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Real Time Optimization for steam management in an evaporation section

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ABSTRACT

The aim of this paper is to implement a Real Time Optimization in an evaporation section of a sugar factory using a methodology that reduces the time required for developing models using an Equation Based Object Oriented Language. The drawbacks, advances and troubleshooting when using this technique are described. In particular, how to determine the observability and redundancy of measurements with an Equation Based Object Oriented Language is explained. For the energy optimization of the evaporation, an approach that minimizes a Resource Efficiency Indicator (REI) is used. Together with this methodology, a configurable tool, integrated with the simulation and optimization packages and connected to the industrial network plant, has been developed. The tool provides a friendly user interface that delivers information about the performance of the process, Resource Efficiency Indicators and trend graphs. The tests performed in the sugar campaign show that the energy efficiency of the process can be increased significantly if the results provided by the RTO are followed.

1. Introduction

Sugar production in Europe is facing a big challenge. Europe is the biggest sugar beet producer in the world, with around 50% of global production (European Commission for Agriculture and rural development, n.d.). The European sugar market is gradually being deregulated, with decreasing fixed prices, while a liberalization in the sector started on October 1, 2017 (Szajner, Wieliczko, Marek Wigier, Hamulczuk, & Wrzaszcz, 2016). In this context, only the most efficient producers will be able to compete in a globalized market. It is imperative to try to minimize costs associated with production so as to increase productivity. In the case of sugar factories, the main production costs are related with energy consumption. This is why Spanish sugar companies requested a tool designed to help the operators to manage the process efficiently, providing energy efficiency indicators and optimizing the process operation in real time. To achieve these objectives, a tool has been designed that, connected to the industrial plant, executes a Real Time Optimization (RTO). The tool helps the operators to take decisions related with the process set points, the steam assignment between producers and consumers, and the time for cleaning certain process units (Markowski & Urbaniec, 2005) to optimize some energy indicators. The tool also warns about possible malfunctions of the process sensors.

RTO tries to find the optimum operation conditions of a process, based on some objective function, updating the set-points of the plant controllers. Good reviews on RTO can be found on (Darby, Nikolaou, Jones, & Nicholson, 2011; Engell, 2007; Naysmith & Douglas, 2008). RTO has been applied mainly to chemical and petrochemical plants (de Prada et al., 2017; De Souza, Odloak, and Zanin, 2010; Rotava & Zanin, 2005; Young, 2006). One of the main RTO challenges is related to the integration between the plant control layer and the usually on-top RTO layer, because the models and objectives are different for both layers and that can lead to conflicts (Adetola & Guay, 2010; Backx et al., 2000; de Prada et al., 2017). Another challenge is related to the problems with the maintenance of the RTO systems (Darby et al., 2011). This is especially critical in industries without an engineering department specialized in simulation, control and optimization, where RTO applications are difficult to develop and maintain. The methodology, and the developed tools described in this paper, try to face this last challenge, aiming to provide techniques and tools to allow plant engineers without a strong background in control and optimization to use and maintain the developed RTO application.

The developed tool is connected to the real plant using a SCADA (Supervisory Control And Data Acquisition) that acquires process measurements and laboratory analysis in real time. Those data are filtered and validated using heuristics and then used to perform a Data Validation and Reconciliation (DVR) that adjusts the process measurements by means of a stationary model based on mass and energy balances

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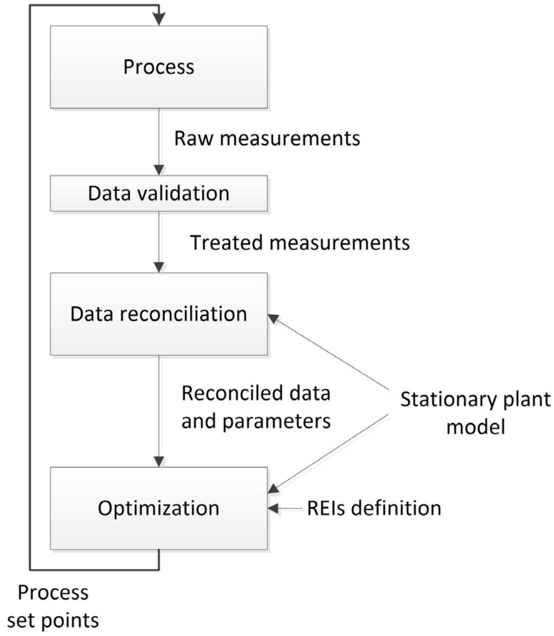

Fig. 1. Steps to perform RTO.

and equilibrium equations. At the same time, system parameters and efficiency indicators for the process are calculated. Once data reconciliation has been solved, the reconciled values calculated at the DVR stage are used to feed the energy optimization that makes use of the same mathematical model used for DVR. The results obtained are shown in a friendly interface based on tables, process diagrams and tendency graphs. During the entire design process of the tool, consideration has been given to the fact that the configuration tool and the modeling task must be easy to reconfigure, so as to be easily adaptable to changes in the process or to configure new systems.

