# Information System for the Performance Assessment of Cooling Equipment in Power Plants

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## ABSTRACT

In this paper, the main features, design, software architecture, and utilization of an offline performance assessment program for power plant cooling systems are illustrated. The program allows to calculate quickly and accurately the equipment performance indicators and diagnose the causes of inefficiencies presented in cooling tower, condenser, and cooling pumps. The program also presents to the users alternatives to solve the detected problems and to improve the system performance. The algorithms for calculating the key performance indicators are based on the documented standard methodology of the Heat Exchange Institute, Cooling Technology Institute, and the America Society of Mechanical Engineers. The assessment of the cooling system is carried out through the comparison between the current indicators and the expected ones, while the diagnosis is made by means of an expert system that uses the methodology of case-based reasoning.

**Keywords**: Expert System, Case-Based Reasoning, Cooling System, Performance Assessment.

## INTRODUCTION

The optimal values of energy efficiency or heat rate for power plants depend on the proper functioning of all systems and equipment. Within these systems one of particular importance is the cooling system, because, malfunctions or performance deviations of the system components relative to their design values can significantly impact in the efficiency of the unit. In the last decade, the Electrical Research Institute IIE has conducted technical studies on cooling systems i.e. surface condenser, cooling tower and circulating water pumps i.e. in Mexican power plant facilities. These studies have shown trends of significant deviations from the design values [1]. An example of such deviations is the high absolute pressure of the condenser due to one of the following factors: fouling of tubes, air in-leakages, excessive thermal load from steam turbine exhaust, low water flow rate and high water temperature at entrance, among others. Some of these deviations are due to problems caused by the other components of the cooling system; i.e. the circulating water pumps and the cooling tower.

The IIE has documented a methodology [2] for evaluating and diagnosing the cooling system, which, implemented in a computer system, calculates the equipment parameters and is able to present the diagnosis of possible causes of inefficiencies, as well as operating and maintenance recommendations for the system optimization. The methodology is based on the standards for equipment performance assessment published by the Heat Exchange Institute (HEI), the Cooling Technology Institute (CTI) and the American Society of Mechanical Engineers (ASME).

## PROBLEM APPROACH

The inefficiencies or performance deviations of components in the cooling system can cause significant power losses in the entire power plant. Therefore, it is necessary to develop and implement a computer system that allows users to evaluate and diagnose the performance of the cooling system through the capture of key operational data in order to define and implement, in an accurate and timely manner, the corrective actions required to reduce power losses and increase efficiency of the power plant.

Because of the aforementioned reasons, an information system called PEDSE for the performance assessment and diagnosis of cooling equipment in power plants was developed.

## COOLING SYSTEM DESCRIPTION

The cooling system mainly consists of a steam condenser, a cooling tower, some circulating water pumps and the pipelines that carry the cold water to the condenser and return the hot water to the cooling tower. The cooling system objective is to supply cooling water at the required conditions to the condenser so that condensation of exhaust steam from the low pressure turbine can be achieved, by means of proper vacuum conditions.

Conventional thermal power plants in Mexico typically use wet cross flow cooling towers with mechanical draft, and once-through systems. The main components of such systems are as follows (see Figure 1):

- Surface steam condenser.

- Cooling tower.
- Circulating water pumps.
- Induced draft fans.

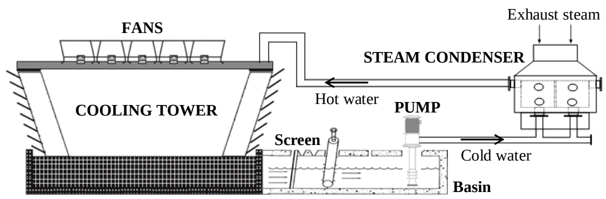



Figure 1. Cooling system layout

Although the design of cooling systems varies from one plant to another, the components shown are common in most of the cases.

## METHODOLOGY & DEVELOPMENT TOOLS

During the design phase for the information system, an evaluation of the techniques and tools for the software development was carried out. Such assessment was divided into two stages; the first concerns the selection of a development platform, such as the operating system, the programming language and the tools necessary to implement the Graphical User Interface (GUI). The second stage concerns the selection of the methodology to be used for the diagnostic system.

