<br>Action plan defined with: activities, materials, deadlines, time provided in each repair activity and maintenance team |
| 5. Elaborate the most indicated maintenance procedures for each engine, auxiliary equipment, and facilities, as recommended in the master plan<br>Consider those in the technical manuals, MaMa2i and create those that do not exist and are necessary | Define a maintenance philosophy to be used in equipment A, B, and C according to priority | Equipment A, B, and C classified and with the type and recommended maintenance plan completed |
| 6. Start the required activities for each engine, auxiliary equipment, and installation A. Follow the MaMa2i plan and add nonexisting services to the system | Organize maintenance and update the data of each engine, auxiliary equipment, and installation A, creating history, technical inspection standards and maintenance procedures<br>Follow template created by engineers for reference | Planning and schedule of activities for engines, auxiliary equipment, and facilities A completed and started |

**TABLE 13.4 Pillar of maintenance education and training.**

| Pillar of maintenance education and training | | Evaluation/progress |
|---|---|---|
| **Evaluation/progress/criteria** | **Background/ objective** | **Expected condition** |
| 1. List all employees who have already been trained and those who require basic Operation and maintenance management program (OMMP) training to participate in the work groups | Level the knowledge of all participants before starting to develop the activities in the working groups | All employees participating in the OMMP program identified to receive the basic training provided by the Pillar Coordinators |
| 2. Elaborate and make available in the network a basic training to minister to all the employees and in the integration of new ones | Standardize the material and information passed to employees | Teaching material for the basic training, completed, approved by the steering committee and made available to the Pillar Coordinators |
| 3. Determine the dates of the training of each pillar and the person in charge of ministering | Organize a schedule of activities to monitor and audit the development of the TPM | Planning/schedule of training to be performed, indicating employees, dates and Instructors<br>TPM training for integration of new employees, completed to be incorporated by HR |
| 4. After the training, disseminate the number of participants to serve as an evaluation indicator of the pillar in the TPM program | To measure the degree of PMS development and to present the technical state (TE) pillar indicators | Constant and updated dissemination of the number of employees trained and hours of training performed |
| 5. Make competency map of all participants in the working groups, to identify the qualification, knowledge and needs | Identify the need for training, planning and implementation in order to allow the activities of the other OMMP pillars to proceed | Worksheet of skills and qualification of the maintainers and operators completed, indicating the basic and specific training required |

(*Continued*)

**TABLE 13.4 (Continued)**

| Pillar of maintenance education and training | | Evaluation/progress |
|---|---|---|
| **Evaluation/progress/criteria** | **Background/ objective** | **Expected condition** |
| 6. Elaborate internal/external training plan, one-point training, APSM, and lectures to adapt the knowledge need of each work group participant | Level the knowledge of the working group participants so they can take on other activities without any problem, according to the steps of the ME, autonomous maintenance (AM), planned maintenance (PM), and audit maintenance system (AMS) pillars | Planning to carry out the training identified in the previous item, including lectures, one-point training, APSM, etc. |

**TABLE 13.5 Checklist pillar auditoria.**

| Activities name | Responsibility | Check list |
|---|---|---|
| Check cleaning of areas | Plant manager | Check leaks, state of conservation, paint, and signage |
| Check the binder where the "cleaning pattern" of the area is located | Supervisors | Check if the cleaning pattern plug is placed in an easy to read location |
| Check if the tags are in control | Plant manager | Check in the label control software if there is any movement of placement of new labels |
| Check action plan to remove labels | Plant manager and supervisors | Check in the label control software if there is an action plan for removing the labels |
| Check signage of plants | Plant manager and supervisors | Check standardization of signaling |
| Check Maintenance Management Program (MMP) frame of the plant | Engineering | Check if the information is up to date |

This tool served as a basis for the resolution of the real problem of preshipment of cargo to satisfy the rationalized methods of just in time of the thermal plant on the operational conditions of the equipment.

A system based on fuzzy logic, as shown in Fig. 13.1, can have its action schematized by the following constituent elements: fuzzifier; rules, or knowledge base; inference, or logical decision-making, and defuzzifier [12].

In the first part the development of the fuzzy rules and of the whole procedure of inference is exposed and in the second part, all the tests to evaluate the maintenance and the technical state of the motors. This tool served as the basis for the resolution of the real problem of preshipment of cargo to satisfy the rationalized methods of just in time of the thermal plant on the operational conditions of the equipment [13,14].

The interfuzz aims to model the mode of reasoning, trying to imitate the ability to make decisions in an environment of uncertainty and imprecision. In this way, fuzzy logic is an intelligent technology, which provides a mechanism to manipulate imprecise information—concepts of small, high, good, very hot, cold—and that allows one to infer an approximate answer to a question based on an inexact, incomplete, or not fully reliable knowledge.

Development of a computational tool to support the cargo dispatch according to the location of motors and generators for thermal energy analyzes the main thermoelectric generation variables for the entire predictive maintenance process.

All variables are inserted considering the intervals determined in the rules of inference as shown below.

The computational interface was useful for the search of some preselected characteristics to enable its implementation. Tables 13.6–13.12 show such characteristics and the respective purposes.

