Respuestas, 25 (2) May-August 2020, pp. 177-189, ISSN 0122-820X - E ISSN: 2422-5053

Respuestas
Journal of Engineering Sciences

RESPUESTAS

Original Article https://doi.org/10.22463/0122820X.2966

Evaluation of artificial intelligence techniques used in the diagnosis of failures in power plants

Evaluación de técnicas de inteligencia artificial utilizadas en el diagnóstico de fallas en plantas de potencia

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How to cite: J.F Caratar-Chaux, A.M. Valencia, G. Caicedo-Delgado, C. Chamorro “Evaluation of artificial intelligence techniques used in the diagnosis of failures in power plants”. *Respuestas,* vol. 25, no. 2, pp. 177-189, 2020.

Received on February 07, 2020; Approved on April 5, 2020

ABSTRACT

This article presents an evaluation about the research related to the development of computational tools based on artificial intelligence techniques, which focus on the detection and diagnosis of faults in the different processes associated with a power generation plant such as: hydroelectric, thermoelectric and nuclear power plants. Initially, the main techniques of artificial intelligence that allow the construction of intelligent systems in the area of fault diagnosis is described in a general way, techniques such as: fuzzy logic, neural networks, knowledge-based systems and hybrid techniques Subsequently A summary of the research based on each of these techniques is presented. Subsequently, the different articles found for each of the techniques are presented in tables, illustrating the year of publication and the description of the research carried out. The result of this work is the comparison and evaluation of each technique focused on the diagnosis of failures in power plants. The novelty of this work is that it presents an extensive bibliography of the applications of the different intelligent techniques in solving the problem of detection and diagnosis of failure in power plants.

Keywords:

intelligent system,
neuronal networks,
fuzzy logic,
Bayesian networks,
expert systems,
fault diagnosis,
power plants.

RESUMEN

Este artículo presenta una evaluación de herramientas computacionales basadas en técnicas de inteligencia artificial, las cuales se enfocan en la detección y diagnóstico de fallas en los diferentes procesos asociados a una central de generación de energía tal como: hidroeléctricas, termoeléctricas y centrales nucleares. Inicialmente, se describen de manera general las principales técnicas de inteligencia artificial que permiten la construcción de sistemas inteligentes para el diagnóstico de fallas en centrales eléctricas, se presentan técnicas como: lógica difusa, redes neuronales, sistemas basados en el conocimiento y técnicas hibridas. Posteriormente se presentan en tablas los diferentes artículos encontrados para cada una de las técnicas, ilustrando el año de publicación y una descripción de cada publicación. El resultado de este trabajo es la comparación y evaluación de cada técnica enfocada al diagnóstico de fallas en centrales eléctricas. Lo novedoso de este trabajo, es que presenta una extensa bibliografía de las aplicaciones de las diferentes técnicas inteligentes en la solución del problema de detección y diagnóstico de falla en centrales de generación eléctrica.

Palabras clave:

sistemas inteligentes,
redes neuronales,
lógica difusa,
redes Bayesianas,
sistemas expertos,
diagnóstico de fallas,
plantas eléctricas.

Introduction

According to the report presented by the United Nations in 2015 "Energy for all", around 90% of the developed or emerging regions worldwide have access to electricity supply. In the world, according to the report in 2017 of International Energy Agency, the projected energy demand for 2040 will grow by 30% with respect to the demand consumed in 2017. These demonstrate the importance that represents the supply of energy for today's society, which is why the generating plants must guarantee reliability in the provision of this service [1]. For this, equipment has been developed to monitor, supervise, control and protect the mechanical and electrical components, among which are the PLC (Programmable Logic Controller) and the relays [2]. These devices protect the plant against abnormal operating conditions [3] and its implementation has reduced the number of accidents like Three Mile Island Pennsylvania, in the US on March 28, 1979 [4], [5] where

