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Day-ahead economic optimization of energy use in an olive mill

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ABSTRACT

This article presents an economic case study on biomass and power dispatch focused on the olive oil extraction industry. A method is proposed to minimize the energy cost associated to olive oil production. This is realized through load shaping and optimal selection of the destination of subproducts and wastes. The mill and the loads linked to the extraction process are modeled using the energy hub concept, and an Economic Model Predictive Control (EMPC) based power and biomass dispatcher is introduced. The control strategy has been simulated over different scenarios to validate the optimization scheme.

1. Introduction

A major transformation is under way on the energy paradigm. On the power supply side, a shift is being conducted from large-scale, concentrated power generation, such as conventional fossil-fired power generation, to diversified types of power generation including renewable energy, co-generation, and various distributed power sources. On the demand side, users are expected to become '*prosumers*' (Favre-Perrod, Critchley, Catz, & Bazargan, 2009). That is, rather than simply consuming power, many households and industries will also produce it, and even sell the portion they do not use. These changes, however, will complicate the control of the balance between power supply and demand. An example of such multicarrier energy generation nodes are those industries that require heat or refrigeration in addition to electricity. Those calorific contributions might be produced through electric machines or through furnaces/boilers consuming other fuels. Given that absolute efficiency cannot be reached, there is always an excess of heat not used in the productive process that might be converted in electricity. Beyond this, wastes and subproducts can be re-used to produce fuels which in turn might be burned to generate part of the heat required for production. So, there is a physical facility that, in terms of energy, can consume electricity and/or heat and/or fuels, while also being able to produce electricity/heat/fuels. Moreover, with nowaday's analysis mechanisms, an industry can know not only its global multicarrier energy profile but also their pricing profiles, both for the demand and offer sides.

Olive mills, whose production process is presented in Section 2, are a good example of such industrial facilities. The first works dealing with the application of automatic control techniques to the Virgin Olive Oil Extraction Process (VOOEP) from a higher level perspective can be found in Nunez-Reyes, Scheffer-Dutra, and Bordons (2002) and Scheffer-Dutra, Núñez-Reyes, and Bordons (2002). These works propose MPC controllers with multiobjective priorization for different performance criteria. A posterior paper proposed a MPC controller focused on the global control of the plant with the objective of maximizing the industrial yield (Bordons & Núñez-Reyes, 2008) to provide the set points for lower-level PID controllers. Recently, efforts have been made to obtain a method capable of determining an optimal production plan for the whole harvesting season, i.e., define what amounts of VOO of which qualities maximize the profit of the company, given pertinent restrictions (Cano-Marchal, Gila, Garcıa, & Ortega, 2014).

Economic Model Predictive Control (EMPC) has attracted significant attention in recent years (e.g. Ellis, Durand, & Christofides, 2014; Rawlings, Angeli, & Bates, 2012), and there exist some examples of its successful applications to continuous manufacturing

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processes (Idris & Engell, 2012), to processes with associated hybrid renewable energy generation (Wang, Teichgraeber, Palazoglu, & El-Farra, 2014) and to systems that include energy storage (Ma, Qin, & Salsbury, 2014; Touretzky & Baldea, 2014). The capability of handling general economic cost functions also make EMPC a promising control algorithm aligned with the core ideas of next-generation manufacturing (e.g., Smart Manufacturing (Christofides et al., 2007; Davis, Edgar, Porter, Bernaden, & Sarli, 2012) and real-time energy management (Siirola & Edgar, 2012)).

The objective of the present work is to simulate the potential improvement in the economic result of a real olive mill due to the implementation of an EMPC scheme used to generate an optimal energy-efficient planning for the VOOEP. This implies minimizing the mill energy cost by means of the Optimal Power Scheduling (OPS) and Optimal Power Dispatch (OPD) of the process (Chao, Jun, Zhi, Jifeng, & Mingsong, 2015; Jayakumar, Subramanian, Ganesan, & Elanchezhian, 2016; Rigo-Mariani, Sareni, Roboam, & Turpin, 2014), without affecting its timing requirements or its quality standards.