### Development Platform

Initially the development platform for the computer system was evaluated by considering the following items:

- Usability. The ability of software to be understood, learned and used in an attractive fashion to the user, under specific conditions of use [3].
- Modularity. It is the property that allows a division of the applications into smaller parts (called modules), each of which must be as independent as possible from the implementation.
- Potential of the program. Concerns the input and editing data, display of results, and ease of use.
- Costs. Refers to the licenses, maintenance and technical support costs.

The final decision was to develop the system by using visual programming languages. The development environment is Microsoft Visual Studio 2005; the programming language is Visual Basic .NET, while the database engine is Microsoft Access. For the design and development of menus and graphical user interfaces Macromedia Flash multimedia platform was used.

### Methodology for the Expert System

In order to achieve a functional computer tool for the solution of the tackled problem it is advisable to use Artificial Intelligence (AI) techniques. A bibliographic review of some AI methodologies that could be used was carried out. These methodologies include the following ones: Fuzzy Logic, Case Based Reasoning (CBR), Rule Based Reasoning (RBR), and hybrid systems. Normally, for the experts are easier to express their knowledge through cases occurred, which allows inferring the problems that arise in the future, so it seems advisable to use the Case Based Reasoning technique [4, 5].

The CBR is an Artificial Intelligence technique that takes advantage of information and experience in solving new problems. This technique allows to store the proposed solutions for past cases, and to use them when a new problem is arising.

This technique attempts to reach the solution of new problems in a similar way as the humans do [6]. When someone is facing a new problem, it begins to look for a solution into its own earlier experiences, which could be or not similar to the current case, and thereafter establishes similarities, differences and combinations of the possible solutions given earlier in order to obtain a new solution.

The CBR tool selected for the implementation of the expert system was the commercial software Induce-it from the company Inductive Solutions Inc. [7], developed on Microsoft Excel ® which is compatible with the development tools selected previously, and allows using some functions such as graphics, formulas, macros, among others.

## COMPUTATIONAL SYSTEM DESCRIPTION

The system includes two main functional modules called Assessment and Diagnosis; complemented with a third module for the data entry and the system configuration module. Figure 2 shows the functional modules.

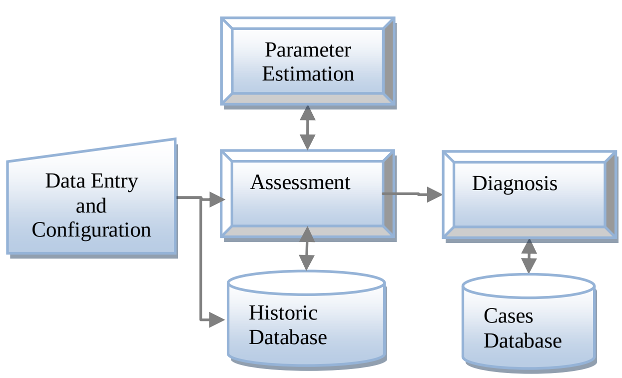



Figure 2. PEDSE functional structure

It is important to note that functional modules can be used both for evaluating the entire cooling system and each individual piece of equipment, i.e. condenser, cooling tower or circulating water pumps.

### User Interface

The visual aspect of any information system is important because it is the first contact between the software and the final user. Moreover, the interface allows the users to manipulate a system and indicate the effects of these manipulations. One of the goals of the software designer is to produce a friendly user interface which makes it easy, efficient, and enjoyable to operate, in the way that produces the desired result, providing minimal input to achieve the desired output.

For this reason the software PEDSE includes a Graphical User Interface (GUI) that is functional, attractive, and easy to use. The GUI was implemented as a Flash movie embedded on a form in the VB.NET application.

The GUI offers graphical icons, and visual indicators, typed command labels or text navigation to represent the information and actions available to the user.

Each of the program functional options is accessible via the main menu, which is shown in Figure 3.


Figure 3. Main menu of the PEDSE software

The menu options correspond to the analysis of each piece of equipment as well as the entire cooling system, plus a basic option for a general configuration of the power plant to be assessed. In this way, users can perform integrated or independent assessments for the same power plant.

As an example in this document the data of the condenser will be used to show results of system PEDSE.