In this context, the following groups of information and data are abstracted: the input values, called crisp, the linguistic variables, and the fuzzy variables. The fuzzy logic is justified in the solution of this case study in

**TABLE 13.6** Manufacturer vibration levels.

| Class | 1–[N] Normal | 2–[P] Permissible | 3–[A] Alert | 4–[C] Critical (mm/s) |
|---|---|---|---|---|
| (Class I) | (0.18–0.71) | (0.71–1.80) | (1.80–4.50) | (Above 4.50) |
| (Class II) | (0.18–1.10) | (1.10–2.80) | (2.80–7.10) | (Above 7.10) |
| (Class III) | (0.18–1.80) | (1.80–4.50) | (4.50–11.2) | (Above 11.2) |
| (Class IV) | (0.18–2.80) | (2.80–7.10) | (7.10–18.0) | (Above 18.0) |
| | A | B | C | D |

**TABLE 13.7 Vibration severity rating relevance function.**

| Zone | Qualification | Operation of machines |
|---|---|---|
| Zone *A* | [N] Normal *0.18–2.80 mm/s* | Commissioned machines should generally operate in this area |
| Zone *B* | [P] Permissible *2.80–7.10 mm/s* | It is acceptable for unrestricted operation for long periods |
| Zone *C* | [A] Alert *7.10–18.0 mm/s* | Unsatisfactory for continuous operations for long periods |
| Zone *D* | [C] Critical *above 18.0 mm/s* | It is sufficient to cause damage to the machine at any time |

**TABLE 13.8 Lubricating oil.**

| Class | 1—[N] Normal | 2—[A] Alert | 3—[C] Critical |
|---|---|---|---|
| (Water% volume) | (% ≤ 0.2) | (0.3) | (Above 03) |
| (Micron iron content) | (% ≤ 49) | (50) | (Above 51) |
| (Micron copper content) | (% ≤ 1) | (20) | (Above 21) |
| | A | B | C |

function of the input variables with better representation in fuzzy sets. The variables due to the dimension of the universe of study were divided into 04 (three), 03 (two) inputs, and 01 (one) output, all independent of each other.

- *The input variable "vibration analysis"*

  For the determination of each variable, it was convenient to divide them into strips to approximate the actual situation to be checked. The calculation of these ranges on a scale according to Tables 13.6–13.12 is shown next.

  As the first level of variation "vibration level," let us consider that better variable levels were subdivided into four variables, normal, permissive, alert, and critical, each corresponding to the classification of vibration, velocity, and displacement levels measured in the equipment.
- *The input variable lubricating oil*

  The "level of analysis of the lubricating oil" can be presented, for example, with the water content in the oil, solid, and nonlubricated particle content (iron and obre), the energy sources of the dispatch of load for generation of energy. The levels of analysis of the command type were subdivided into three variables, correspondence and information quality [9].

**TABLE 13.9 Function of pertinence of the severity according to the oil.**

| Zone | Qualification | Operation of machines |
|---|---|---|
| *A* | [N] Normal | Commissioned machines should generally operate in this area |
| Water% volume | % ≤ 0.2 | |
| Micron iron content | % ≤ 49 | |
| Micron copper content | % ≤ 19 | |
| *B* | [A] Alert | Unsatisfactory for continuous operations for long periods |
| Water% volume | 0.3 | |
| Micron iron content | 50 | |
| Micron copper content | 20 | |
| *C* | [C] Critical | It is sufficient to cause damage to the machine at any time |
| Water% volume | Above 0.3 | |
| Micron iron content | Above 51 | |
| Micron copper content | Above 21 | |

**TABLE 13.10 thermography to determine hot spots.**

| (Zone) | (Thermography) | |
|---|---|---|
| *(A)* | *([N] Normal less or equal 94.0 F)* | |
| *B* | *[P] Permissible* | |
| (B/C) | (94.0 F) | (164.2 F) |
| *C* | *[A] Alert* | |
| (C/D) | (164.2 F) | (199.3 F) |
| *(D)* | *[C] Critical above 199.3 F* | |

**TABLE 13.11 Function of pertinence of the classification of thermography.**

| Zone | Qualification | Operation of machines |
|---|---|---|
| Zone *A* | [N] Normal ($T \leq 34.5°F$) | Commissioned machines should generally operate in this area |
| Zone *B* | [P] Permissíble ($34.5°F < T \leq 73.5°F$) | It is acceptable for unrestricted operation for long periods |
| Zone *C* | [A] Alert ($73.5°F < T \leq 93°F$) | Unsatisfactory for continuous operations for long periods |
| Zone *D* | [C] Crítical ($T > 93°F$) | It is sufficient to cause damage to the machine at any time |

**TABLE 13.12 Variable "engine technical status" (ETS).**

| ETS for operating conditions | | Operation of machines |
|---|---|---|
| Normal | 76 at 100% | Commissioned machines should generally operate in this area |
| Permissible | 51 at 75% | It is acceptable for unrestricted operation for long periods. |
| Alert | 26 at 50% | Unsatisfactory for continuous operations for long periods |
| Critical | 0 at 25% | It is sufficient to cause damage to the machine at any time |

- *The input variable thermography analysis level*
  Thermographic analysis is a third input variable, which can be used as a load dispatch tool for power generation. The levels of analysis thermographic were just subdivided into four variables, each corresponding to the dynamic memory, the use of images thermal plants in the alert in the reason. Materials and methods: Infrared radiation is a base of studies on thermal images, which has a function of capturing this radiation, interpreting, and generating a quantitative image of the body temperature studied [15].
- *Output variable "Technical condition of the motor"*

The "estimated technical state of the engine" is the output variable of the system, in relation to vibration (oil, water, iron, and copper). Table 13.12

describes the operating state of the generating units. The variable under study, as well as the variable "Level," was transferred to a percentage scale of 100, where "EXCELLENT" corresponds to the range of maximum values and the variable "BAD" corresponds to the range of minimum values up to zero. This value gives a greater range of possibilities, making the case study more precise. Thus we can deduce that the equation that defines the estimation is. These variables are used for decision-making involving the predispatch of the unit generators, as shown in Table 13.6.

