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Smart Process Operations and Control Lab

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Flexible Electrochemical Plant of the Future - Integration of process design and control strategies for plant optimization

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Introduction

Electrochemical CO_2 reduction for synthesizing base chemicals and fuels has been identified as a potential technology to lead the energy transition in the process industry. Developing efficient electrochemical reactors that can compete with conventional technology using renewable resources is necessary. Traditional methods for designing, operating, and controlling a chemical plant are unsuitable for an Electrochemical Plant of the Future (EPoF). To facilitate this transition, the FlexEchem project proposes to

- Developing new reactors for the electrochemical reduction of CO_2 to C_2H_4
- Multiscale modeling of chemical reactors
- Integration of process design and control strategies for plant optimization

Need for Flexibility

The electrochemical reduction of CO2 can be carried out continuously; however, the uncertainty and intermittency in renewable energy sources, the Fig 1, represent a challenge in the operation of the EPoF.

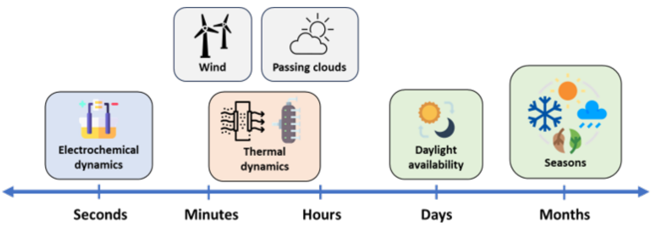

Figure 1: Uncertainties present in an EPoF and their timescales [?]

Integrated process design and control

Processes that operate under variations in the inputs (magnitude and nature), operating points, and production rates have motivated the simultaneous operation, design, and control of a process. This methodology consists of a bi-level optimization problem.

$$\left.\begin{array}{ll}\min_{x\in X} & F(x,y)\\ \text{s.t.} & G(x,y)\leq 0\\ & y\in P(x)\end{array}\right\}\ \text{Upper-level problem}$$

$$P(x)=\left.\begin{array}{ll}\operatorname{argmax}_{y\in Y} & f(x,y)\\ \text{s.t.} & g(x,y)\leq 0\end{array}\right\}\ \text{Lower-level problem}$$

The upper problem minimizes the capital and operational expenses by sizing the energy collection units, maximum and minimum production rates, storage units and plant capacity constrained by production goals, and limitations in the plant operation. The lower level problem maximizes the production taking into account the dynamic model of the plant and uncertainty in the energy sources.

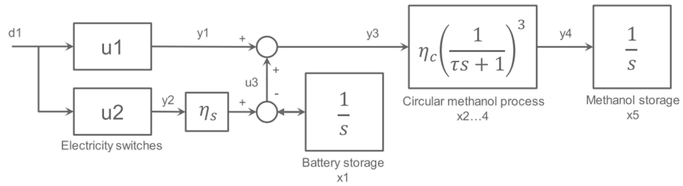

Figure 2: A block flow scheme of a solar fuel plant [1].

A Case Study

The plant presented in Fig. 2 takes the renewable energy and routes it either straightaway or through battery storage to fuel a circular methanol process, which encompasses four key units: Direct Air Capture of carbon dioxide, water electrolysis, methanol synthesis, and distillation.

Results

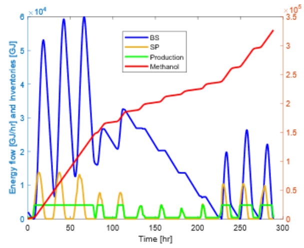

Figure 3: Optimal trajectories with solar energy as input

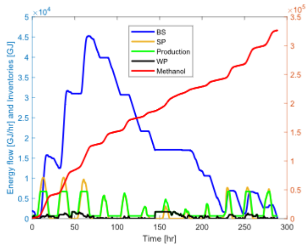

Figure 4: Optimal trajectories with solar and wind energy as input

This study used an open-loop perfect control strategy, in which uncertainties are not considered in any section of the process.

Conclusions & Recommendations

- The operational flexibility of electrochemical reactors allows them to be coupled to the variability of energy availability.
- A balance must be found between the amount of energy harvesting units and energy storage units to make the EPoF economically viable.
- The future work should consider uncertainty in the energy input profiles. Methods that use the worst-case variation approach will be avoided, as they lead to conservatism.

Acknowledgement

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References

1. Huesman, A, Computers and Chemical Engineering, Vol.140, 2020

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