REAL TIME OPTIMIZATION OF a FCC REACTOR USING LSM DYNAMIC IDENTIFIED MODELS IN LLT PREDICTIVE CONTROL ALGORITHM

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Abstract: This work shows a new way to perform Real-Time Optimization using two important control technology. The first one is the LLT nonlinear model predictive controller and the second one is the LSM dynamic model identification method. This two concepts associated constitute a complete technology for Real-Time Optimization using nonlinear models. The application of this technology was tested on the FCC (fuel catalytic cracking) reactor which shows the advantages and disadvantages of its application.

Keywords: Real Time Optimization, .nonlinear identification, nonlinear predictive control, Advanced Control.

1. INTRODUCTION

The control process has been each time more developed in different levels due to the desire of having the best results of a industrial process. Increasing the level of control of a industrial process , the concept of Real-Time Optimization becomes very important, since, in this level, the results are more visible and it can be easily transformed in profit.

The process called Fuel Catalytic Cracking (FCC) represents, in profitable terms, the most important industrial process in a petroleum refinery. Through this process, all the most valuable products of the petroleum refinery, like gasoline and Liquefied petroleum gas (LPG), are produced, and, for this reason, it is usual this process receives a special attention in the industrial environment, which make the application of Real-Time Optimization becomes strongly justified. The main goals of this optimization is to reach the maximum conversion of the feed flow in products, the maximum production of valuable products as gasoline and LPG, maximum profit and maximum production.

In this work, a first principle model was used to simulate the industrial process behaviour, in order to perform an analysis of the application possibility of the two techniques (LSM and LLT) in real process. for this study a mono-layer optimization structure was developed on the LLT algorithm which produce a dynamic optimization of the process.

2 THE FUEL CATALITC CRACKING PROCESS (FCC)

The FCC process is a important period in petroleum refine, It uses a fraction of the distillation called gasoil and transforms this feed flow in gasoline (NC), liquefied petroleum gas (LPG), light cracking oil (LCO), clarified oil (OCLA), fuel gas (GC) and coke (CK). The gasoil is loaded in the converser together with the catalyst, previously warm. This mixture gets up through the converser generating the products which are separated on the top of the converser . In this separation, gaseous products are separated from the catalyst and the coke, and sent to distillation column. The catalyst covered by coke turns back to the system, being loaded in the regenerator, where the coke is fired and generates energy to the reaction. This energy keeps accumulated on the catalyst which is introduced back to the converser together with gasoil.

The model used to represent this process was developed by (Secchi et. al 2001) and consist in a first principles model with 265 states, 20 outputs, and 8 inputs. This model describes de converser as a plug-flow reactor (PFR) in which, the axial variable was discretized in twenty stages.

3 THE LOCAL LINEARIZATION ON THE TRAJECTORY (LLT) ALGOTITHM

The LLT algorithm (Duraiski, 2001) is a kind of sequential predictive control method which consists in a sequence of iterative steps. The first step in the control action design is to predict the up-to-dated trajectory of the system. This trajectory is determined using the current value of the inputs of the process applied to the nonlinear model. In this first trajectory, linearized models are obtained using a dynamic linearization. The set of models obtained on each point of the trajectory is grouped performing one deviation model from the original trajectory, which is used in the optimization step. This optimization will generate a set of control actions to the system, which, not necessarily, will be the best set of control actions, once that it was obtained using a linearized deviation model. Therefore, this set of control actions obtained are applied to the nonlinear model and a new trajectory is generated. On this trajectory, a new set of linearized models is obtained and a new optimization performed. This sequence of steps keep going on until the nonlinear predicted trajectory converges to the setpoint and no more variations are observed in the control actions designed.

3.1 Optimization Layer

The original LLT algorithm do not allow optimization and, therefore, a additional implementation was necessary to do such work. In predictive control, a closed shape of objective function can be obtained, since the goals of the control is very well defined. This conclusion makes that the algorithm use hessian and gradient matrices previously defined based on the model equations. When including a optimization layer such matrices can not be previously defined because the expression of objective function can take any shape. This fact makes necessary evaluate the hessian and gradient of the objective function in each iteration since the system is solved by a quadratic programming in each step. The gradient vector in this implementation is been estimated by numerical approach using conventional perturbation of variables. The hessian uses an estimation suggested by used in BFGS optimization method. A linesearch step was included in this algorithm to improve the quality of the solution. This implementation had to be done because the nature of the objective function have change considerably. in the original formulation of the LLT algorithm the objective function was completely quadratic which turns possible the use of successive QP solutions without any correction. using this new formulation of objective function, a linesearch turns necessary since the new objective function can take many nonlinear shapes, and the successive quadratic approach indicates only the direction of the search.