### Configuration module

This module allows the user to capture the general information of the power plant (name, location, power, main steam flow rate, fuel flow rate, among others), as well as the design data for each of the cooling system equipment, which are then used for the calculation of the performance indicators and the operational diagnosis. Whenever the system is started or it is desired to analyze a new case, it is necessary to enter the configuration screen from which it is possible to keep and recover historical data (see Figure 4).

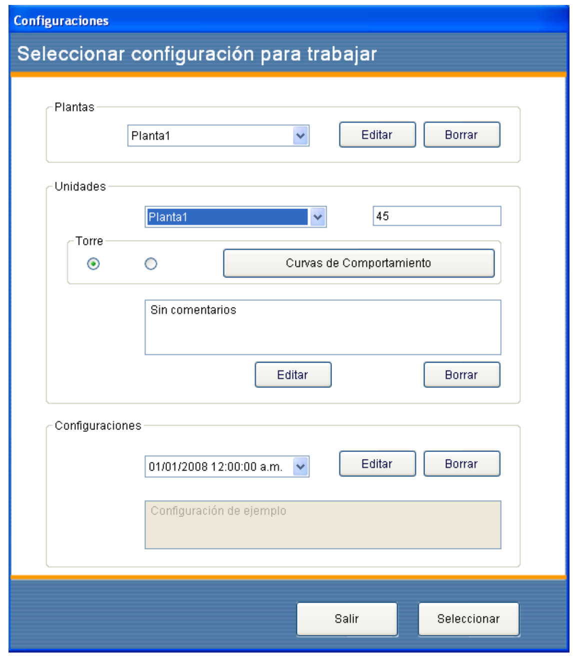



Figure 4. Configuration module

### Assessment module

The main functions of the computational system are to calculate the values of the parameters that indicate the current performance of the equipment, and to diagnose the causes of their inefficiencies. The First stage is carried out through the performance assessment module, from which the efficiency indicators are obtained from a previously developed procedure [2], which is based on the standards for equipment performance assessment published by the Heat Exchange Institute (HEI), the Cooling Technology Institute (CTI) and the American Society of Mechanical Engineers (ASME).

The assessment module allows entering the operative data for the present case analyzed. Once the parameters are calculated, the program is ready to make the diagnosis for each piece of equipment and for the entire cooling system.

The computational system has an historical database that includes the parameters captured by the user and the calculated indicators. For the condenser, the data include: cleanliness factor, heat transfer coefficient, heat duty, cooling water temperature rise, logarithmic mean temperature difference, terminal temperature difference, condensate subcooling, and pressure loss in tubes. Parameters of the cooling tower include the tower capability and the expected cold water temperature, among others. Finally, for the circulation water pumps the parameters include: pump capacity, overall efficiency, total heat, driver input power, and pump output or hydraulic power.

Figure 5 shows the screen corresponding to the evaluation module of the condenser.

