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OPTIMAL CONTROL OF BRINE ELECTROLYSIS IN ION EXCHANGE MEMBRANE REACTORS

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ABSTRACT. In an earlier work an optimal management of brine electrolysis plan was presented to minimize the electric energy costs by taking into account the different electric energy costs between day and night[1]. This is maintained by the national electric energy suppliers to compensate the different consumption demanding in the electric network system between day and night period of the day. For the brine electrolysis industry it is important to use this situation in its one advantage. The main way to do this is by varying the current load of the reactors between day/night time period in order to minimize the cost of electric energy.

In this paper, based on simulations using a mathematical model of an IEM (Ion Exchange Membrane) reactor, the optimal control of a brine electrolysis plant is presented, taking into account these possibilities.

By simulation, it is proved that Model Predictive Control (MPC) of the electrochemical reactors can be used to apply the results obtained by the optimization algorithm.

It is possible to estimate that the electric energy cost savings obtained by this way can be between 5 to 20%, depending by the ratio between day/night energy costs and the ratio between the current daily production and the nominal daily capacity of the plant.

INTRODUCTION

In an earlier work[1] the minimization of electric energy costs for a brine electrolysis plan equipped with ion exchange membrane (IEM) reactors was presented.

The main issue was to maintain the production level of the plant but operating at different current load thus to benefit as much it is possible by the different electric energy costs between day and night.

The optimization results (figure 1 and 2) showed us that a saving between 5-20% in electric energy costs could be obtained without diminishing the production level of the plant. This result could be implemented by using an efficient control system in order to maintain the quality of the products which could lead to a total annual saving of about 1 million $.

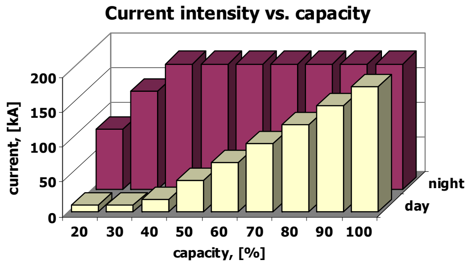

Figure 1. The results of the optimization.

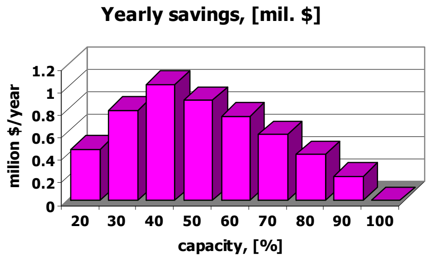

Figure 2. Yearly savings.

OPTIMAL CONTROL

The goal of optimal control of the IEM plant, minimizing the electric energy costs involved in the process can be reached by using an efficient control system in order to minimize the perturbing effect of a steep change in the cells current load.

The structure of the optimal control system of the IEM (Ion Exchange Membrane) plant includes two levels (figure 3):

- optimization level;
- control level.

The optimization level of the optimal control system includes the elements presented at the optimization section of this paper.

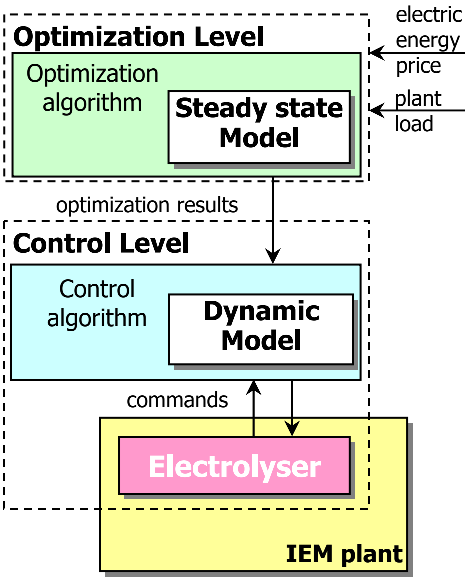

Figure 3. Optimal control system structure of the IEM plant.

The goal of the control level of the optimal control system is to maintain the quality of the products between the specifications. By this we understand to preserve de NaOH concentration and the brine concentration at the outlet of the cell at their nominal values.