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a short circuit in the plant operated at 97% of maximum capacity (1000 Mv), start an escape of radioactive water. The widespread use of these monitoring and control mechanisms allows knowing and storing information about the state of the devices that make up the generation plants [3]. This information allows the implementation of new fault detection and diagnosis techniques based on the use of intelligent systems. Currently, intelligent systems are a branch of artificial intelligence that allows to provide knowledge and experience on a specific domain to a machine, with the aim that it develops a specific activity. Intelligent systems (SI) are developed using techniques such as fuzzy logic, neural networks, genetic algorithms and rule-based systems. Each of these techniques gives the SI different qualities, which is why it is important to know in detail each technique to determine the characteristics that the developed tool will have [6].

This article presents a description of the main techniques used in the creation of SI dedicated to the diagnosis of failures in power plants. At the end of each technique, a table is presented with the investigations found to perform detection and diagnosis of failures based on SI using this technique.

Methodology for the analysis of articles

The methodology of this article initially describes the concept of faults in electric power plants, then describes the concept of intelligent system and finally describes some of the techniques used in the fault diagnosis in power plants.

Faults in Power Plants

According to what is stated in [1], electric generation plants are those that transform a type of base energy into electric energy. Currently, the main generation systems include thermoelectric, hydroelectric, solar and wind power plants. These systems involve in its operation different elements that can be classified as mechanical and electrical, therefore, the failures that may occur in these power plants are mechanical or electrical, where a fault is defined as a state of operation outside the nominal or admissible values of the system.

Therefore, power plants have implemented protection systems, which allows to clear the fault to reduce or mitigate the negative effects that these can cause on the system. Currently, protection systems use devices called PLCs and relays [7] which have different protection functions (PF) previously parameterized [8].

When a fault occurs, the personnel dedicated to the identification and diagnosis of faults analyze the information generated by the PLC and the Relay, handling large volumes of information [7], which makes evident the need for tools based on intelligent systems that can assimilate the experience of human experts and organize the information associated with the fault to speed up diagnostic processes.

Intelligent Systems (SI)

Intelligent systems are computational tools that implement artificial intelligence techniques with the objective of providing knowledge and experience on a specific procedure of a machine [9]. For the development of an intelligent system there are several techniques that can be implemented according to the type of application, for this reason it is of great importance to study each of these techniques before starting the development of an intelligent system [10].

Below are the main techniques used in the development of intelligent systems focused on the detection and diagnosis of faults in power plants.

Fuzzy logic

"Fuzzy logic is a branch of Artificial Intelligence (AI) that allows a computer to analyze real-world information on a scale between the false and the true", this technique emulates human decision making, which reasons into a realm of assertions partially true thanks to common sense [9].

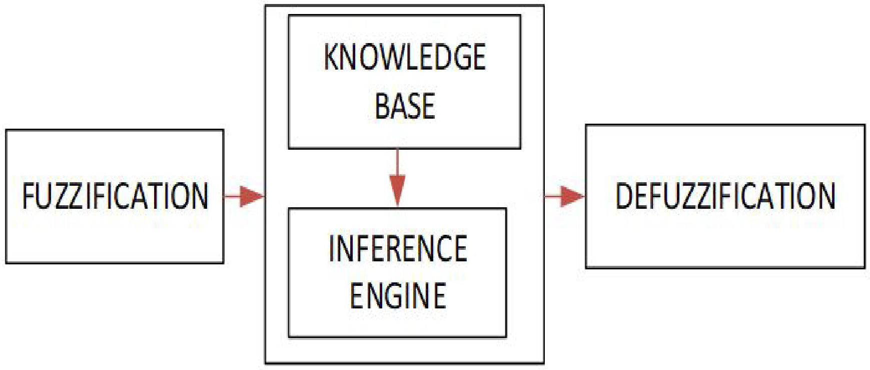

Figure 1. Structure of a fuzzy logic system

Source: [11]

According to [11] fuzzy logic is widely used in applications where there is no mathematical model that describes the system; Therefore, these types of applications can be modeled by adapting the values of the variables to qualitative values and subsequently defining rules that allow make inferences in these applications. It can be seen in Table 1, the main investigations developed in power generation plants using fuzzy logic for the detection and diagnosis of faults.

