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Comparison between Different Control Approaches of the UOP Fluid Catalytic Cracking Unit

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Abstract

Different traditional and advanced control strategies have been tested and the performance investigated, revealing their incentives. The investigated control approaches are: conventional decentralized PID control, MPC control based on analytical model, MPC based on Artificial Neural Networks (ANN) model and Fuzzy Logic Control (FLC). Comparative control results are shown for the multivariable control structures, aimed to control the main variables of the unit, such as: reactor and regenerator temperature, catalyst inventory in the reactor and oxygen content in the regenerator stack gas, in the presence of typical disturbances. The results reveal the incentives of the investigated approaches (with analytical or ANN models) over the classical decentralized PID control scheme but also the benefits of the Fuzzy Logic Control.

Keywords: PID, Model Predictive Control, Artificial Neural Networks, Fuzzy Logic Control.

1. Introduction

Importance of the catalytic cracking process has been constantly preserved at high level during its continuous development.

Modelling and control of the FCC process have been growing in importance during the last decades as they may bring significant profit. Their task is to cope with challenging tasks such as: complex raw material characteristics, non-linearity and interactions between process variables. A large amount of effort has been devoted both in academia and industry to study aspects of FCCU as: chemistry of the catalytic cracking, modelling [1], nonlinear dynamic behaviour [2] with steady state multiplicity and chaotic characteristics, dynamic simulation [3], on line optimisation and control [4].

2. Description of the UOP FCCU

The FCCU for which the study has been carried out is of UOP type and is presented in Fig. 1.

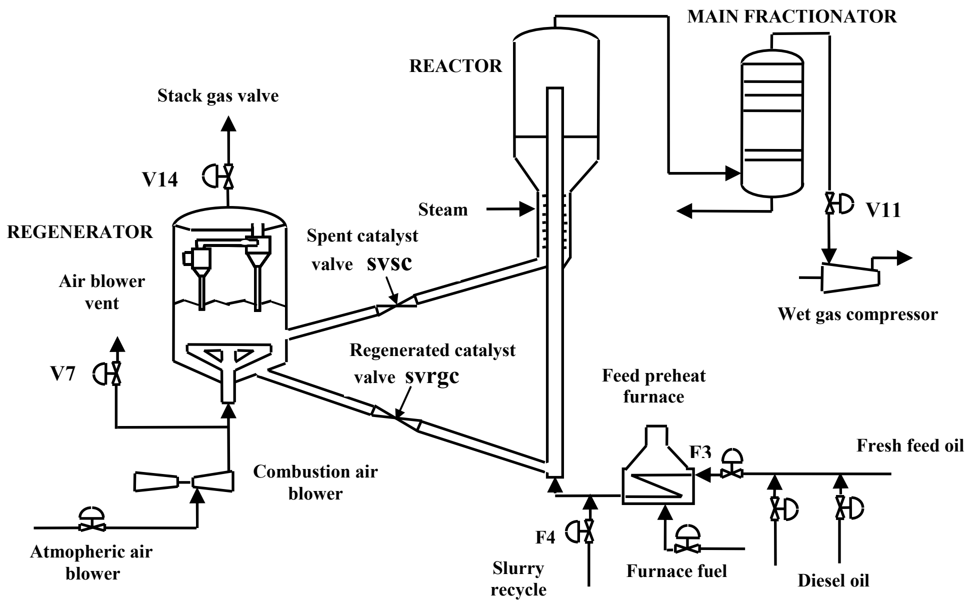

Figure 1. Representation of the UOP Fluid Catalytic Cracking Unit.

Both first principle and ANN models have been developed. The dynamic models have been built on the basis of construction and operation data from an industrial unit. Models describe the reactor-regenerator assembly consisting in its main components: feed and preheat system, reactor, regenerator, air blower, wet gas compressor and catalyst circulation lines. The main fractionator is included in the models only by its buffer vessel effect on the flow of gaseous products produced in the reactor. The FCCU is operating in partial combustion mode.

The developed models succeed to reflect the dynamic behavior of the FCCU. They will be further used both for building the dynamic simulator and as internal model used by the MPC algorithm.

3. Investigated Control Approaches

3.1. Control Methodology

Different control strategies have been applied for FCCU control during the development of the control theory. Starting with the classical control approach that uses the PID controllers, the FCCU control has later experienced model predictive techniques using both first principle and statistical models. Development of first principal models involves several simplifying assumptions: lumping the individual components of the feed and products into groups, the simplification of complicated processes occurring on the catalytic surface during the cracking process or during coke removal from the spent catalyst, associated to the complex heat and mass transfer phenomena occurring in the fluidized bed. All these assumptions limit the capability of developing accurate dynamic simulators based on first principle models but challenge the modeling approach based on the means offered by artificial neural networks. Artificial intelligence instruments, such as fuzzy logic and genetic algorithms may bring value to the control law.