## 13.5 Fuzzy simulation

The fuzzy simulation containing the system variables was performed using the MATLAB version 8.0 tool, and the fuzzy model applied in this simulation was Mamdani. This model is characterized by adopting the semantic rules used for the processing of inferences and is commonly referred to as maximum–minimum inference. Such an inference model applies well to this type of problem since it uses union and intersection operations between sets. The implementation is done by the Mamdani model applied to this case study. All variables are entered considering the intervals determined in the rules of inference. Fig. 13.2 shows the variables "vibration," "water," "thermography," "iron," "copper."

All variables are entered considering the intervals determined in the rules of inference. Figs. 13.3–13.6 show the variables "vibration," "water," "thermography," "iron," and "copper."

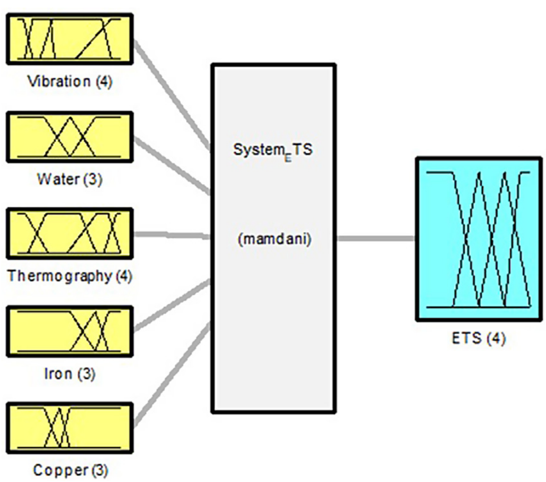



**FIGURE 13.2** Mamdani's model.

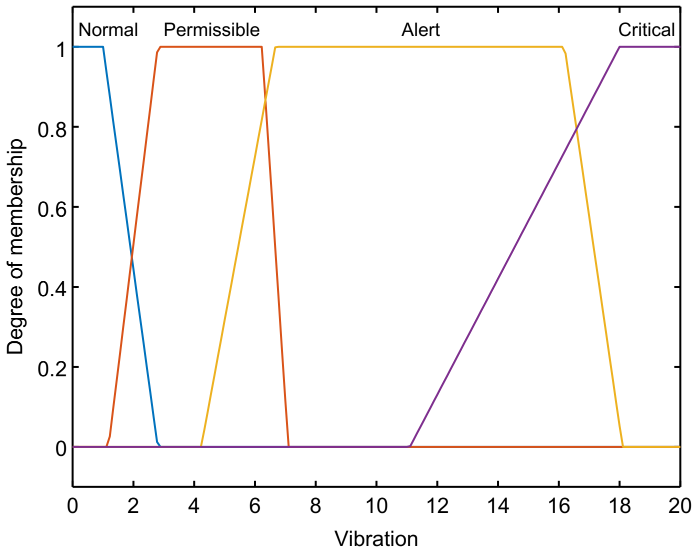



**FIGURE 13.3** Vibration level.

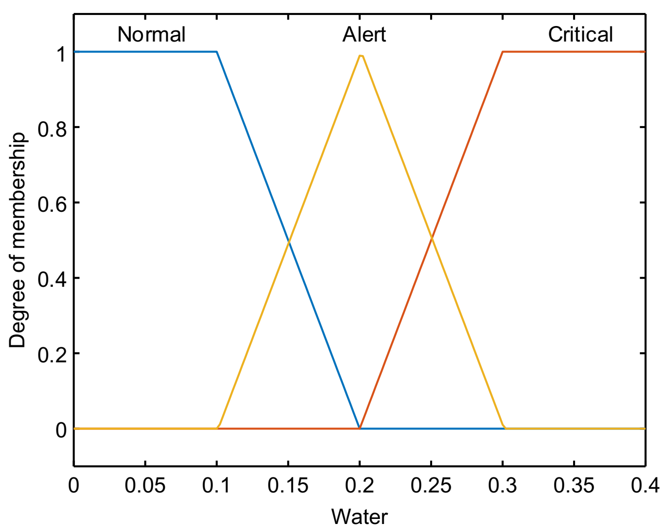



**FIGURE 13.4** Water.

The first input variable is vibration. According to Tables 13.6 and 13.7, the variable "vibration" is represented in Fig. 13.3.

The second input variable is water produced by the generating units. According to Tables 13.8 and 13.9, the variable water is shown in Fig. 13.4.