Table I. Research developed in power generation plants using fuzzy logic

Ref.	Year	Description
[12]	2005	An application based on fuzzy logic is presented to detect isolated faults in the reactor of a nuclear power plant.
[13]	2007	A tool is presented to automatically diagnose faults in the electrical transformer of a hydroelectric plant, using an expert system based on fuzzy logic.
[14]	2007	An algorithm is presented to develop a tool to detect and classify high and low voltage electrical faults, using Adaptive Network based Fuzzy Inference System techniques.
[15]	2010	Uses Artificial Intelligence techniques applied in the development of condition-based maintenance systems.
[6]	2009	It presents the schematic design, the functional module and the key techniques for the development of an expert system based on fuzzy logic focused on failure analysis in the protection relay of a hydroelectric plant.
[16]	2008	Verification of diffuse reasoning is presented using Petri nets in fault-tolerant equipment diagnostic systems.
[17]	2010	A tool is presented that diagnoses and assists as an assistant during a fault using fuzzy logic and neural networks.
[18]	2014	A maintenance model is presented focused on the study of electrical circuits using diffuse theory and evident reasoning.
[19]	2014	A technique for evaluating faults in electrical power systems is presented using a new technique based on reducing the rules of fuzzy logic.
[20]	2014	A proposal is presented to detect and diagnose faults in the electrical network in the event of dynamic load changes using fuzzy logic and probabilistic neural networks.
[21]	2016	An expert system for fault identification and analysis based on fuzzy logic and the Lean Six Sigma artificial intelligence technique is presented.

Source: Authors

This technique can be easily implemented in cases where the rules that make up the knowledge base are subjective or difficult to specify, since it allows the use of natural language in its construction [9]. It also has great potential for managing processes in which there is uncertainty in the input data due to the way in which this technique is constituted; however, the need to work with other techniques to improve the performance of the tools developed is evident.

Neural Networks

Neural networks are computation techniques inspired by biological models that imitate the reasoning process of the human brain, for this the neural network takes solved problems as examples to find relationships and build its own network, which classifies information to make decisions [9], [10].

The neural network is made up of three main layers, as can be seen in Figure 2, the input layer where the data is entered, the hidden layer made up of one or several layers depending on the complexity of the network and the output layer, for more information see [22].

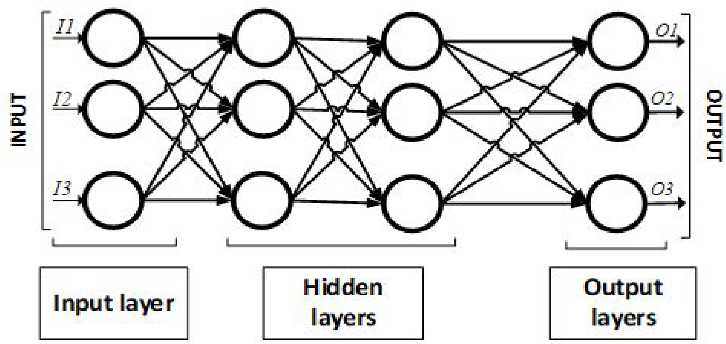

Figure 2. Example of a neural network

Source: [22]

Neural networks offer the advantage of adaptive learning, self-organization, fault tolerance, real-time operation, and easy implementation in current technology.

In Table 2 presents the research developed for the detection and diagnosis of failures in power plants using intelligent systems based on neural networks. The main quality of this technique is that it offers a solution to cases where it cannot or is very complicated to extract the knowledge of specialists to formulate a knowledge base. The neural networks present as limiting the great amount of information that the network requires for its training, limiting to a great extent its field of application.