The original objective function of the LLT algorithm was transformed in the following expression:

$$J = \min_{s,\delta U\left[\begin{smallmatrix} M \\ 0 \end{smallmatrix}\right]} \left(\begin{array}{l} \sum_{i=0}^{P} \left(\gamma_i \cdot (y_i - r_i)\right)^2 + \\ \sum_{i=0}^{M} \left(\lambda_i \cdot \left(u_i - u_{i-1}\right)\right)^2 + \\ \sum_{i=0}^{M} \left(\psi_i \cdot \left((\delta u_i + u_{i-1}^{B}) - z_i\right)\right)^2 + \\ \left(\varphi |s|\right)^2 - \sum_{i=0}^{P} \alpha_i \left(Lucro_i\right) - \\ \sum_{i=0}^{P} \beta_i \left(\frac{\%conv_i}{100} F_{CG\,i} \right) \\ - \sum_{i=0}^{P} \mu_i \left(\frac{\eta_{GLP\,i}}{100} F_{CG\,i} \right) - \\ \sum_{i=0}^{P} \nu_i \left(\frac{\eta_{NC\,i}}{100} F_{CG\,i} \right) - \\ \sum_{i=0}^{P} \pi_i \left(\frac{\eta_{LCO\,i}}{100} F_{CG\,i} \right) \end{array} \right) \quad (1)$$

where P is the prediction horizon; M is the control horizon; γ_i is the weight of the error in the controlled variables; y_i is the value of the controlled variables; r_i is the value of setpoints to the controlled variables; λ_i is the weight for variation of the control actions; δu_i is the variation of the control actions related to the reference trajectory; u_i is the absolute value of the control actions; ψ_i is the weight to the error in the proposed target for manipulated variables; z_i is the target established to the manipulated variables;φ is the weight for violation of softconstrains set to the controlled variables; s is the violation of the softconstrains of the controlled variables; αi is the weight for the profit in the objective function; βi is the weight of the conversion degree;%conv is the conversion degree of the gasoil in products; FCG_i is the gasoil feed flow; μ_i is the importance of the LPG production; η_{GLPi} is the mass fraction of LPG; ν_i is the weight of the production of gasoline; η_{NCi} is the mass fraction of gasoline; πi is the weight of the importance of the production of LCO; η_{LCOi} is the mass fraction of LCO in the output; $lucro_i$ is the expression of the profit of the process given by equation 2:

$$Lucro_i = \sum \frac{F_{prod\,i-1} + F_{prod\,i}}{2} \cdot \Delta t_i \cdot P_{prod\,i} \quad (2)$$

F_{PRODi} is the feed or output é rate of some of the following product or inputs:
- Catalyst (CAT) (input);
- Gasoil (CG) (input);
- Potência do soprador (SOP) (input);
- fuel gas flow (GC) (product);
- liquefied petroleum gas flow (GLP) (product);
- gasoline flow (NC) (product);
- Light cvcle oil flow(LCO) (product);
- coke produced (CK) (product);

- clarified oil flow (OCLA) (product);

P_{PRODi} is the price of the product (positive) or input (negative).
Δt_i time interval between two consecutive instants of the prediction.

4 THE LINEARIZATION ON THE STATIONARY MANIFOLD (LSM)

The LSM Algorithm developed by (Fernandes 2005) is a identification method that can describe nonlinear models as a approach of multiple linear models by developing a interpolation rule to this models. This interpolation generates a matrix A of the state space representation dependent of the inputs of the system. The final shape of this model can be represented in the equation 3:

$$\frac{dx}{dt} = A(u)\left(x - SS(u)\right) \quad (3)$$

where A(u) is the interpolation of the matrices A of the multiple models; SS(u) is the steady states as a function of inputs, which are also obtained by interpolation; x is the current state.

5 THE APPLICATION OF RTO IN THE FCC REACTOR

A sensibility analysis was performed. to decide which points was important to perform the identification of the system.

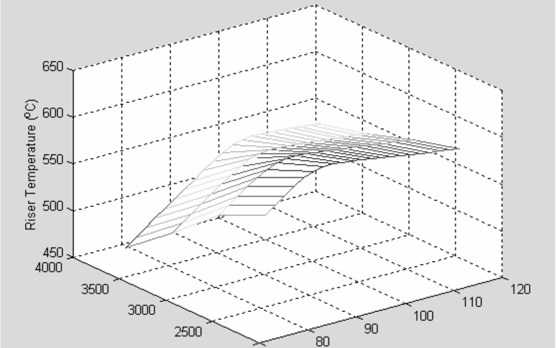

Fig 1: Sensibility analysis for the temperature on the riser

Although the other results of sensibility analysis are not shown here, the figure 1 shows the main behavior of interest of the process. In this figure is shown that the temperature is almost linear with gasoil feed flow, however it presents a nonlinear behavior with the air flow. As the main nonlinearity is this one produced by the air flow the linear models identified were distributed in five points of operation varying only the air flow rate. Two of then in the region of positive gain, two in the region of negative gain and one in the region near by gain zero.

The interpolation performed in this case for the A matrix has used a linear rule which was the most appropriated form, since the negative signal of the poles have to be kept through all space. The steady state function follow a quadratic interpolation, because it gave to describe the inversion of the sign of the gain of the system.

Although the results of the sensibility analysis were not presented here, it is known that, in FCC reactor, the conversion of the products are straight related to the temperature of the riser and the behavior of this variables are equal to the temperature behavior.