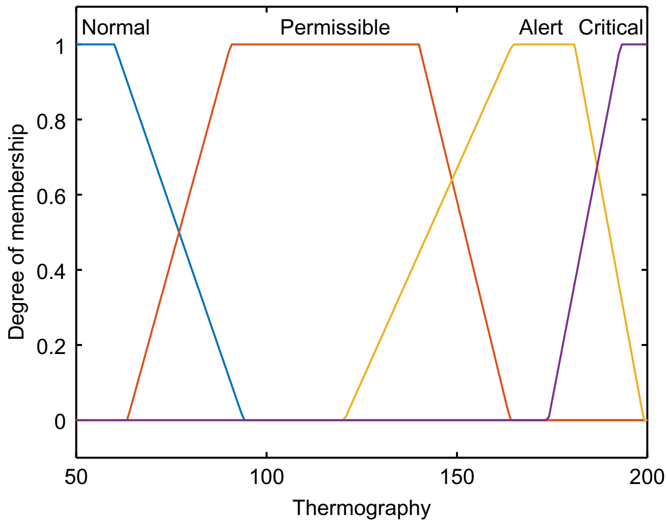



**FIGURE 13.5** Thermography.

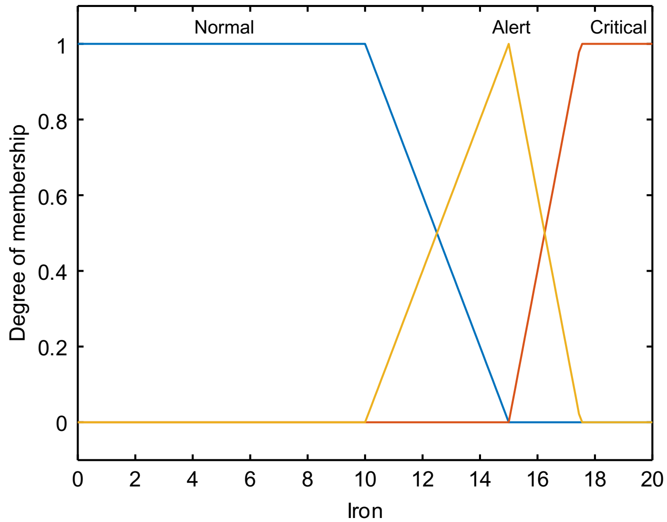



**FIGURE 13.6** Iron.

The third input variable is the thermography, produced by the generating units. According to , the variable thermography is shown in Fig. 13.5.

The fourth input variable is iron produced by the generating units. According to Tables 13.8 and 13.9, the variable "iron" is shown in Fig. 13.6.

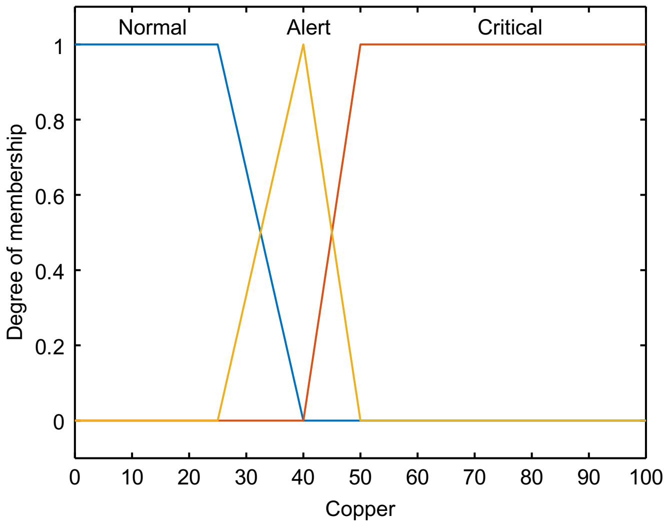



**FIGURE 13.7** Copper.

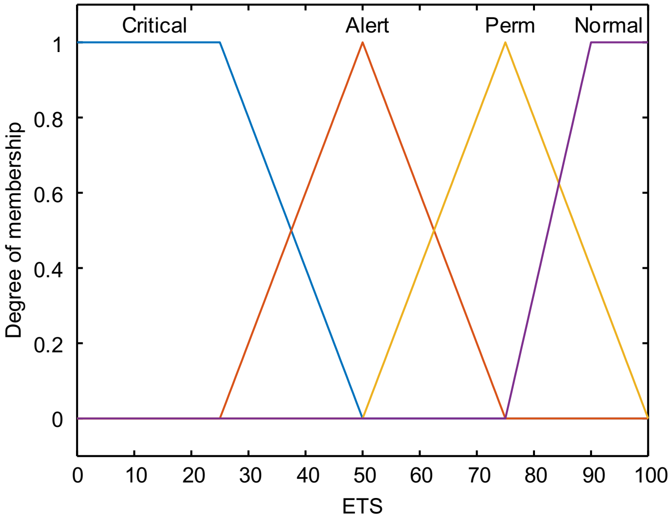



**FIGURE 13.8** Output variable: technical status.

The fifth input variable is copper, produced by the generating units. According to Tables 13.8 and 13.9, the variable "copper" is shown in Fig. 13.7.

The Motor Technical State is a product of the relationship between the input variable and output variable, which compose the pertinence functions expressed in the curves of Fig. 13.8.

After editing the pertinence functions of all variables, the implemented rules are arranged in Table 13.7, as shown in Fig. 13.9 for the visualization of the linguistic variables, thus forming antecedents and subsequent ones based on the fuzzy inference rules.

To better understand the screen expressed, Fig. 13.10 shows all the possibilities that the simulation can produce. The movement of the red lines determines the other rule to be evaluated.

Figs. 13.11–13.14 show the results of the inference rules from the 3D surface of the graph. In blank are present all the forms of execution that can exist within the simulation.