Table II. Research developed for the detection and diagnosis of failures in generating plants using neural networks

Ref.	Year	Description
[23]	2008	A methodology is presented for the application of an intelligent system based on fuzzy logic and neural networks to do maintenance based on conditions of a client-server system.
[12]	2005	Presents a tool to analyze faults in a nuclear reactor using neural networks and fuzzy logic.
[24]	2009	Presents a study on the different artificial intelligence techniques used in the development of tools for protecting power plants.
[25]	2016	A new technique for diagnosing photovoltaic panel failures using neural networks is introduced.
[17]	2010	Presents a tool that diagnoses and assists as an assistant during a fault using neural networks and fuzzy.
[26]	2017	A computational model of an intelligent system for real-time fault detection and diagnosis is presented.
[27]	2018	A system based on neuronal networks is presented to diagnose the deterioration of the components of a gas generator using thermodynamic models.
[28]	2019	This paper analyzes the use of AI for emergency operation after an accident occurred in a nuclear plant, adopting the artificial red neuronal (ANN) to calculate the emergency operation strategy, in which the parameter vector Post-accident status is the entry of the model and the emergency operation strategy is the exit.
[29]	2020	Present an online fault diagnosis system for nuclear power plants based on neural networks and a protocol responsible for managing data called a sliding window.

Source: Authors

Knowledge-based systems

According to [30], knowledge-based systems are defined as those that "contain the erudition of a human specialist versed in a specific field of application". With this technique it is possible to condense the knowledge of human specialists in such a way that it can be accessed and processed by computers, obtaining computer models with the reasoning and problem-solving capacities of human specialists within an established domain.

It can be seen in Figure 3 the generic architecture of a knowledge-based system [9], in which its main components and actors are identified.

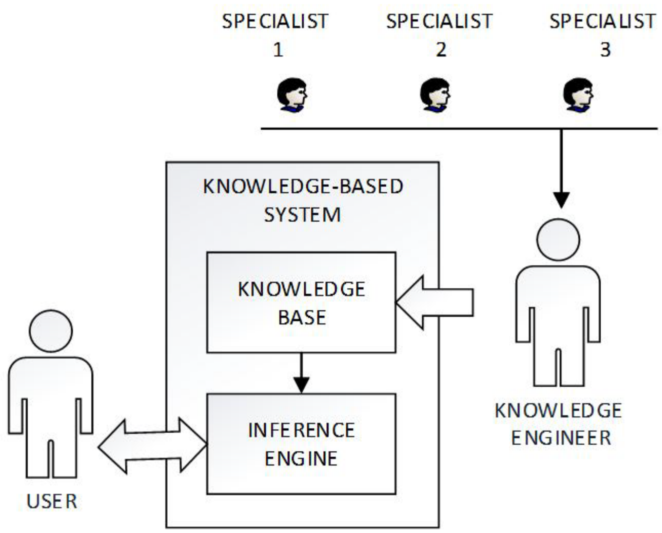

Figure 3. general architecture knowledge-based systems
Source: Authors

Knowledge-based systems are composed mainly of the knowledge base, place where all the information of human specialists is stored, the knowledge of specialists is represented into rules and objects of type IF ... THEN, so that they can be accessed by the inference engine, which relates user inputs that can be in the form of questions with rules and objects to get an answer [10].

Next, Table 3 presents the main research focused on the detection and diagnosis of power plant failures using knowledge-based techniques. However, there is a difficulty in the application of this technique in cases where there is uncertainty in the diagnosis, since the system is only capable of diagnosing the cases of failure that have been contemplated previously. Another difficulty observed in the development of this technique is the difficulty of extracting all the knowledge of human specialists to cover all cases of failure.

