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A Fuzzy Supervisory System for Improving Temperature Control in an Industrial Gas Processing Unit

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Abstract—**In this paper, a supervisory control system based on fuzzy reasoning is designed for a real gas processing unit. The system controls the gas temperature flowing through an industrial heat exchanger which is the main component of the unit. The design procedure aims at improving the performance of the existing conventional temperature control system by providing instantaneous monitoring of the control loop through auto-tuning of PID parameters. To show the performance of the designed system, simulations under different situations are performed and some implementation issues on DCS system are given.**

Keywords-supervision; control loop;, fuzzy reasoning; gas processing unit

I. INTRODUCTION

In most industrial applications, physical plants usually operate under conventional regulatory strategies based on the common proportional-integral-differential (PID) controllers. Traditionally, plant controller designers have developed this type of control configuration in order to minimize costs of real implementation, maintenance and operators' training [6]. Operators' experience with this type of controller plays a substantial role while choosing the control strategy to be implemented for a particular application. Indeed, in highly sensitive processes such as chemical, petrochemical and nuclear units, for instance, control loops are often equipped with conventional PID controllers rather than sophisticated strategies [8]. However, PID controllers usually show decreasing performance under varying operating conditions and system nonlinearities [1,6,7]. Manual tuning of PID parameters is usually performed to cope with some critical situations. However, this heuristic procedure does not take into account the required level of operational performance.

More advanced control mechanisms, like intelligent control, adaptive control or predictive control show considerable improvements, especially for processes operating under severe disturbances and over wide-range zones. Sevaral works in the literature reported interesting theoretical and experimental results about intelligent control techniques and their robustness with respect to process and environmental variations, even in the absence of systematic design methodologies [9]. Intelligent paradigms can be integrated to the process control level and/or the supervisory level depending on the application of concern [1,4]. Supervisory control aims at making conventional PID controllers more flexible through auto-tuning so that optimal or near optimal parameters can be found to meet some predefined stringent control requirements.

This paper discusses some experimental issues related to the design of a fuzzy supervisory system to improve temperature control performance of an industrial gas processing unit. More precisely, the design procedure is achieved for an industrial co-current heat exchanger aiming at tuning the PID parameters of the gas temperature control loop based on fuzzy reasoning. The present study was subjected to a simulation-based evaluation on DCS (Distributed Control System) using the real parameters of the gas processing unit together with the on-site parameters of the temperature control loop.

II. INDUSTRIAL PROCESS DESCRIPTION

Natural gas feeding the industrial processing unit arrives from different production sites through twelve collectors at 84 kg/cm^2 and 50°C. The main task consists in achieving total condensate recovery, gas compression and recycling to other units. To this end, five processing lines labeled as 10 to 40 and 70 are installed. Each processing line is composed of two parts: the high-pressure (HP) part for the treatment of gas-liquid phase, and the low-pressure (LP) part for unstable condensate processing. The crude gas passes first via the slugcatcher unit, and after flowing through different pipes, it is supplied to a co-current heat exchanger for cooling, and then evacuated with temperature 22°C to a triphasic separator for separation purposes.

In this paper, the heat exchanger under investigation is labeled as 20E02, as depicted in the schematic picture of Figure 1. This physical plant of 16.5 m height and 1418 tubes is one of the most important and critical component of the gas processing unit. The crude gas entering the exchanger is cooled through a heat exchange process with cold gas coming from the gas/gas primary exchanger 20E01. The outlet temperature is controlled at 22°C with a conventional PID controller and must be maintained around this value in order to meet the stringent separation process requirements and keep safe the processing line equipments.

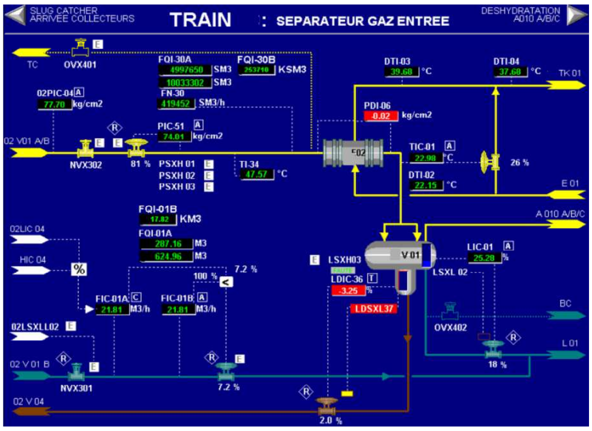

Fig. 1. Schematic picture of the heat exchanger 20E02 in line 20.

