Control Engineering Practice 18 (2010) 67–76

Contents lists available at ScienceDirect

Control Engineering Practice

journal homepage: www.elsevier.com/locate/conengprac

# Multi-objective optimization and selection for the PI control of ALSTOM gasifier problem

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ARTICLE INFO

*Article history:*
Received 17 October 2007
Accepted 3 September 2009
Available online 6 October 2009

*Keywords:*
Multi-objective optimization
Gasification
PI control

ABSTRACT

Based on the baseline PI control structure, the control parameters of non-linear ALSTOM gasifier benchmark problem are optimized. Firstly, taking all the input and output limits under three load conditions as constraints, the relative IAE indices at six scenarios are calculated and optimized by using multi-objective optimization algorithm NSGA-II. A set of non-dominated solutions are obtained which facilitate the further improvement on the performance under coal quality change. Then among those non-dominated solutions, the solution with best coal quality flexibility comes to the fore through a selection procedure. The simulation results show that the optimization and selection procedure presented in this paper improves the baseline PI control performance with better dynamic responses and coal quality flexibility.



## 1. Introduction

After the publication of the gasifier control benchmark problem by ALSTOM Power Technology Centre (Dixon & Pike, 2004; Dixon, Pike, & Donne, 2000), many advanced control methods have been developed for this problem, such as PI/PID control (Asmar, Jones, & Wilson, 2000; Farag & Werner, 2006; Liu, Dixon, & Daley, 2000; Munro, Edmunds, Kontogiannis, & Impram, 2000; Simm & Liu, 2006; Xue, 2005; Xue, Li, & Lv, 2005), $H_2/H_\infty$ control (Chin & Munro, 2003; Gatley, Bates, & Postlethwaite, 2004; Griffin, Schroder, Chipperfield, & Fleming, 2000; Prempain, Postlethwaite, & Sun, 2000), predictive control (Al Seyab, Cao, & Yang, 2006; Rice, Rossiter, & Schuurmans, 2000), PIP control (Taylor, McCabe, Young, & Chotai, 2000; Taylor & Shaban, 2006), state-feedback control (Wilson, Chew, & Jones, 2006), etc., among which the PI control shows obvious advantage owing to its feasibility in design and implementation.

Though most control strategies for ALSTOM gasifier benchmark problem can meet the performance specifications under pressure disturbances and load tracking, their control behavior is influenced seriously by the feed coal quality, which was not considered in the control system design of the above published articles.

Coal quality variation is one of the significant factors that influence the operation of coal gasifier. It will deteriorate the control system performance, and bring difficulties to the operator's manipulation. Providing the operator with analysis data of coal components and calorific value, or scheduling the controller parameters based on the identification of coal quality variation online (Qiu, 2007; Zhang, 2004), are the general approaches to ameliorate the control effect when coal quality varied frequently. In order to deduce the key variables or rules of coal quality variation, a lot of industry experiments on various coal species are required for these methods. So they are not suitable for this gasifier benchmark problem which have no published theoretical model and coal species data. Moreover, it is difficult to accurately measure the coal quality variation online; and those strategies which estimate and compensate the uncertainty of coal quality still need further investigations.

Since a set of finely tuned control parameters, which aimed to get best dynamic performance at various pressure disturbances and load conditions, may not meet the specifications at coal quality variation comfortably, a natural thinking is to integrate the influence of coal quality variation into objective function of control optimization problem. However, for the ALSTOM gasifier benchmark problem, the optimization of coal quality feasibility will take too long time to observe and calculate the influence of coal quality variation under various pressure disturbances and load conditions, and the dynamic performance at nominal coal quality will become worse inevitably. High performance computer may be helpful to speedup the calculation, but the entire optimization procedure is still time-consuming at present.

In this paper, a tradeoff optimization method is presented for the benchmark gasifier control problem to obtain better disturbance rejection and coal quality feasibility for PI control

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doi:10.1016/j.conengprac.2009.09.004

strategy. The baseline control structure is adopted, and the decentralized PI controller parameters are optimized through two-steps: optimization and selection. In the first step, disturbance rejection is the main objective. A set of non-dominated solutions is obtained by using multi-objective optimization algorithm NSGA-II (Deb, Pratap, Agarwal, & Meyarivan, 2002). These solutions can meet all the input and output constraints under various disturbances and load conditions, so provide abundantly good optional solutions for further selection. In the second step, the coal quality variation is considered. Selection procedure upon those non-dominated solutions makes the solutions with best coal quality flexibility come to the fore. The optimization and selection procedure improve the baseline PI control performance with better dynamic responses and coal quality flexibility simultaneously.