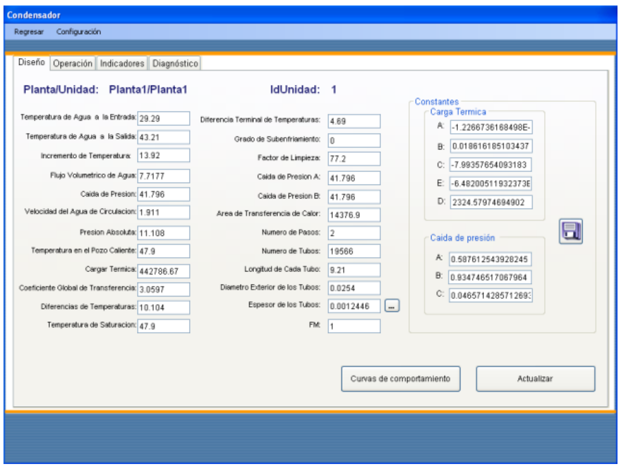


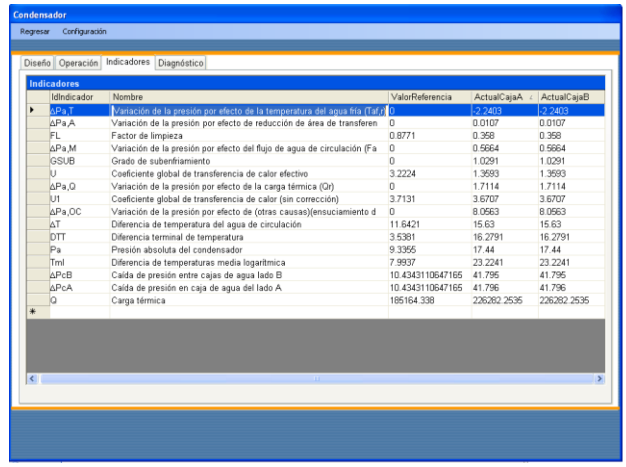

Figure 5. Condenser evaluation screen

In this screen the design and operation data required are entered so that the system calculates the corresponding reference and current indicators for each of the two water boxes of the condenser, which is shown as a list to the user, as it can be seen in Figure 6.

### Diagnosis Module

After entering the data of the cooling system configuration and making the calculation of performance indicators, the user can access the module for equipment operational diagnosis, whose function is to process the design and operative information, as well as the results from the assessment module in order to diagnose the operating status of equipment and to provide the user with a list of operation recommendations and maintenance actions to be implemented in order to restore the system efficiency.

Based on the causes of inefficiencies that the expert system could identify, the software will display a list of corrective or preventive actions that can help to recover the optimal operation conditions for the cooling system and the whole power plant.




| IdIndicador | Nombre | ValorReferencia | ActualCajaA | ActualCajaB |
|---|---|---|---|---|
| ΔPa,T | Variación de la presión por efecto de la temperatura del agua fría (Taf,r | 0 | -2.2403 | -2.2403 |
| ΔPa,A | Variación de la presión por efecto de reducción de área de transferen | 0 | 0.0107 | 0.0107 |
| FL | Factor de limpieza | 0.8771 | 0.358 | 0.358 |
| ΔPa,M | Variación de la presión por efecto del flujo de agua de circulación (Fa | 0 | 0.5664 | 0.5664 |
| GSUB | Grado de subenfriamiento | 0 | 1.0291 | 1.0291 |
| U | Coeficiente global de transferencia de calor efectivo | 3.2224 | 1.3593 | 1.3593 |
| ΔPa,Q | Variación de la presión por efecto de la carga térmica (Qr) | 0 | 1.7114 | 1.7114 |
| U1 | Coeficiente global de transferencia de calor (sin corrección) | 3.7131 | 3.6707 | 3.6707 |
| ΔPa,OC | Variación de la presión por efecto de (otras causas)(ensuciamiento d | 0 | 8.0563 | 8.0563 |
| ΔT | Diferencia de temperatura del agua de circulación | 11.6421 | 15.63 | 15.63 |
| DTT | Diferencia terminal de temperatura | 3.5381 | 16.2791 | 16.2791 |
| Pa | Presión absoluta del condensador | 9.3355 | 17.44 | 17.44 |
| Tml | Diferencia de temperaturas media logarítmica | 7.9937 | 23.2241 | 23.2241 |
| ΔPcB | Caída de presión entre cajas de agua lado B | 10.4343110647165 | 41.795 | 41.795 |
| ΔPcA | Caída de presión en caja de agua del lado A | 10.4343110647165 | 41.796 | 41.796 |
| Q | Carga térmica | 185164.338 | 226282.2535 | 226282.2535 |

Figure 6. Performance indicators for the condenser

The equipment diagnosis module is integrated as an expert system based on the methodology of Case Based Reasoning. The database cases were initially integrated with the information obtained from expert engineers in the field of study and with the cases reported in the literature [8-11]. The general knowledge database allows identifying previous cases that can help to the deal with a new problem by providing the most reasonable causes and the most effective maintenance actions to eliminate or reduce the causes that affect the performance of the cooling system.

The content of the knowledge database was defined by the contributions of a group of experts from chemical, thermal, mechanical and fluid flow fields, taking into account their level of expertise and readiness to participate in interviews and working sessions. Also contributions of potential users were considered at this stage.

The diagnosis module of the PEDSE was implemented following the phases of the CBR cycle, which are shown in Figure 7.

The steps followed by the expert system in order to accomplish the diagnosis and issue proper recommendations, are outlined below.