III. GAS TEMPERATURE FUZZY SUPERVISOR DESIGN

All of control loops in the gas treatment unit are based on conventional PID controllers. The temperature control loop of the heat exchanger 20E02 is designed to ensure regulatory task about 22°C of the outlet gas temperature. This value is to be maintained to ensure good separation between gas, water and condensate in the high-pressure triphasic separator 20V01. Efficient separation process should be achieved in order to avoid the formation of hydrates in the corresponding line which could occur at 18°C and 77 kg/cm^2. Alarm generating devices are installed to prevent reaching the limit value which is fixed at 19°C. Obviously, it can be noticed that ensuring suitable operation of the whole unit depends strongly on the “perfect” functioning of the gas temperature control loops. This issue remains of substantial interest for systems engineers.

From a modeling viewpoint, heat exchanger dynamics are difficult to capture accurately by simple model structures since the underlying physical effects are quite complex and a number of real parameters are unknown. Key dynamical properties of the heat exchange process are generally described by distributed-parameter models that are of little interest for control purposes [5]. Approximations through lumped-parameter models are usually used for dynamics analysis and control systems design. However, the simplified models upon which PID control strategies are built could not ensure a robust wide-range operation [2,3]. Indeed, it was easy to notice that in many practical situations, PID parameters need to be tuned manually to avoid performance degradation during gas processing unit operation. This heuristic tuning procedure which is applied with conventional operators’ experience methods cannot give optimal PID parameters for the gas temperature control system.

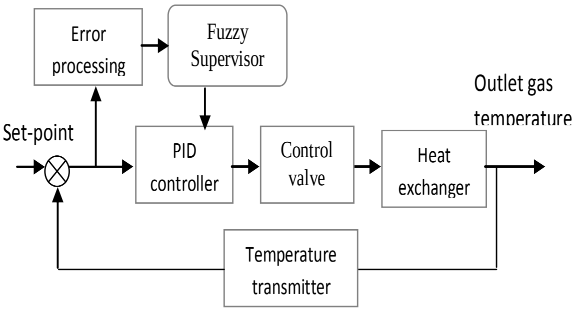

Fig. 2. Block diagram of the fuzzy supervisory gas temperature control system.

The fuzzy supervisory system designed in this paper aims at improving the performance of the conventional gas temperature control loop through auto-tuning of the PID parameters. The three PID parameters, *i.e.* K_p, K_i and K_d can be altered based on a fuzzy reasoning mechanism according to the size, the direction and the changing tendency of the system error. The diagram of the fuzzy supervisory PID control system is depicted in Figure 2. For the heat exchanger operation, control error e and the change of error Δe are the input linguistic variables of the fuzzy supervisor, and ΔK_p, ΔK_i and ΔK_d are their output linguistic variables. Each linguistic variable has seven values labeled as NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZO (Zero), PS (Positive Small), PM (Positive Medium) and PB (Positive Big). These triangular-shaped fuzzy sets are uniformly distributed on the common normalized universe of discourse [-1 1]. The fuzzy supervisor is a rule-based system composed of a set of n IF-THEN rules as follows:

$$\begin{gathered} IF\ e(k)\ is\ LE^j\ and\ \Delta e(k) is\ L\Delta E^j\ THEN \\ \Delta K_p(k)\ is\ LK_p^j\ and\ \Delta K_i(k)\ is\ LK_i^j\ and\ \Delta K_d(k)\ is\ LK_d^j \\ j = 1, \cdots, n. \end{gathered} \tag{1}$$

where LE^j, $L\Delta E^j$, LK_p^j, LK_i^j and LK_d^j represent the j-th linguistic values of the input/output fuzzy variables e, Δe, ΔK_p, ΔK_i and ΔK_d, respectively. The PID tuning mechanism is performed instantaneously according to the following equations [1]:

$$K_p = K_{p0} + \Delta K_p \tag{2}$$
$$K_i = K_{i0} + \Delta K_i \tag{3}$$
$$K_d = K_{d0} + \Delta K_d. \tag{4}$$

where K_{p0}, K_{i0} and K_{d0} denote the actual (on-site) PID parameters. The PID parameters tuning procedure based on this fuzzy reasoning mechanism defines a nonlinear mapping between the fuzzy supervisor outputs, and the control error and its rate of change.