Based on literature survey and analysis of current industrial FCCU operation, a set of process variables has been selected as having first role importance in efficient and safe operation of the unit. The controlled variables considered in the study are: inventory of catalyst in the regenerator W_r, regenerator temperature T_{reg}, reactor temperature T_r and the oxygen concentration in stack gas xO_{2sg}. The manipulated variables are: spent catalyst valve position (flowrate) *svsc*, regenerated catalyst slide valve position (flowrate) *svrgc*, air vent flowrate V_7, and stack gas flowrate V_{14}. The coking characteristics (coking rate constant) of the feed oil K_C (*+3.2%* step increase) and main fractionator pressure drop Δp_{frac} (*+10%* step increase) have been considered as representative disturbances.

3.2. Results for FCCU PID and MPC control

Pairing of controlled and manipulated variables used for the PID decentralized control has been suggested by the Relative Gain Array study [4]. They are: W_r-*svsc,* T_{reg}-*svrgc,* T_r-V_7 and xO_{2sg}-V_{14}. Compared to previous investigations of the control structure design based on RGA [5], the present work considers a larger dimension of the control scheme (i.e. 4×4), revealing the incentives of the proposed control approach. Anti-windup PID digital controllers have been used. Unconstrained MPC has been used for the control of the same process variables. The tuning has been made in a way to obtain good control performance for both test disturbances taken into consideration. Results obtained for the case of the coking rate K_C disturbance are presented in Fig. 2.

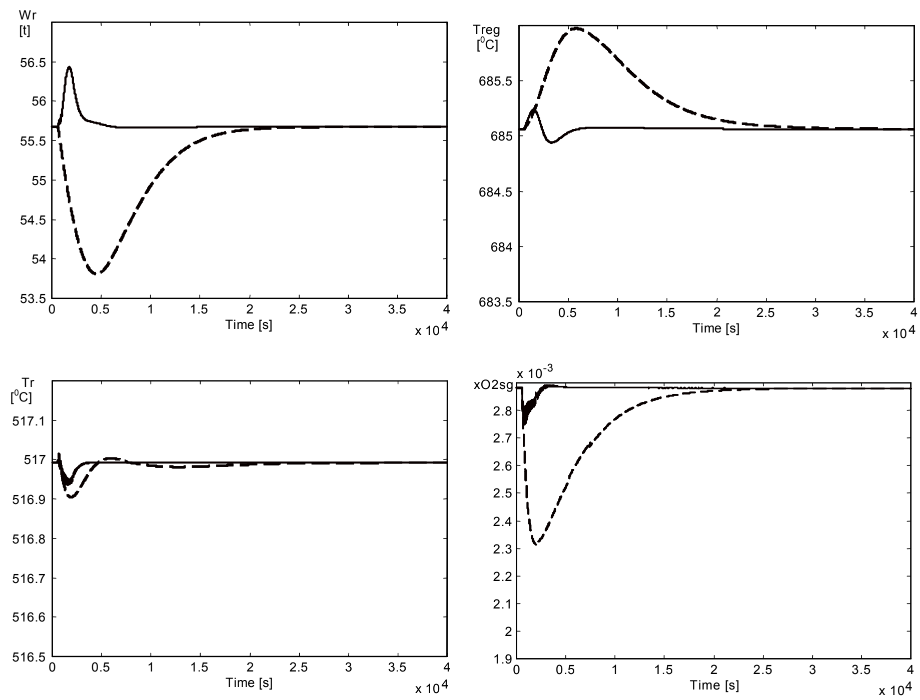

Figure 2. Comparative results for PID (dashed line) and MPC (solid line) control of: catalyst inventory in the regenerator W_r, regenerator temperature T_{reg}, reactor temperature T_r and oxygen concentration in stack gas xO_{2sg}, in the presence of the coking rate K_C disturbance.

Results reveal superior behaviour for the case of nonlinear MPC based on scheduling linearization, both with respect to overshoot and response time. The MPC tuning was performed by choosing the output and input weights based on the maximum allowable deviation of the corresponding variables, followed by a trial and error refining step. Following the performed simulations it may be concluded that, as the number of controlled variable is higher and the interactions between them is strong, the MPC multivariable control strategy is more efficient compared to the decentralized PID approach. As FCCU control implies satisfying safety, equipment and operating constraints the MPC control becomes again the preferred control approach.

3.3. Results for ANN based MPC control

An ANN model of the FCCU has been developed for using it as inherent model further used by MPC. As ANN inputs has been considered the set of ten states/outputs of the first principle model together with the manipulated variables, all considered at the current moment of time *t*. The ANN outputs (targets) have been selected as consisting in the same set of state/outputs variables but considered at the next moment of time $t+\Delta t$. Slide valve position on both spent and regenerated catalyst circulating lines have been considered as most effective manipulated variables. The ANN has been trained to predict the values of the change in the state/output variables, from one sample time to the next one, based on the current values of the states/outputs and manipulated variables. A two-layer feed-forward/back-propagation training ANN was used for computing the network biases and weights.