Table III. Research carried out to detect and diagnose faults in power plants using knowledge-based systems

Ref.	Year	Description
[31]	1995	expert system to evaluate the performance of the protection functions implemented in a digital relay when a fault occurs.
[32]	1999	The design of an expert system for protection of the electrical system is presented, analyzing the relay inputs and load conditions on the transmission lines, transformer and busbars.
[33]	2002	Presents an expert system for the diagnosis of electrical faults in the rotor of an electric generator of a power plant.
[34]	2004	This article presents the design of an expert system that emulates the behavior of a human specialist to evaluate and diagnose faults in isolation conditions.
[35]	2005	This article presents an expert system that predicts the operation of protection functions, identifies unexpected protection functions and diagnoses symptoms, using the information contained in the digital relay failure reports.
[36]	2008	A tool is presented to do predictive maintenance in a hydroelectric plant using expert systems based on rules, the prototype presented analyzes the alternator turbine set taking fault information on the whole hydroelectric plant.
[37]	2008	A discussion is presented on the components and each part of an expert system for fault detection and diagnosis in the cooling process of a hydraulic power station using the minimum set of measurements.
[15]	2010	The design of a software called SIMPREBAL is presented, based on an expert system to diagnose faults in real time in the machinery of a hydroelectric power plant.
[38]	2012	Presents the development of a methodology that allows to improve the selection of the rules of an expert system to do FMECA predictive maintenance.
[39]	2013	It shows an expert system focused on predictive maintenance of the alternator turbine group. This system is validated with historical data from the hydroelectric plant
[40]	2017	It presents an integrated knowledge-based system for the diagnosis of faults in a small hydroelectric power station located far from the control and maintenance center.
[41]	2019	This document proposes the methodological development and computational implementation of a system to diagnose failures in power generation assets in order to assist in the maintenance and operation of a hydroelectric plant.

Source: Authors

Bayesian Networks

Bayesian networks are graphs that represent information through a set of variables and the dependency relations between them. In this way a Bayesian network can represent the probabilistic relationships between a fault and the symptoms of a system.

These networks are built on DAG (Directed Acyclic Graph) graphs as shown in Figure 4, where each node represents a random variable and the edges represent conditional dependencies.

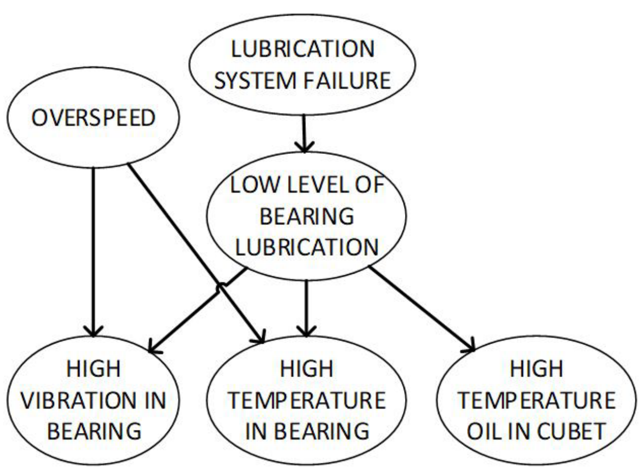

Figure 4. Example of a Bayesian network **Source:** Authors

Table IV. Research carried out in the area of diagnosis of failures in power generation plants using intelligent systems based on Bayesian networks

Ref.	Year	Description
[42]	2005	a Bayesian network-based approach to fault diagnosis is proposed, establishing distributed models containing temporal order attributes.
[43]	2006	three models are proposed for elements based on simplified Bayesian networks with Noisy-Or and Noisy-And nodes to estimate the defective section of a transmission power system.
[44]	2006	a large-scale grid failure diagnostic approach based on the Bayesian grid and the MCMC method is proposed, establishing trawl models to construct the Bayesian grid of the electricity grid.
[45]	2011	shows a Bayesian network made in MATLAB used to analyze faults caused by uncertain elements in a complex system.
[46]	2013	a generic strategy of detection and diagnosis of faults is proposed to simulate the real diagnostic thinking of the experts.
[47]	2014	proposes a fault diagnosis methodology based on the fusion of information from multiple sources using the Bayesian network.
[48]	2016	proposes a methodology for real-time failure diagnosis of complex systems with repetitive structures using object-oriented Bayesian networks.
[49]	2017	This article proposes a fault analysis method based on the Bayesian network, from which new methods of sensitivity analysis, inference and fault identification are developed.
[50]	2018	It develops an architecture based on Bayesian networks to diagnose faults in nuclear plants, describing the advantages of the tool when working with incomplete data.
[51]	2020	Performs an analysis of sensitivity regarding the parameterization of the conditional probability model of Bayesian networks to test the robustness of the networks in the diagnosis and prognosis.