6 RESULTS AND DISCUSSION

Optimizations of the FCC reactor were performed using different weights for each term of the objective function. This usage of different weights looks for show the behavior of the optimizer when goals are changed. The first simulation were performed using a weight 1000 for the profit term and 0 for the other ones (except move suppression which were kept with weight equal to 10). Figure 2 shows the control actions taken by the optimizer when the goal was maximum profit. in this figure is shown that the air flow rate increases until a value related to the maximum temperature of the riser. The value reached for the temperature can not be increased by the air flow rate at this point and for this reason the total feed flow has to be decreased to allow that conversion in the riser be effective, as shown in figure 3, and the most valuable products were produced, reducing the output of gasoil from the riser.

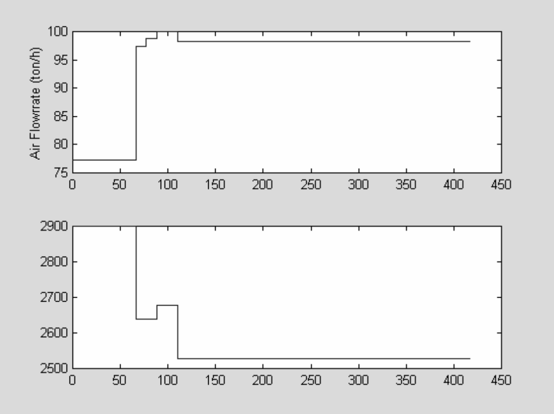

Fig 2: Control Actions taken by the optimizer

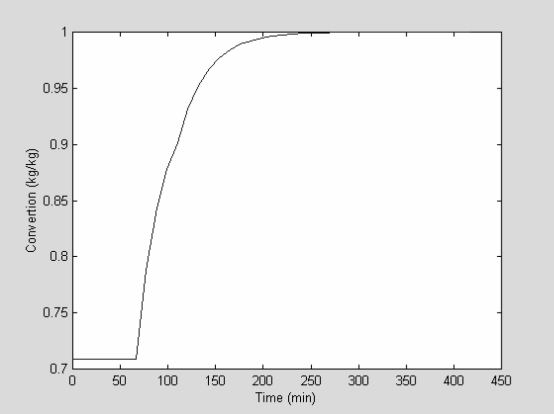

Fig 3: Conversion of gas oil in products

The same sequence of control actions can be seen when the objective of the optimization is the maximum conversion. This goal implies in reducing the feed flow rate to allow the best conversion possible since the limit of the equipment is reached.

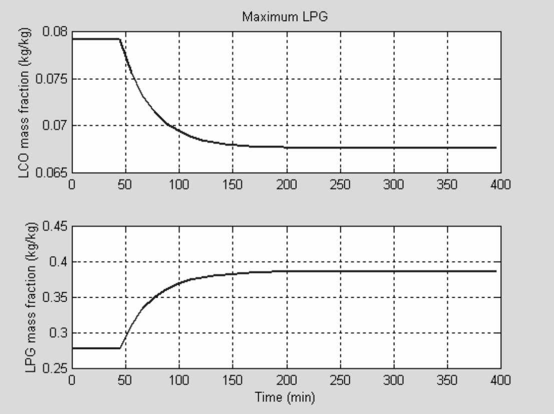

Fig 4. Responses of the system optimization using maximization of LPG as the goal of the optimizer

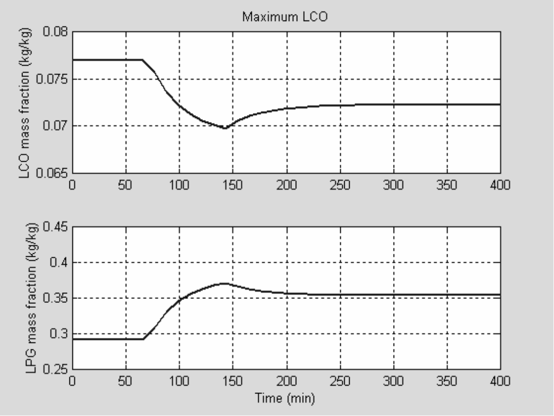

Fig 5. Responses of the system optimization using maximization of LCO as the goal of the optimizer

A comparison between other two goals of optimization is shown in figures 4 and 5. Figure 4 shows the responses of the system optimization using maximization of LPG as the goal of the optimizer and figure 5 shows the responses of the system optimization using maximization of LCO as the goal of the optimizer. Comparing this two figures, it is possible to see that the mass fraction of each component changes according with the main objective of optimization.

7 CONCLUSIONS

The optimizer used in this paper shows a good solution to perform real-time optimization of continuous dynamic process although, is still needs some adjusts. As presented in previous section, it is possible to see that the optimizer takes the process to a new condition as close as possible of the main goal of optimization.
it is still possible to perform so improvements in this tool since some problems were found in its application on the model of FCC reactor. In some specific cases oscillatory behavior were captured when the plant reaches the optimum. which implies in a more detailed analysis of the problem to arise its possible reasons.

8 REFERENCES

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