IV. RESULTS AND DISCUSSION

The original conventional temperature control configuration of the gas treatment unit is implemented on DCS which provides many facilities allowing systems analysis, simulation and control through its IEE (Infusion Engineering Environment) software. The results presented in this paper are based on the physical parameters of the industrial heat exchanger and the on-site parameters of the PID control loop which are set as $K_{p0} = 2.5$, $K_{i0} = 1.11$ and $K_{d0} = 0.38$. The fuzzy supervisor blocks are embedded in DCS according to the diagram shown in Figure 3. The control parameters K_p, K_i and K_d of the real PID controller are tuned off-line under different situations in order to check the effectiveness of the designed self-tuning mechanism.

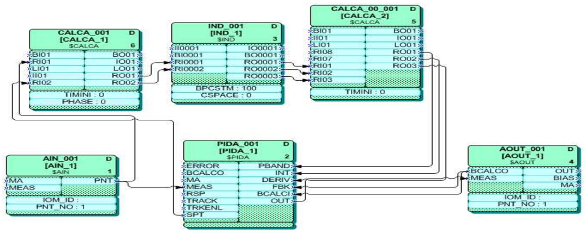

Fig. 3. Configuration of the fuzzy supervisory gas temperature control system on DCS.

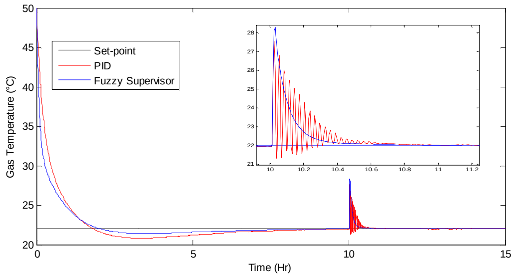

Fig. 4. Outlet gas temperature response in normal operation.

Figure 4 shows the outlet gas temperature response in normal regulatory operation. This situation corresponds to inlet gas cooling process before evacuation to the HP triphasic separator. Here the gas temperature is decreased from 50°C (slugcatcher outlet gas temperature) to 22°C. It can be clearly seen that the fuzzy supervisor performs considerably well, mainly after applying an input disturbance on the control valve at t = 10 hrs. The PID controller induces an oscillatory response which is efficiently damped by the fuzzy supervisor through auto-tuning of the PID parameters.

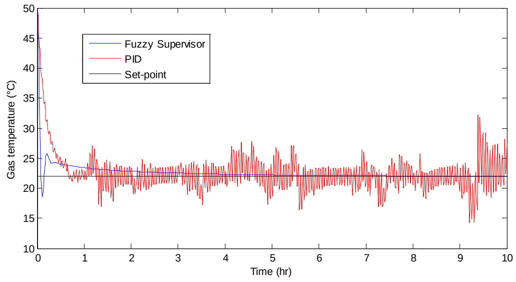

Fig. 5. Outlet gas temperature response under system parameter variations.

Degradation of the control loop performance is mostly caused by parameter variations of the controlled heat exchanger due to aging, thermal stress or environmental changes, for instance. To illustrate this situation, we considered a test case corresponding to parametric variation of the heat transfer coefficient. This physical parameter is generally unknown and difficult to obtain through first-principle modeling; it can only be estimated using observation data. In this case study, Figure 5 shows clearly the poor performance of the PID control loop. The gas temperature response fluctuates around non-admissible values that would contribute to the formation of hydrates in the gas processing line. In this case, an alarm would occur when the temperature reaches the limit of 19°C. However, the heat exchanger operation under the supervisory control system seems very acceptable and the regulatory requirement is achieved efficiently. This demonstrates the robustness of the fuzzy control system with respect to the system parameter variations which are frequent in practice and for which manual tuning is usually operated to prevent the degradation of the plant operation.

V. CONCLUSION

Throughout this contribution, a simulation-based evaluation on DCS of the performance of a fuzzy supervisory control system is achieved using the real parameters of an industrial gas processing unit together with the on-site parameters of the temperature control loop. Auto-tuning of the PID parameters through fuzzy reasoning improves considerably well the outlet gas temperature control loop performance. This problem is of major interest for systems engineers since the manual tuning of the PID parameters based on operators' experience could not always give satisfactory operational performance. In practical situations, stringent requirements on control strategies are usually imposed to meet production conditions. Embedding intelligent paradigms into conventional control configurations would achieve better results as shown in the present study.

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