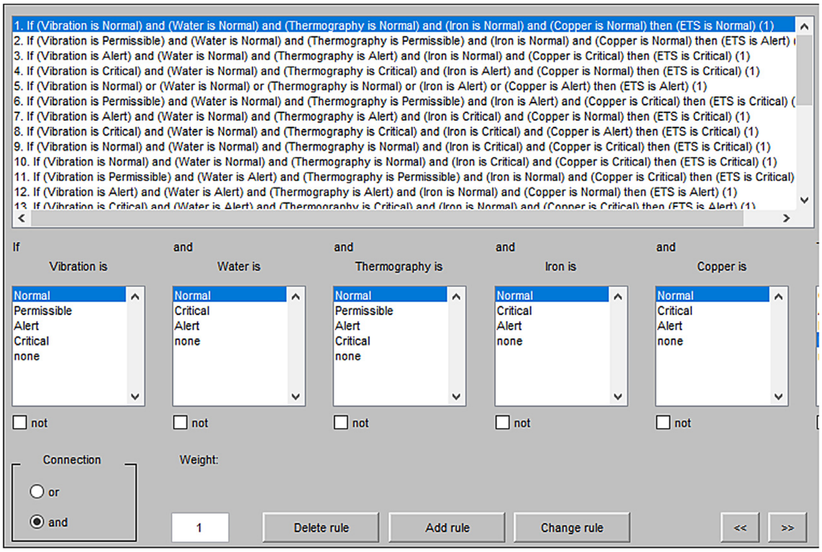



FIGURE 13.9 Implemented inference rules.

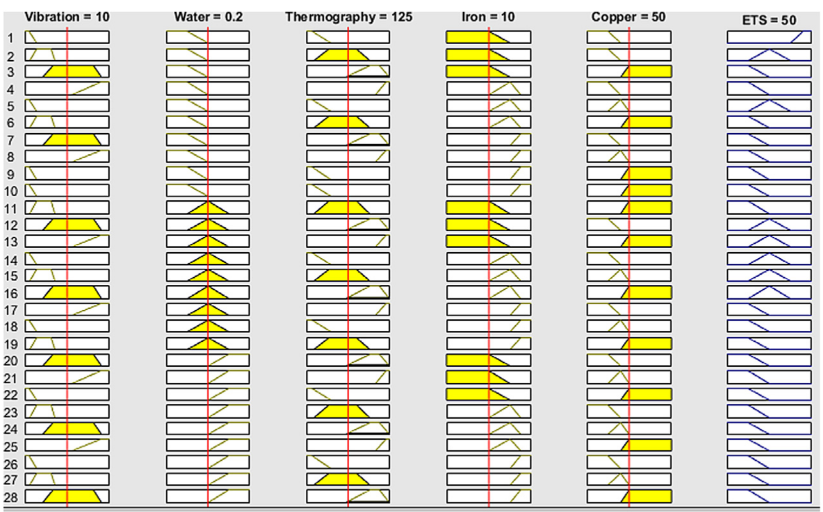



FIGURE 13.10 The input and output variables.