Control of the catalyst inventory in the reactor-stripper W_r and temperature of the regenerator bed T_{reg}, has been investigated in the presence of the coking rate constant K_C disturbance, with regenerated *svrgc* and spent *svsc* catalyst slide valve position as manipulated variables. Simulation results are presented in Fig. 3. They show the two controlled variables for the case of the K_c disturbance applied at moment $t=50000\ s$ and starting with initial conditions of the controlled variables different from the setpoint values set for time $t>0$.

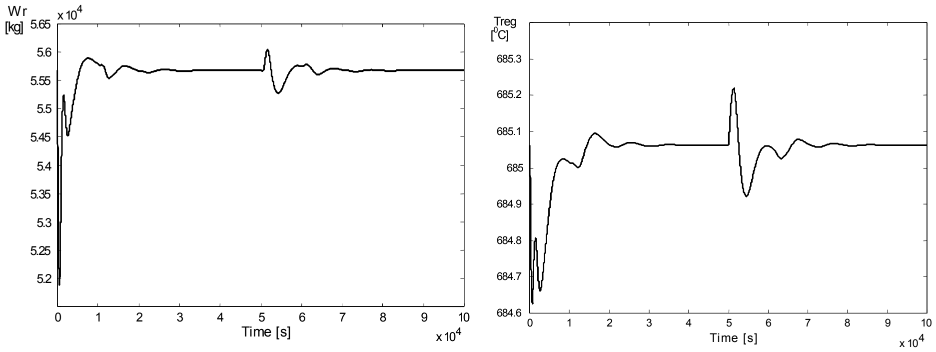

Figure 3. ANN based MPC of the catalyst inventory W_r in the reactor and regenerator temperature T_{reg}, in the presence of the K_c disturbance.

Simulation results of the MPC based on ANN model show a good setpoint following performance also demonstrating zero offset. The disturbance rejection ability is efficient as short settling time and low overshoot prove it. The ANN model based control approach also features a significant reduction of the computation time implied by the model predictive control algorithm.

3.4. Results of FCCU fuzzy logic control

The investigated FLC approach considered triangular and trapezoidal membership functions in order to fuzzify both manipulated and controlled variables. Mamdani's inference method and centroid defuzzification were used together with a set of cross-connected rules aimed to perform decoupling and efficient control. Integral action has been also added. Results of the fuzzy logic control for the FCCU main variables are presented in Fig. 4. They show very short settling time and reduced overshoot, but also small steady state offset.

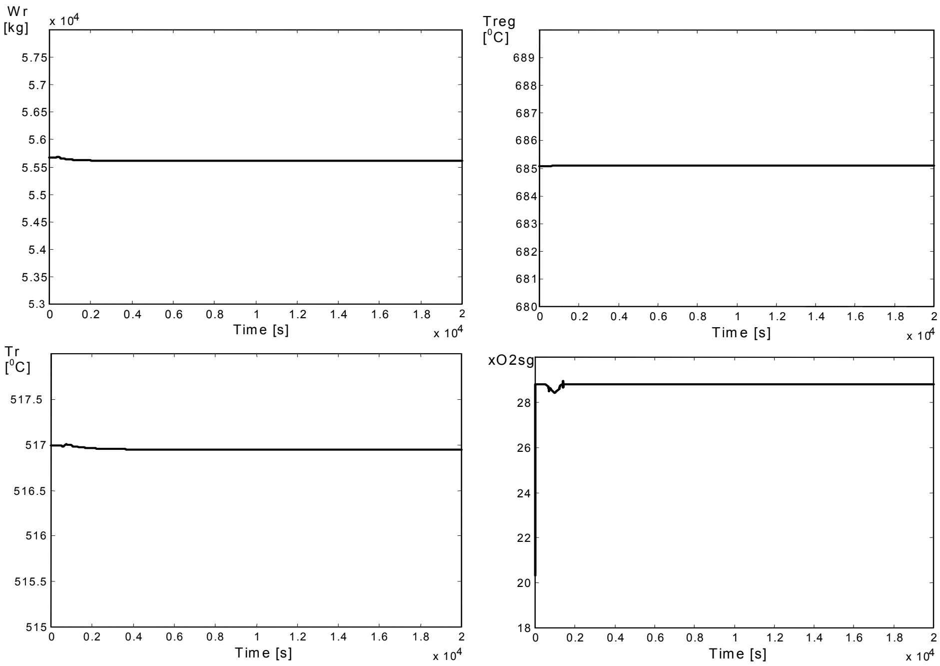

Figure 4. FLC of W_r, T_{reg}, T_r and xO_{2sg} in the presence of the K_c disturbance

4. Conclusions

Simulation results reveal the incentives of the model-based control over the traditional decentralized PID approach. Moreover, the ANN model based MPC offers the opportunity for making reliable control using statistical models built by process data, but also for considerably reducing the computational effort. Despite its simplicity, the FLC proves to have the shortest settling time and overshoot although integral action should be added in order to reduce the steady state offset. Combining incentives of the investigated control approaches may develop control systems with increased performance for the FCCU.

Acknowledgements

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