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A Bio-inspired knowledge system for improving combined cycle plant control tuning

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ABSTRACT

This study presents a novel bio-inspired knowledge system, based on closed loop tuning, for calculating the Proportional-Integral-Derivative (PID) controller parameters of a real combined cycle plant. The aim is to automatically achieve the best parameters according to the work point and the dynamics of the plant. To this end, several typical expressions and systems were taken into account to build the model for this multidisciplinary study. Each of these expressions is appropriated for a particular system. The novel method is empirically verified under a real case study based on an auxiliary steam system of a combined cycle plant.

1. Introduction

It is well known that the typical power generation plants are far from achieving an optimal operating point [40]. Consequently, these plants are not operating at an optimal point of production in economic terms. In an effort to reverse this situation a large number of Combined Cycle Power Plants have been built in recent years. These new plants allow higher efficiency levels and reduced pollutant emissions. Compared to traditional power plants, they guarantee higher efficiency and reduced emissions [41].

However, it is also well known that Combined Cycle Power Plants experience significant losses of efficiency and are usually used to control the net frequency [42]. The primary reason for this is the auxiliary services of the plant, which are not optimized [42]. Recently much research has been made in this field with the aim to improve this type of power plants and to increase their overall efficiency [41,42,49–52].

Although the PID controller is one of the most traditional control mechanisms, researchers are still working with it to improve its control action and performance [1–4]. While there are several studies oriented to the same objective, they are always tailored to specific systems such as, for example, Robot Fault Diagnosis [2], speed controller [3] and, mobile robot control [4].

Despite this, there are many controllers operating far below the most favorable state [7], or general system controllers that are not self-tuning. Thus it is indispensable to achieve new ways to solve this problem. In many research studies related to the PID controller, the method followed is to try to obtain the best parameters according to the system [26–30]. Another way is to achieve self-tuning controller topologies [4–6].

Rule based systems are models based on the experience of human experts [43,58]. These experts deduce rules from a system and structure the rules according to their behavior [43]. These methods allow the implemented system to emulate the expert's behavior in a certain field [43,44], and have been one of the most implemented methods in both research and operation [44]. There are several examples of those models. For instance [56] combines both rule based systems and case based reasoning to provide product design decision support. [57] shows a rule based system that complements the Risk Metrics Wealth Bench system for portfolio optimization with nonlinear cash-flows and constraints. [58] describes a robust and general rule-based approach to manage situation awareness. Bio-inspired models are inspired by nature [45], which can be applied in many systems ranging from such diverse fields as industry, network security and health-care [45,53,55]. These models provide a deeper insight of biological phenomena. Bio-inspired systems provide solutions to problems that could not be solved satisfactorily by other techniques

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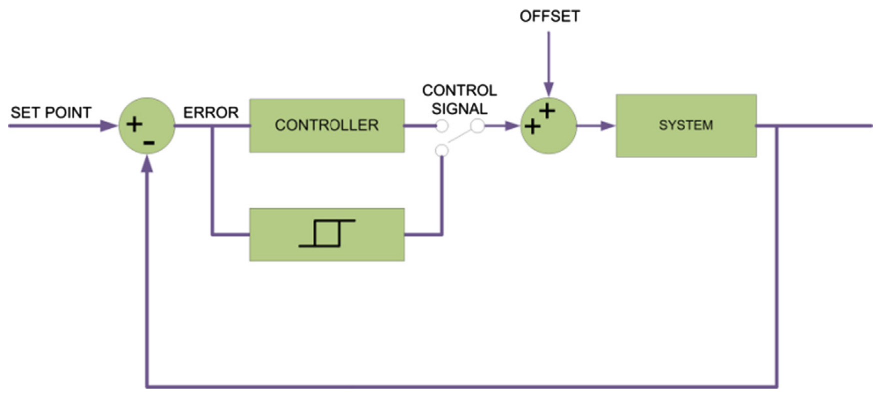

Fig. 1. Typical configuration of Relay-Feedback.

[46,47,48]. Some examples of Bio-inspired models are: neural networks [53], evolutionary systems [54] and the ant colony [55].

The use of rule based systems and Bio-inspired models in a knowledge system is befitting for solving the control problem of the auxiliary steam system of a combined cycle plant and improving the overall efficiency of the power plant.

The novel Bio-inspired Knowledge System (BIOKSY) presented in this study consists of two phases. The first phase is based on expert rules [31,32] and the second on a bio-inspired method [33–35]. The basic element of the model based on rules only contemplates techniques with a thoroughly tested implantation in the industry. BIOKSY is based on practical and robust methods [7,12]. There are several methods and applications that combine rule-based systems and bio-inspired models. For instance [36] shows an approach that maps a rule-based system into the neural architecture in both, the structural and the behavioral aspects. In [37] a medical application is used to test the behavior of the proposed hybrid systems. [38] studies an expert system designed to assist managers in forecasting the performance of stock prices; it was developed to demonstrate the advantages of this integrated approach and how it can enhance support for managerial decision making.

Essentially the novel method proposed in this paper achieves the best tuning parameters of a PID controller to improve a certain desired specification. Typical results of previous research [9–12] were taken into account, but it is possible to include any other method in the model.

The model is verified over the part of the cycle plant that provides electric power. While many other studies have been made to improve the operation and the efficiency of this type of industry [22–25], the objectives in this case are achieved through control optimization.

This paper is organized as follows. It begins with a brief description of the general diagram followed by an explanation of the PID controller format, and a brief review of PID controller tuning in a closed-loop. BIOKSY is then presented, followed by an empirical verification made over the auxiliary steam system of a combined cycle plant. Finally conclusions and future works are presented.

2. PID controller

A PID controller is a generic control loop feedback controller widely used in industrial control systems [7]. PID is the most commonly used feedback controller [8]. Essentially, a PID controller calculates an error value as the difference between the measured process variable and the desired setpoint [7]. The controller attempts to minimize the error by adjusting the process control inputs. The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control, in reference to the proportional, the integral and derivative values [10].

2.1. PID controller format

There are several topologies of PID controllers, but this study employs the standard format presented in Eqs. [(1),(7) and (8)].

$$u(t) = K\left[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}\right] \quad (1)$$

where 'u' is the control variable and 'e' is the control error given by '$e = SP - y$' (difference between the setpoint 'SP' and conditioned output 'y'). The other terms are the tuning controller parameters: proportional gain 'K', integral gain 'Ti' and derivate gain 'Td'.

2.2. PID controller tuning in closed-loop

This section presents the PID controller tuning method in closed-loop. BIOKSY is based on this tuning technique. First of all, the general procedure to calculate parameters will be presented, followed by an explanation of the procedure used to obtain the response characteristics. Finally, typical expressions used to obtain the PID controller parameters are shown.

2.2.1. General procedure to calculate parameters

Two steps are necessary to obtain the controller tuning parameters in closed loop:

- 1st Step. It is necessary to carry the system response to a permanent state of oscillation, after which certain characteristics of the response must be measured.
- 2nd Step. According to the information achieved from the plant response, appropriate expressions must be applied to obtain correct controller parameters for the desired specifications.

2.2.2. Obtaining the response characteristics in closed-loop

Different methods can be used to obtain the controller parameters. BIOKSY uses a relay-feedback method proposed by Aström and Hägglud [7]. The results are very similar to those obtained by the traditional method proposed for Ziegler–Nichols [9], but with some very important advantages including the fact that the system operates at a state that is far from unstable, and also the fact that tuning can be made at any time for any working point.

The implementation scheme of relay feedback is shown in Fig. 1. A relay with hysteresis centered on the zero value with an