A minimal control structure in which we have 2 controlled variables (brine and NaOH concentration at cell outlet) and two manipulated variables (brine and caustic soda flow at cell inlet) can be selected [2, 3, 4].

This control structure can be performed by two main ways:

- SISO (Single input/Single Output) control structures using two PID controllers;
- MIMO (Multiple Inputs/Multiple Outputs) control structure based on Model Predictive Control (MPC).

For the SISO control structure the following control loops were selected:

loop 1:	controlled variable:	brine concentration at cell outlet
	manipulated variable:	brine inlet flow
loop 2:	controlled variable:	caustic soda concentration at cell outlet
	manipulated variable:	caustic soda inlet flow

Two PI controllers were used for these two loops. Controller tuning was made by simulation using the Ziegler-Nichols method. Parameters for these controllers are presented in table 1.

Table 1.

Controller parameters

Controller	Type	K_r	T_I [s]
1	PI	15	4500
2	PI	30	5200

For the MIMO control structure, using MPC, a dynamic model of the IEM reactor was used. This model is an analytical model and includes 14 differential and more than 65 nonlinear algebraic equations [2].

In the case of MPC of the membrane cell, the same controlled variables and manipulated variables were used and the optimal values for the internal parameters of the controller were determined by simulation as follows [10, 11]:

- model horizon T = 14400;
- control horizon U = 2;
- prediction horizon V = 10;
- weighting matrix for predicted errors W_1 = [0.05 0.05];
- weighting matrix for control moves W_2 = [1 1];
- sampling period Δt = 1 s.

The controlled variables were subject to the following constrain:

$$y_{min} \leq y(k+l|k) \leq y_{max}$$

where:

$y_{min} = 0$, [m^3/s]

$y_{max} = 2 \cdot y_{nom}$

y_{nom} - nominal flow for brine/caustic soda, [m^3/s].

For a comparison of the performances of the SISO and the MIMO control structures in the case of the optimal control of an IEM plant, simulations were used. The simulations were made in Matlab and SIMULINK computational environment (figure 4).

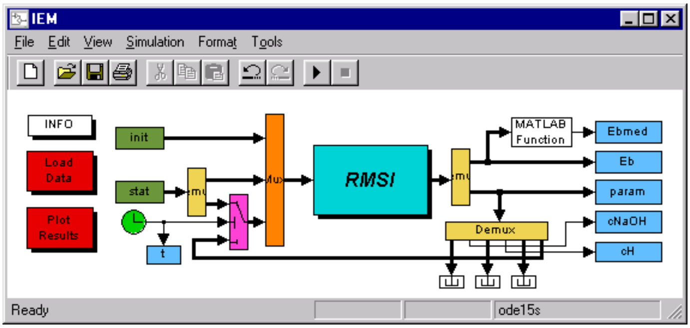

Figure 4. SIMULINK program for IEM reactor.

The simulations test how the control systems are working when the current load of the electrolyser suffers a steep change (according to the results obtained in the optimization level of the optimal control system).

The following results were obtained for a change in current load corresponding to a modification in the plant capacity from 70% to 50% from the nominal capacity of the plant.

In figure 5 we can observe that in the case of the SISO control structure the control is inefficient because the current load modification induces a perturbation which cannot been eliminated after a quite long period of time (more than 1 hour).