The rest of this paper is organized as follows. Section 2 gives an introduction to the ALSTOM gasifier benchmark problem and its specifications. The PI controller optimization and selection method are presented in Section 3. Section 4 gives an introduction of the multi-objective optimization algorithm used in this paper, and the performance test is presented in Section 5. In Section 6 some conclusions are drawn from above work.

## 2. The gasifier model and control specifications

A non-linear model of coal gasifier plant is provided in the Challenge II of ALSTOM gasifier benchmark problem. Gasifier is a reactor in which pulverized coal mixed with limestone, is conveyed by pressurized air into the gasifier, and gasified with air and injected steam, producing a low calorific-value fuel gas. The remaining char is removed from the base of the gasifier. The non-linear ALSTOM gasifier benchmark model have five manipulated inputs (mass flow of coal, limestone, air, steam and char extraction) and four outputs (pressure, temperature, bed-mass and gas quality). The limestone is used to capture the sulfur in the coal, so its flow rate is set to a fixed ratio of coal flow. This leaves the gasifier model a four-input four-output system.

**Table 1**
Fuel gas production of three loads.

| Load | 100% | 50% | 0% |
|---|---|---|---|
| Fuel gas production (kg/s) | 29.635 | 21.627 | 13.521 |

Other non-control inputs include boundary conditions, a pressure disturbance input *Psink*, and a coal quality input. The input and output equilibrium point data under three operating conditions 100%, 50% and 0% is also provided (see Dixon & Pike, 2004 for details). A calculation on the provided data indicates that the fuel gas production decreases along with the load reduction, which can be seen from Table 1.

The control specifications of gasifier non-linear model are as follows:

(1) *Downstream pressure disturbances test*: A downstream pressure disturbance *Psink* is applied to the system, then run the simulation for 300 s, no input and output constraint violations should be observed; and calculate the integral of absolute error for the gas quality *CVgas* and gas pressure *Pgas* over the complete run.

(2) *Load change test*: Start the 50% load system from steady state, then ramp it to 100% over a period of 600 s. The measured load should follow the load demand as closely as possible with minimal overshoot at the end of the ramp. The input constraints need to be adhered to the controller outputs all the time.

(3) *Model error test*: Coal quality can change quite significantly depending on its source. It should be changed incrementally within the range ±18%, and any effect on the performance of the controller should be noted.

## 3. Optimization and selection method

For the ALSTOM benchmark problem, the baseline controller structure has been verified to be the most suitable and simplest PI control structure by engineering approach (Asmar et al., 2000), so it is adopted in this paper, see Fig. 1.

To obtain better dynamic performance for pressure rejection and simultaneously obtain improved coal quality feasibility, a multi-objective optimization and selection procedure can be carried out as follows:

*Step* 1: *Multi-objective optimization*. A multi-objective optimization problem is formulated to get a set of non-dominated solutions, which totally meets the performance specifications under the disturbances of *Psink* for nominal non-linear gasifier model.

*Step* 2: *Selection*. The third specification of benchmark problem is considered. Upon those non-dominated solutions, a selection for best coal quality feasibility index is carried out. The obtained controller parameters will have best coal quality flexibility under the specified disturbances and load conditions.

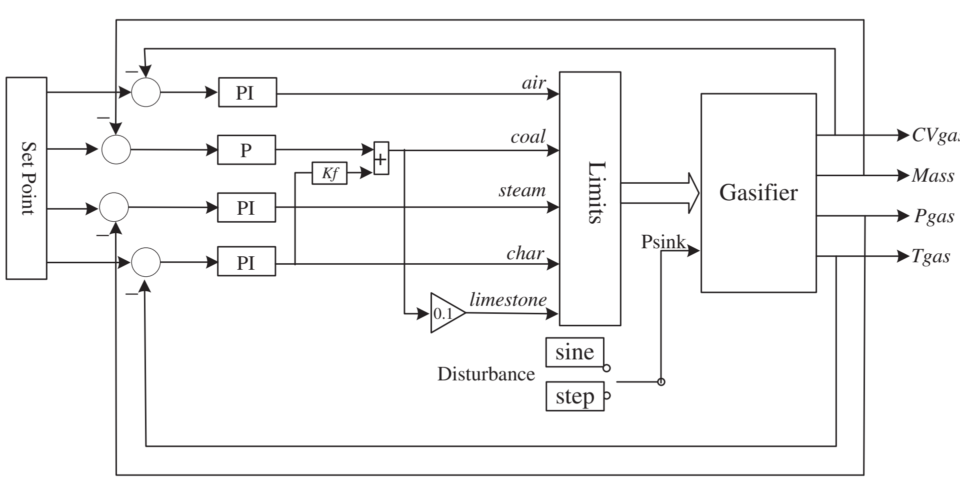


**Fig. 1.** Control system structure.