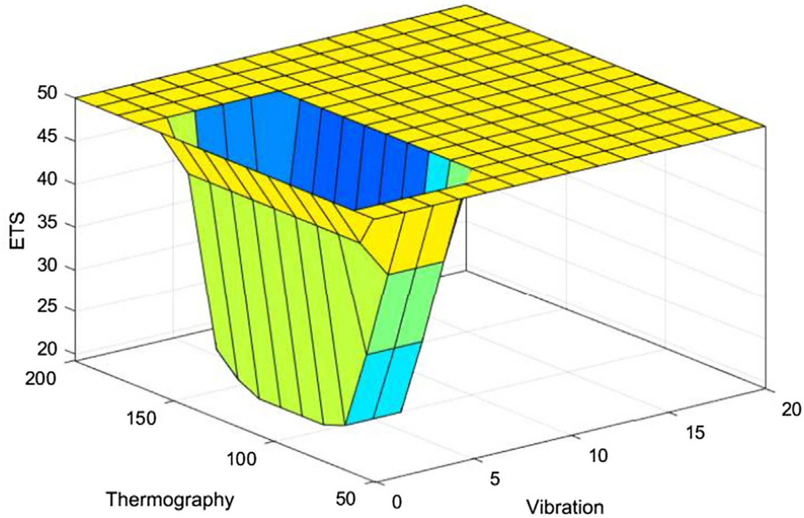



**FIGURE 13.11** Thermography × vibration.

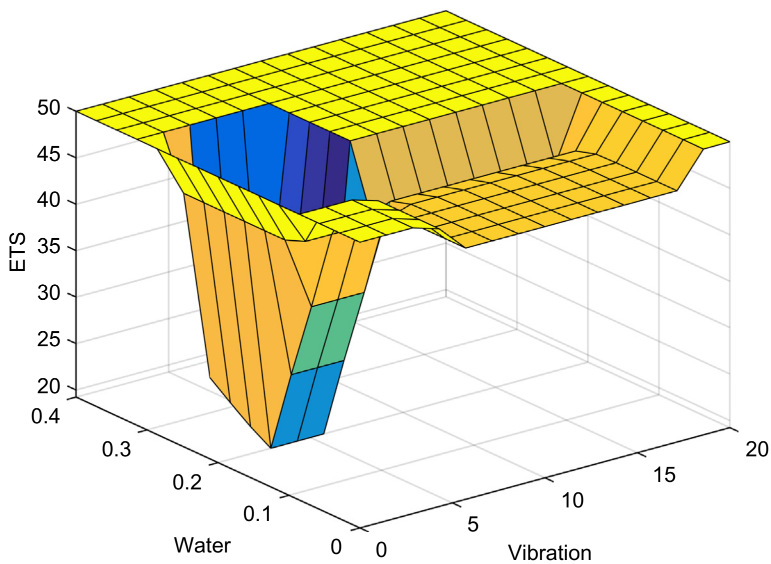



**FIGURE 13.12** Water versus vibration.

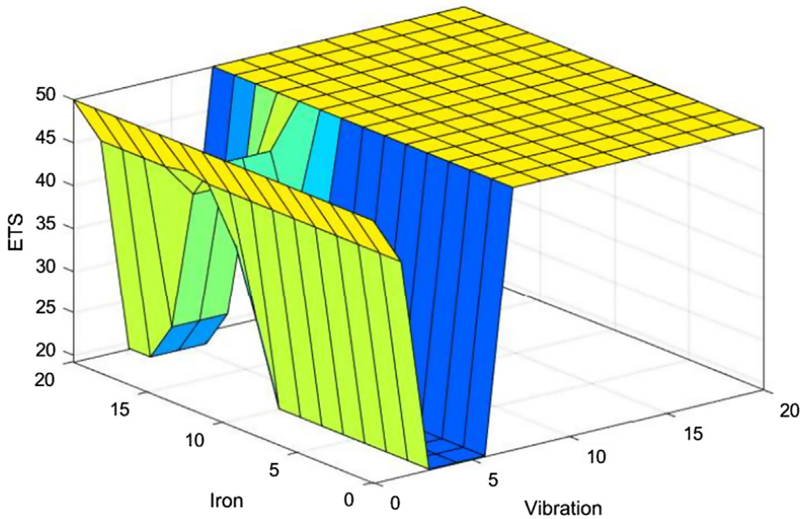



**FIGURE 13.13** Iron × vibration.

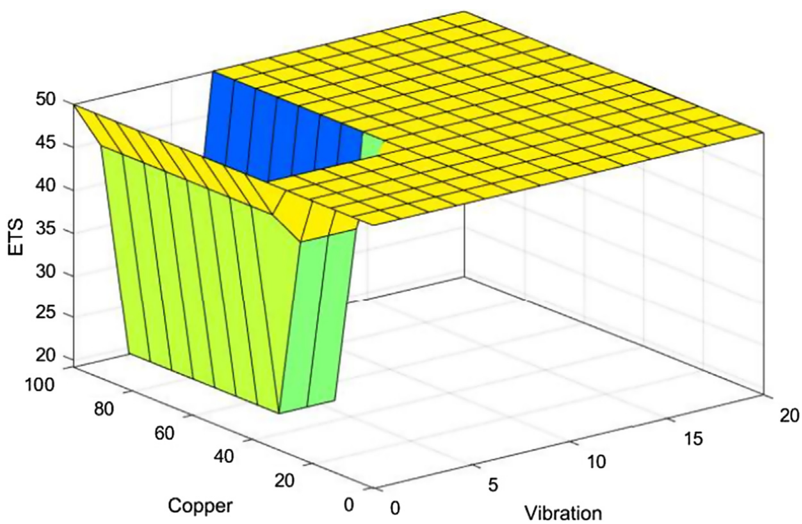



**FIGURE 13.14** Copper versus vibration.

## 13.6 Case study (fuzzy logic with predictive maintenance)

**1.** *Vibration analysis*

Equipment status control is performed based on a calculated global value for the vibration signal measured at critical points on the machine surface. Since this value is due to a response signal from the structure to the dynamic excitation of the equipment operation, it represents a measure of the amplitude level of its vibration signal. In the case of the application for predictive maintenance, the international technical standards, among them the ISO, define two criteria for adoption of a global value (Fig. 13.15).

2. *Analysis of water content in lubricating oil*

The determination of the presence and content of water in the case of study was carried out through the distillation by drag. The sample is subjected to heating for distillation under controlled conditions, thus verifying the water content in the lubricating oil.

The graph shows the results of the analysis of water content, done periodically as predictive, showing normal levels, since the tolerable is 0.3% (Fig. 13.16).

a. *Analysis of metal content in lubricating oil*

The graph made by direct reading (iron and copper) ferrography, which was carried out based on the extraction of the magnetizable

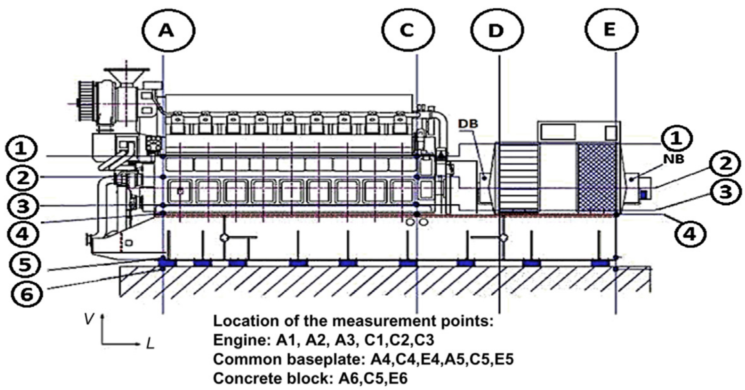



**FIGURE 13.15** Measurement points in the vibration analysis (2018).

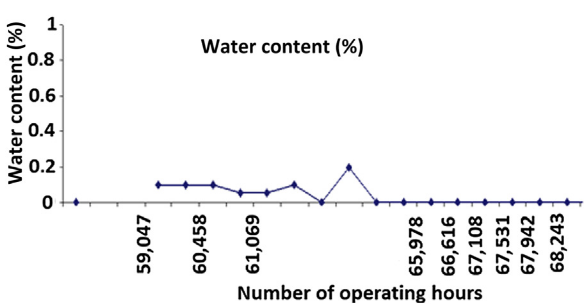



**FIGURE 13.16** Water content and lubricating oil (2018).

contaminant particles, contained in the lubricant, through the action of a magnetic field (Figs. 13.17 and 13.18).