1. The system retrieves the data entered by the user in the configuration or settings module, as well as the indicators calculated in the assessment module; these data constitute the problem or new case.
2. The new case is sent to the expert system module where the programmed algorithm looks for similar historical cases.
3. The algorithm retrieves the case number that is

closest to the current problem. If the system finds some kind of error in this process, it returns an error message.

4. The number of case is searched in the cases database in order to obtain the applicable diagnosis and recommendations.
5. Finally, the results are presented to the user by means of the GUI. The user can see the respective diagnosis and the recommendations for the new case, or else a message of an error occurred during the diagnosis process.

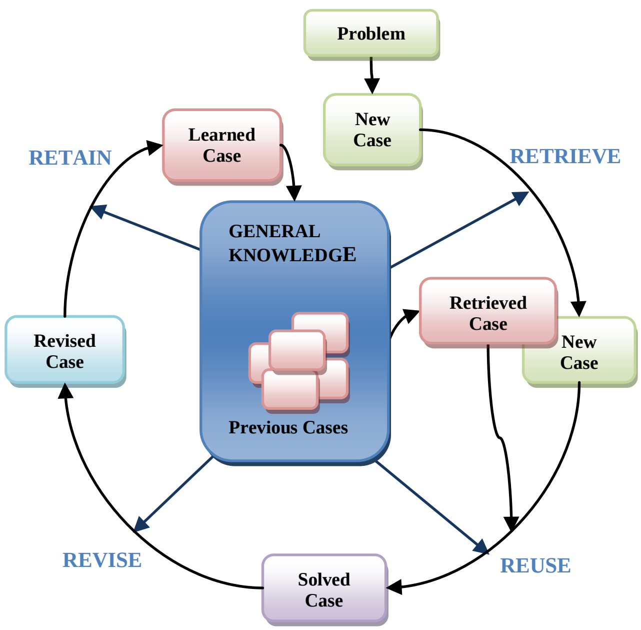



Figure 7. The Case Based Reasoning Cycle [12]

The results of the assessment and diagnosis for a condenser in a 300 MWe power plant with data measured immediately after its annual maintenance is shown in Figure 8.

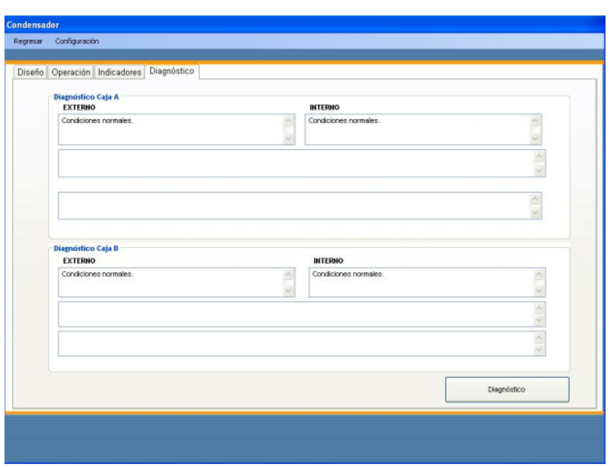



Figure 8. Results from the Diagnosis module

As it is shown in the Figure, no recommendation is issued because the equipment did not show deviations in their operational performance indicators. The expert system only shows a diagnostic message indicating that equipment are operating under normal operating conditions, which means that maintenance performed in the condenser was carried out correctly, and the cooling tower is delivering water at the required temperature condition, since the circulating water pumps are handling the water flow rate for which they were designed, and also the exhaust steam from the turbine is maintained at normal conditions corresponding to the power plant current load.

The above findings as well as the numerical indicators that support them are also presented to the user in predefined Word and Excel formats, including operative and executive reports.

## CONCLUSIONS

This paper presents an approach to the solution of identifying and diagnosing problems and causes of inefficiencies for the operational performance of equipment in the cooling systems of thermal power plants.

The PEDSE software, which is based on a previously published methodology for the calculation of performance indicators [2], is a tool that allows assessing and diagnosing the causes of inefficiencies in equipment by comparing the current indicators to the expected ones, and through an expert system that uses the Case Based Reasoning technique.

The development of the program outlined here, allowed to analyze and managed the inefficiencies of cooling systems in several power plants in Mexico, as well as validate a real time monitoring and diagnosis system implemented in a 300 MWe power plant.

The ESDP is an important reference for both studies by the IIE, and users of the electricity generation industry.

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