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DADICC: Intelligent system for anomaly detection in a combined cycle gas turbine plant

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Abstract

DADICC is the abbreviated name for an intelligent system able to detect on-line and diagnose anomalies as soon as possible in the dynamic evolution of the behaviour of a power plant based on a combined cycle gas turbine. In order to reach this objective, a modelling process is required for the characterization of the normal performance when any symptom of a possible fault is present. This will be the reference for early detection of possible anomalies. If a deviation in respect to the normal behaviour predicted is observed, an analysis of its causes is performed in order to diagnose the potential problem, and, if possible, its prevention. A multi-agent system supports the different roles required in DADICC. The detection of anomalies is based on agents that use models elaborated using mainly neural networks techniques. The diagnosis of the anomalies is prepared by agents based on an expert-system structure. This paper describes the main characteristics of DADICC and its operation.

Keywords: Anomaly detection; Normal behaviour; Diagnosis; Multi-agent system; Neural network; Expert system

1. Introduction

The Monitoring, Diagnosis and Simulation Center of Iberdrola S.A. (referred to as CMDS in Spanish) is in charge of supervising the 31 Combined Cycle Power Plants (CCPP) all around the world with a production of 67,000 GW h/year. The data acquisition systems of the CMDS are working in real-time with all combined cycle power plants, analyzing operational and maintenance data and suggesting recommendations about the improvement of the availability, reliability and efficiency of the plants.

The mission of the CMDS is to identify asset performance degradations and malfunctions in the CCPPs by means of symptoms and indicators of initial stage problems and to provide timely solutions and recommendations regarding plant management, operations, and maintenance that will enable them to optimize their CCPP performance (Mendivil, Alvarez, Sandrea, & García, 2003).

DADICC has been developed for the CMDS as a remote monitoring and diagnostic tool which allows to be kept under constant control the operating conditions of the CPPP. This monitoring and diagnosis system automatically detects incipient deviations of both performance and condition from normal operation at an early stage, thus enabling plant management to avoid and reduce performance losses and more serious damage to the assets.

DADICC is a tool which was developed by IIT (Instituto de Investigación Tecnológica) in cooperation with IBERDROLA, a Spanish electrical company.

The organization of this paper is as follows. Section 2 provides an overview of the main features and architecture of DADICC. Section 3 describes the scope of the system and its knowledge sources. Section 4 is dedicated to the strategy of anomaly detection and process of the normal behaviour modelling. Furthermore, Section 5 describes the multi-agent intelligent architecture of DADICC and

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in Section 6, the main characteristics of the basic types of agents in DADICC are explained. Finally, Section 7 presents an example of the DADICC operation.

2. DADICC: Objectives and architecture

DADICC has been developed as an intelligent system able to reach a double objective:

(a) The detection as soon as possible of anomalies in the normal behaviour predicted for the dynamic evolution of variables that characterize the components of a Combined Cycle Gas Turbine (CCGT) Plant inside the scope of DADICC. This process is performed in real-time when new information about those components is collected usually by sensors installed on them. The anomalies detected or their symptoms could correspond either to faults already present or to an incipient state.
(b) The diagnosis in real-time of causes for the anomalies detected. This is a process oriented to help the personnel in charge of the CCGT plant operation in order to focus their attention on the most critical aspects of problems taking place and, if possible, to guide them in their correction.

The early detection and diagnosis of possible anomalies will allow for rapid action to cut or mitigate the consequences of them in the life of the plant and its maintenance.

In order to reach these objectives, DADICC performs the following main tasks:

- Continuous collection of data coming from the CCGT plant supervision system related to the components inside the scope of DADICC.
- Continuous processing of the information collected in order to detect if some symptoms of anomalies are present or could become present (Davies, 1998). This process is based on *normal behaviour modelling* (that is, in absence of failures) of the plant components. Thus, *normal behaviour models* have to be obtained previously using real data in order to characterize the normal dynamics of the representative variables of each component without any failure. The different operation conditions of the components are also taken into account in the models. DADICC works on-line taking current measurements from the process and evaluating the prediction of values from the models. The comparison between measured and predicted values of particular variables permits the detection of anomalies in the normal behaviour predicted. These could be symptoms of incipient failure modes or faults that in any case have to be investigated.
- Diagnosis of the root causes of the anomalies detected using knowledge coming from the experience of the CCGT plant operation. This is implemented using the structure of an expert system.

Each of the previous three tasks have to be performed for the different components of the plant and for the detection and diagnosis of different possible failure modes of them. The events happening in the plant occur in parallel, and as consequence there is no reason to do a serial process of this information. All these features have suggested a distributed architecture for DADICC, but even more, the tasks of anomaly detection and diagnosis have to be performed using intelligence in the context of a particular autonomy of the decision to be taken. These considerations are the basis for the selection of a multi-agent intelligent architecture for DADICC. In this architecture, there are several agents in charge of the process of anomaly detection according to criteria concerning the type of anomalies to be detected, the type of models be used and the plant component be analyzed. Furthermore, there are agents in charge of the diagnosis of different aspects of the components in the DADICC scope. Fig. 1 presents an overview of the DADICC architecture.

Fig. 1 shows a set of components of the CCGT plant that supply information through sensors to the DADICC agent in charge of the collection of this information. A set of agents in Fig. 1 have the role of anomaly detectors based on models of normal behaviour. They are coordinated by one specific agent for that role. Another set of agents are in charge of the diagnosis of the causes of the anomalies detected, also coordinated by one coordinator agent. Finally all the information is shared among all the agents and other services not included in Fig. 1 using a web service. They will be described later.

As is shown in Fig. 1, there are a set of models that support the operation of the agents for anomaly detection, they are the normal behaviour model. These models are able to predict on-line the normal behaviour (or reference behaviour) expected for each particular component of the CCGT plant analyzed, according to its current working and environmental conditions. These models are created mainly by means of *artificial neural networks* due to their ability to model dynamic non-linear industrial processes (Haykin, 1994; Muñoz & Sanz-Bobi, 1998). The prediction of the models is activated and required by the anomaly detection agents, each one having different models under its domain. For each variable predicted by a model the anomaly detection agent compares its normal behaviour estimation with its real behaviour and as a result a *normal behaviour deviation degree* as well as an *estimation certainty degree* are obtained. These are used to recognize an anomaly present and the certainty of it (Cruz García, Sanz-Bobi, & del Pico Aznar, 2006; Iserman, 1984; Patton, Frank, & Clark, 2000; Sanz-Bobi et al., 2002).

Each diagnosis agent in Fig. 1 has as its main goal the identification of the possible failure modes that are present or in development in some plant component before it faults in an irreversible way, for this reason, these detection and diagnosis tasks are called incipient (Rasmusen, 1993). In order to reach this objective, this agent is based on an *expert system* able to represent in a flexible way both the