The necessary steps to perform RTO are shown in Fig. 1. Data validation, reconciliation and the following energy optimization problems can be solved using different strategies. One method is the simultaneous approach to directly solve the NLP problem using an optimization software, such as GAMs (GAMS Development Corporation, 2013) or IPOPT (Vigerske & Wächter, 2013), where model equations are written as constraints to the optimization problem (Leibman, Edgar, & Lasdon, 1992; Schraa & Crowe, 1998; Zhang, Pike, & Hertig, 1995). Another strategy is to implement a Sequential Quadratic Programming (SQP) algorithm that uses simulation software, in which the model is described, to calculate the value of the cost function and constraints using the boundary conditions of the plant model, these being the decision variables provided by the SQP optimization library. In Sarabia et al. (2012), a comparison of the use of these two strategies applied to an industrial process can be found.

Modeling is one of the most time consuming tasks when implementing DVR and RTO in real plants. On the other hand, models are continuously evolving, so they must be modified continuously. In this context, the use of the simultaneous approach with an optimization package for solving the NLP problem is advantageous in terms of calculation speed, convergence and accuracy, but it has some disadvantages related to the use and maintenance of the models. In these tools, the model is usually implemented as a set of constraints in the optimization problem, which implies that the interface is not usually very user friendly. Furthermore, when the application involves complex models, it is difficult to modify and maintain. On the other hand, the use of thermodynamic equations in the form of tables, or the use of calls to external applications, for the calculation of these properties is not direct.

The use of a commercial simulation package based on the object oriented modeling paradigm (Fritzson, 2015) allows models to be developed, modified and reused quickly. The fact of using an Equation Based Object Oriented Language (EBOOL) tool, which allows the aggregation and reutilization of models, considerably reduces the time needed to develop them. This approach also allows the use of existing libraries, or calling external applications, for the calculation of physicochemical properties, as well as all the powerful tools for the mathematical treatment of equations, interpolation in tables, mathematical libraries, etc. Finally, the validation and testing of the developed models is much easier in the software simulation environment. In the case study shown in this paper, Ecosimpro© (EcosimPro Webpage, n.d.) is the EBOOL used to write the libraries. There are other possibilities in the field of EBOOL tools, such as Modelica© (Elmqvist, 1978), with the algorithms for optimization provided by Jmodellica.org (Åkesson, Bergdahl, Gäfvert, & Tummescheit, 2009). Other commercial tools could be used to implement the sequential approach, such as gProms© (PSE: gPROMS - Home, n.d.) or Aspen© (AspenTech: Optimizing Process Manufacturing, n.d.).

Nevertheless, the use of a simulation package to solve an NLP problem presents some difficulties. The main disadvantage is that, unless the simulation software provides automatic differentiation or allows the calculation of sensitivities using the adjoint method (Cao, Li, & Petzold, 2002), gradients for optimization must be estimated by means of the method of finite differences performed by calls to the objective function. In Carlos, Pitarch, and Prada (2015), difficulties associated with the use of simulation packages and optimization problems are explained and an approach is developed using an EBOOL to develop the model and then extract it to be implemented in CppAD (Bell & Burke, 2008), which provides automatic differentiation.

Another inconvenience is the convergence problems that appear when trying to solve the model. With stationary models, algebraic loops frequently appear, generating loss of robustness that frequently causes convergence problems. This is especially important in optimization problems, because the model has to be robust when boundary conditions change continuously between big margins and arbitrarily from a physical point of view.

In this paper, a sequential approach has been used to develop an RTO to optimize the use of the steam in an evaporation section in a sugar factory. The mathematical model of the plant is described in Ecosimpro©, and two simulation models are obtained. The first one, together with the cost function and constraints for DVR, uses process measurements to solve the DVR problem. After that, the reconciled values and parameters are used to evaluate the second simulation model, together with the cost function and constraints for the energy optimization. Both simulation models are encapsulated in a DLL (Dynamic-Link Library) that is called from a SCADA connected to the process. The simulation experiment for these models calls the optimization algorithm. In this case, the SNOPT (Sparse Nonlinear OPTimizer) (Gill, Murray, & Saunders, 1997) software package has been used as the optimization solver. Each time the optimization solver needs the value of the cost function or constraints, it calls the simulation to get back these values. This procedure is repeated until the optimum value is calculated for both NLP problems, first to perform DVR and then, once this has been completed, the same procedure is used to perform the energy optimization. Process values are obtained from the plant and sent, through the SCADA, to the models to perform the optimizations. Finally, optimization results are sent to the SCADA in order to be available for the operators and plant engineers (Fig. 2).

The main contributions of the paper are:

- Application of an RTO to a real factory, tackling the real implementation, communication issues, out-layer detection, etc., to provide satisfactory results. To make the real plant implementation possible, a set of tools has been developed; DLL generation, generation of OPC (OLE for Process Control) servers, SCADA, etc.