3. *Thermography*

In addition to the use of the supervision system provided by the 9 FLUKE software, a thermovision is used, as shown in Fig. 13.19, for measurement in low or high voltage electrical systems, temperature

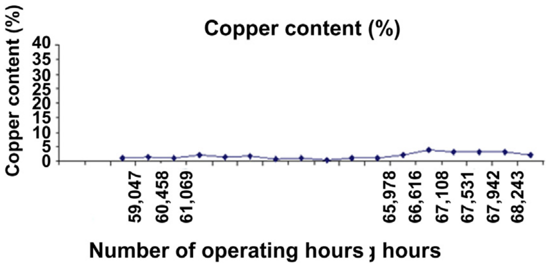



**FIGURE 13.17** Copper content in the lubricating oil (2018).

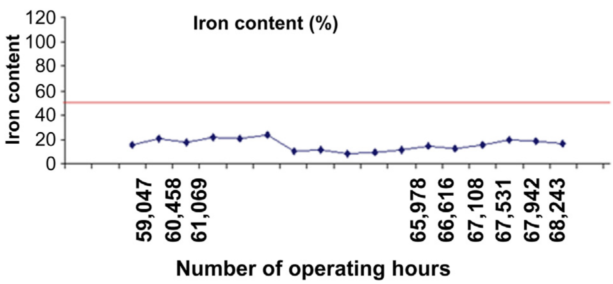



**FIGURE 13.18** Iron content in the lubricating oil (2018).

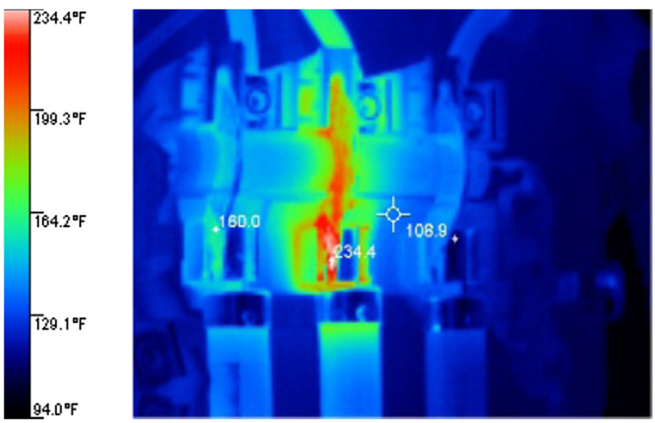



**FIGURE 13.19** Copper content in the lubricating oil (2016).

variations caused by excess electric current in the furnace motor/ generator 01 be with the hot spot and it will not be able to predispatch cargo.

**a.** *Fuzzy logic goes into the operating conditions of the equipment*

In Fig. 13.20, we can identify the anomalies likely to occur in the electric motor of the generator 1 for all effects of temperature caused by excessive electric current. The heating screen of Fig. 13.21 indicates that the engine/ generator 1 cannot be related for preloading under operating plants. The other motors and generators are in the normal comfort area (A) and can be classified for normal operation of the diffuse rule, such as the motors and tuners 2, 3, 4, 5, 6, 7, 8, 9, and 10. 5 and 25 mark as normal operations without interruption and execution of restriction only for the motor/generator 1. Activate the excluded points in your electronic connection.

In Fig. 13.20 the parameters for the location of the equipment, according to the engine/generator 1, are not allowed to operate because they are not in good operating condition. The other engines and generators are located in the area A (N) Normal, 2, 3, 4, 5, 6, 7, 8, 9, and 10 and are able to position themselves according to the needs of the organization. Fig. 13.21 informs, which engines are conditional ideal for preshipment of cargo under operating conditions.