To that end, in Section 3 the mill is modeled as a mass–energy hub. This is a generalization of the energy hub concept (Geidl, 2007), which has been widely applied to the modeling of energy transmission systems, used to model a manufacturing facility including both its energy and mass flows. Section 3 also comprises the determination of unitary energy demand profiles, i.e., the hourly time series of electricity and heat consumption generated per tonne of manufactured olives.

Then, the EMPC strategy is presented in Section 4. The proposed scheme uses multicarrier energy demand/production profiles and its respective pricing profiles as inputs, and provides both optimal manufacturing timing and power dispatch configuration to minimize the energy cost associated to the productive process. This strategy can be easily adapted to fit other continuous manufacturing processes, only knowing its energy demand profiles per unit of manufactured goods. Actually, it might be much more beneficial for batch processes, where the variability of energy pricing could be fully utilized by advancing or postponing the subsequent stages of the productive process.

Four different operating scenarios are simulated in Section 5 using the same olive reception profile, showing that the proposed strategy leads to an improvement in the net revenue obtained by the mill. Finally, a set of conclusions are stated along with the future work to be done.

2. Brief description of an olive mill with a waste valorisation line

The primary extraction of olive oil from raw olives is a thermo-mechanical process consisting on several sequential stages (see Fig. 1). All the steps demand the use of electric energy, while the churning of the paste additionally needs a thermal contribution to warm up the paste to about 27–40 °C. During the two-phase extraction process, currently the most extended in the main producing countries, two

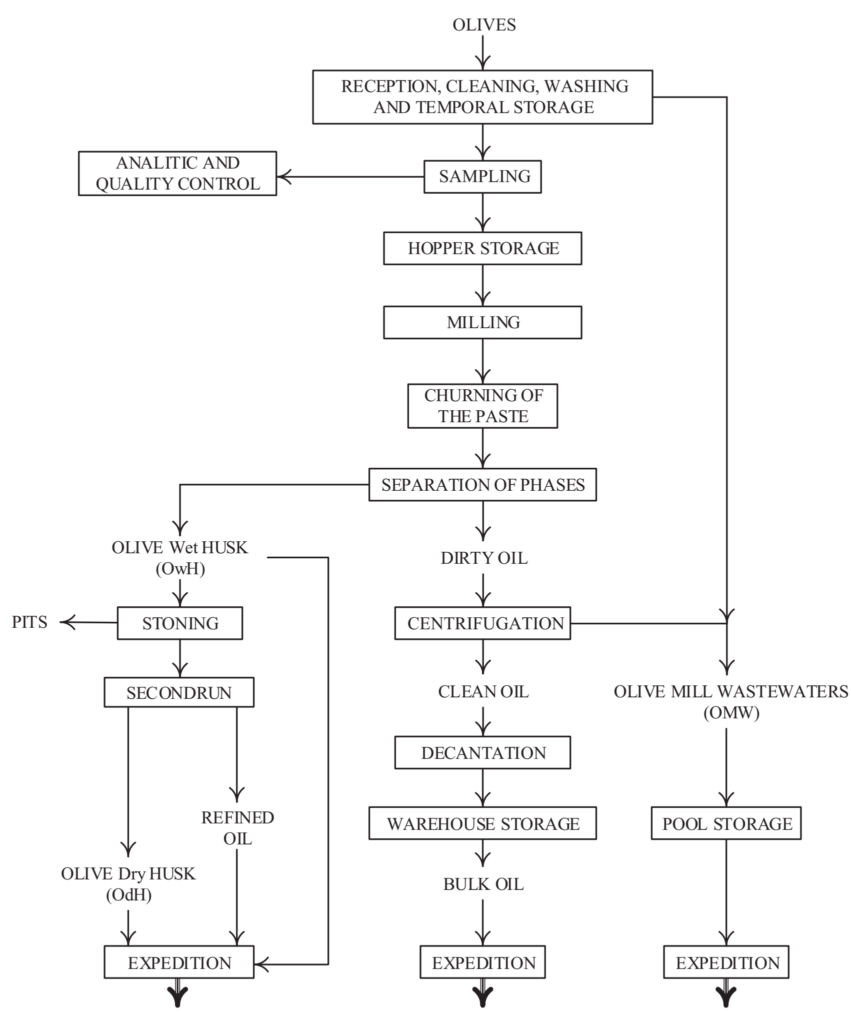

Fig. 1. Two phase olive oil extraction process.