Source: Authors

In the investigations presented in Table 4 it is observed that the intelligent systems developed under this technique present a great deal of uncertainty, which allows decisions to be made with partial input information. According to the above, it is considered that Bayesian networks give intelligent systems the ability to determine possible solutions from fragments of information in their entry. As a difficulty in the application of Bayesian networks is establish all the relationships between the different symptoms and types of failure so that the network can make a more approximate diagnosis.

Hybrid techniques

Up to this moment some of the most used techniques in the development of intelligent systems have been presented, each one of these techniques presents qualities and deficiencies during its application, reason why it can be assured that a perfect technique does not exist to develop intelligent systems, this has taken to develop systems that integrate different techniques of artificial intelligence, obtaining as result the denominated hybrid techniques.

In Table 5 is presented a compilation of the research developed with hybrid techniques that have had the greatest impact in recent years to detect and diagnose failures in power plants.

Table V. developments with hybrid techniques of artificial intelligence for the diagnosis of failures in power generation plants

Ref.	Year	Description
[12]	2005	An application based on a hybrid technique between fuzzy logic and neural networks to detect isolated faults in the reactor of a nuclear power plant is presented.
[14]	2007	A tool is presented to automatically diagnose faults in the electrical transformer of a hydroelectric plant using an expert hybrid system based on fuzzy logic and neural networks.
[23]	2008	A methodology is presented for the application of an intelligent system based on hybrid techniques of fuzzy logic and neural networks that allows maintenance based on conditions adapted to a client-server system.
[36]	2008	It presents a tool to do predictive maintenance in a hydroelectric power plant using rule-based expert systems, the presented prototype analyzes the alternator turbine assembly.
[17]	2010	Artificial intelligence based on the hybridization of neural networks and fuzzy logic is presented to make a condition-based maintenance system.
[15]	2010	The design of a software called SIMPREBAL is presented, based on an expert system to diagnose faults in real time in the machinery of a hydroelectric power plant.
[38]	2012	Development of a methodology that combines meta rules and expert systems to determine the type of failure of a hydroelectric power plant.
[39]	2013	It shows an expert system focused on predictive maintenance of the alternator turbine group; this system is validated with the historical data of the hydroelectric plant.
[52]	2014	This article presents an expert system for diagnosing the behavior of a power plant transformer. Input information is obtained using a combination of new and traditional techniques.
[53]	2014	It presents a hybrid intelligence approach based on diffuse neural network (FNN) and data fusion. Where, at the local level, FNN was used to diagnose individual failures, and globally, data fusion was used to deal with more failure characteristics.
[19]	2014	A technique is presented to evaluate faults in electrical power systems based on reduction of fuzzy logic rules using individual bases of inference and control of static processes.
[20]	2014	It presents a hybrid technique of fuzzy logic and probabilistic neural networks to make detection and diagnosis of faults in the electrical network to changes of dynamic load using.
[21]	2016	An expert hybrid system based on fuzzy logic and Lean Six Sigma for fault identification and analysis is presented.
[26]	2017	A computational model of an intelligent system for real-time fault detection and diagnosis is presented.
[27]	2018	A hybrid system based on neuronal networks with thermodynamic models is presented to diagnose the deterioration of the components of a generator.
[54]	2019	It presents a methodology that combines fuzzy networks with knowledge-based systems in order to evaluate the impact of demand response on the long-term demand of electricity and expansion planning in interconnected Brazilian power system.
[55]	2019	Development of intelligent early warning system for steam turbine. In this work, the artificial neural network and genetic algorithms were used.
[56]	2019	It is a work where the machine learning technique is combined with knowledge-based techniques for the diagnosis of failures in nuclear power plants.
[57]	2020	This work combines dynamic Bayesian networks with fuzzy networks for the analysis of faults at the beginning and during the progress of the fault in nuclear power plants.