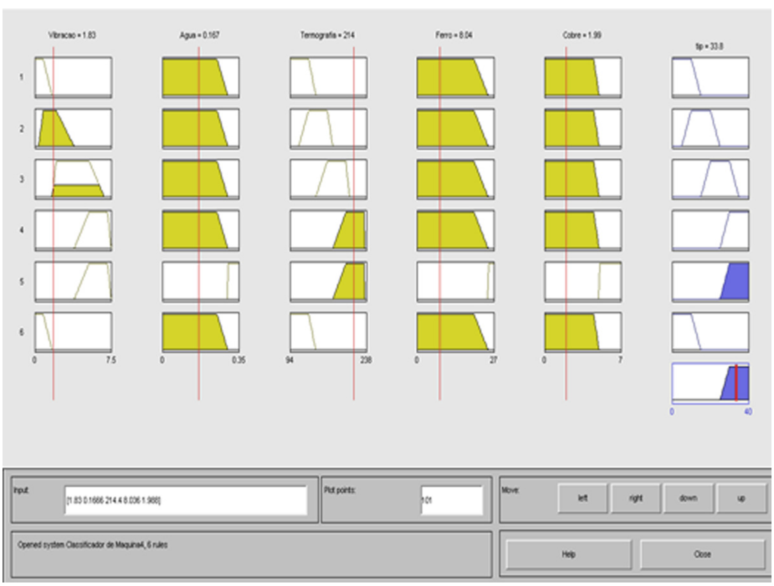



**FIGURE 13.20** Copper content in the lubricating oil (2016).

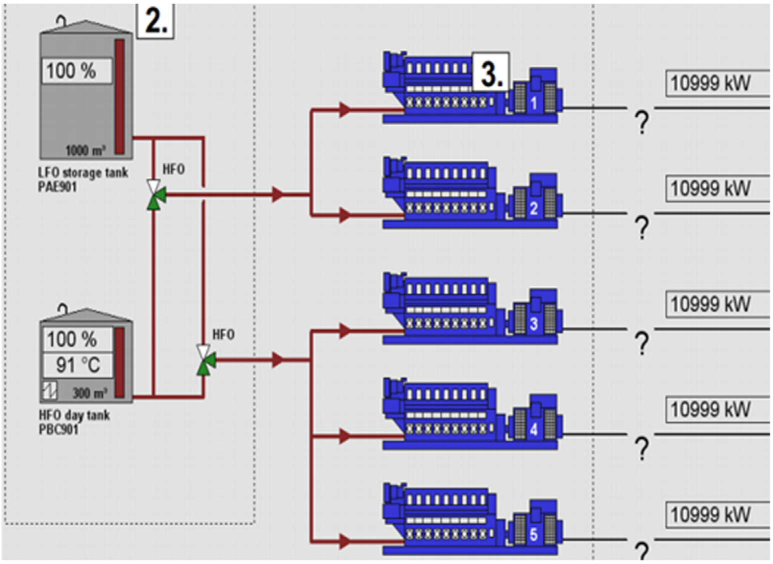



**FIGURE 13.21** Technical state of the engine for load dispatch.

### 13.6.1 Results achieved

The objective of this work was to analyze the maintenance management system and its optimization through nebulous logic for the development of an intelligent system of support and decision-making for an ideal load dispatch demand.

The interface of the developed computational tool achieved the simplicity desired by the users themselves, as well as the ease of learning in their operation. According to the facts presented in this paper, it was possible to show that, currently, a predictive maintenance program and a total maintenance program are indispensable for large companies. This is to provide reliability to processes and equipment, detecting problems still in the initial phase. Programs of this type provide good maintenance planning for the maintenance industry. Thus, the company grows with regard to meeting deadlines, resulting in an increase in customer satisfaction.

In the present study, the gains from the two plans mentioned earlier could be assessed based on the information from the case study, we verified the reduction of corrective maintenance and we verified the results with the increase of the MTBF and the decrease of the MTTR. The observed case can be implemented in any power generation machine that uses the fuel oil and, consequently, the use of oil stock, independent of the tank capacity and storage tank scales, which have only the standards of this system. The case study presented here can be implemented in any thermoelectric plant, independent of the loads to be dispatched, since the variables of this system are common to all.

## Acknowledgment

The authors gratefully acknowledge the support of this research by FAPEAM, UFPA, ELETROBRAS, and ITEGAM.

## References

[1] S.G. Silva, Sistema interligado nacional: Análise das penalizações impostas às transmissoras com foco na aplicação da parcela variável. 2016.

[2] M.A. Haiping, et al., Multi-objective biogeography-based optimization for dynamic economic emission load dispatch considering plug-in electric vehicles charging, Energy 135 (2017) 101–111. ISSN 0360-5442.

[3] J. Pless, H. Fell, Bribes, bureaucracies, and blackouts: towards understanding how corruption at the firm level impacts electricity reliability, Res. Energy Econ. 47 (2017) 36–55. ISSN 0928-7655.

[4] N. Kumar, A non convex cost function based optimal load dispatch using tlbo algorithm, J. Eng. Sci. Technol. Rev. 10 (1) (2017) 155–159. ISSN 1791-2377.

[5] N. Alam, M.F. Karim, S.A. Islam, A.N. Ahsan, A 0/1 mixed integer linear programming approach to establish an effective preventive maintenance policy for power plant, Int. J. Ind. Syst. Eng. 25 (4) (2017) 478–498.

[6] S. Alaswad, Y. Xiang, A review on condition-based maintenance optimization models for stochastically deteriorating system, Reliab. Eng. Syst. Saf. 157 (2017) 54–63.

[7] R. Arya, Ranking of feeder sections of distribution systems for maintenance prioritization accounting distributed generations and loads using diagnostic importance factor (DIF), Int. J. Electr. Power Energy Syst. 74 (2016) 70–77.

[8] A. Azadeh, S.M. Asadzadeh, N. Salehi, M. Firoozi, Condition-based maintenance effectiveness for series–parallel power generation system—a combined Markovian simulation model, Reliab. Eng. Syst. Saf. 142 (2015) 357–368.

[9] R. Baidya, S.K. Ghosh, Model for a predictive maintenance system effectiveness using the analytical hierarchy process as analytical tool, IFAC-PapersOnLine 48 (3) (2015) 1463–1468.

[10] M. Fonseca, et al., Pre-dispatch of Load in Thermoelectric Power Plants Considering Maintenance Management Using Fuzzy Logic, IEEE Access, 2018.

[11] M. Fonseca Junior, et al., Maintenance tools applied to electric generators to improve energy efficiency and power quality of thermoelectric power plants, Energies 10 (8) (2017) 1091.

[12] S. Larguech, et al., Fuzzy sliding mode control for turbocharged diesel engine, J. Dyn. Syst. Meas. Contr. 138 (1) (2016) 011009. ISSN 0022-0434.

[13] B.P. Gonçalves, et al., Avaliação de impactos harmônicos na rede elétrica através dos indicadores THD e fator de potência utilizando lógica Fuzzy, Rev. Bras Energ. 19 (1) (2013) 9–27.

[14] E.L. Nogueira, M.H.R. Nascimento, Inventory control applying sales demand prevision based on fuzzy inference system, J. Eng. Technol. Ind. Appl. 3 (2017) 31–36. <https://doi.org/10.5935/2447-0228.20170060>.

[15] D. Lopez-Perez, J. Antonino-Daviu, Application of infrared thermography to failure detection in industrial induction motors: case stories, IEEE Trans. Ind. Appl. 53 (3) (2017) 1901–1908. ISSN 0093-9994.