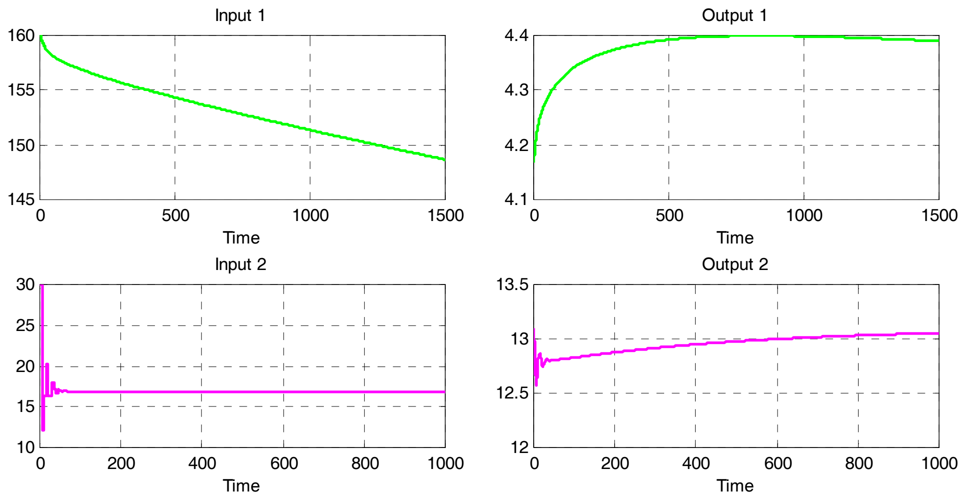

Figure 5. SISO control structure – simulated behavior.
Input 1 brine flow at the inlet of the cell, in [l/h]
Input 2 caustic soda flow at the inlet of the cell, in [l/h]
Output 1 brine concentration at the outlet of the cell, in [kmol/m^3]
Output 2 NaOH concentration at the outlet of the cell, in [kmol/m^3]

From the results presented in figure 6 we can observe that the MIMO structure has a much better performance than the SISO control structure. In less than 20-25 minutes the controlled variables return to their initial values.

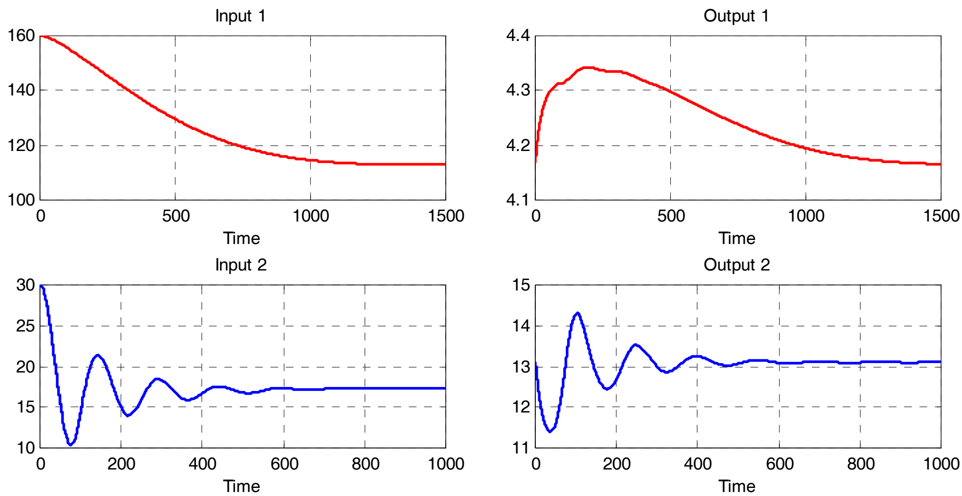

Figure 6. MIMO control structure – simulated behavior.
Input 1 brine flow at the inlet of the cell, in [l/h]
Input 2 caustic soda flow at the inlet of the cell, in [l/h]
Output 1 brine concentration at the outlet of the cell, in [kmol/m^3]
Output 2 NaOH concentration at the outlet of the cell, in [kmol/m^3]

CONCLUSIONS

The optimal control problem of an IEM plant was studied in the case of electric energy consumption costs minimization.

Taking into account that the price of electric energy is differentiated by the moment of the day, it is possible to use this to obtain important cost savings.

The results of the optimization proves that it is possible to obtain 5-20% electric energy cost savings, depending on the relative capacity at which the plant is operated at a given moment.

For the implementation of the optimization results two simple control structures were tested: the SISO and the MIMO control structures.

By means of simulation it was proved that a MIMO control structure could be more effective.

NOMENCLATURE

k, l	step index
T	model horizon in MPC
U	control horizon in MPC
V	prediction horizon in MPC
y	controlled variables
y_{max}	maximal value of the controlled variable
y_{min}	minimal value of the controlled variable
y_{nom}	nominal value of the controlled variable
W_1	weighting matrix for predicted errors in MPC
W_2	weighting matrix for control moves in MPC
Δt	sampling period in MPC

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