Source: Authors

The hybrid techniques allow to increase the field of action of the proposed projects without worrying about the limiting particularities of each technique.

Results and discussion

Table 6 shows a comparative evaluation between the different techniques presented in this work; with this evaluation the reader can compare the advantages and disadvantages of intelligent systems developed by each of the artificial intelligence techniques.

Table VI. Comparison of artificial intelligence techniques

Characteristic of intelligent system	Fuzzy logic	Neural Network	Knowledge-based Systems	Bayes Network
It can be implemented when there is no mathematical model or algorithmic method that allows the identification of faults.	X	X	X	X
It can be implemented when the rules that allow the identification of failures are clear and easy to determine	X		X	
It is recommended when the rules that allow the identification of failures are composed of reasoning based on natural language.	X		X	
To identify failures handles a high degree of uncertainty.	X			X
It can easily train when have data of system behavior in fault situations.	X	X	X	X
The relationships between variables and fault diagnoses cannot be observed.		X		
You can diagnose failures even if part of your inference structure is compromised.		X		
It allows the handling of noise in the input information to make an effective diagnosis.		X		X
It can identify failures in real time.	X	X	X	X
A diagnostic system can be easily implemented under these techniques.	X		X	X
It allows to incorporate the knowledge of a human specialist for the identification of failures.			X	X
It does not require examples of the behavior of the plant in fault situations for its construction.	X		X	
You cannot perform automatic learning of faults and their relationships with system elements	X		X	
It requires many examples the types of failures for training		X		
Deliver fault diagnostics with considerable margin of error.	X	X		X
It requires learning time before delivering good results in identifying failures.		X		
The identification of failures obtained under these techniques are imprecise compared to a mathematical model.	X			
It presents high difficulty in developing the knowledge base of the identification system due to the complexity of the plants.			X	

Source: Authors

According to the foregoing, it is considered that for the development of an intelligent system to detect and diagnose faults in a power plant, hybrid techniques must be included to comply with a greater number of attributes that allow for a more complete solution, maintaining a simple design and direct application.

Conclusions

This article presents an evaluation of the main techniques used in the development of intelligent systems, seeking to provide the reader with a primary source of information on these techniques and their application in the problem of failure analysis in power plants. On the other hand, the reader will have criteria to determine the technique that best fits the complexity of his own system.

There are multiple intelligent systems techniques that can be used in the solution of different problems, therefore, the characteristics of each problem and the resources available must be analyzed carefully before selecting the technique.

The fuzzy technique acquires greater relevance when working in hybrid form with other techniques of artificial intelligence that allow to relate the interpretation of data that this one offers.

Neural networks are highly applicable in systems where it is very complex to extract the knowledge of human specialists, or this knowledge evolves over time, its main deficiency is in the large number of data required for training, limiting its application to diagnostic systems where there is extensive documentation of symptoms and consequences.

Systems based on knowledge present an excellent performance in a specific domain when the capture of knowledge is done in an adequate way, since its efficiency depends on the quality of the knowledge base.

The systems that present a better behavior are those where hybrid techniques are implemented, since they compensate for the weaknesses of each technique. For example, this work was used by the authors to select the appropriate techniques for the development of an intelligent hybrid system for fault diagnosis in a hydroelectric power station, obtaining the combination of expert systems and Bayesian networks since these techniques fit the available information.

Acknowledgements

Colciencias for its support in the framework of the call for national doctorates 727 of 2015.
Univalle in the framework of the C.I. 105 of 2017.

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