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Optimal management of power generation assets: Interaction with the electricity markets

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Abstract

For historical reasons, many large industrial sites have their own power generation units, whether it is because the site was isolated when built up or the local network wasn't reliable enough to ensure a regular production. This can apply for energy-intensive industries like refineries or LNG plants in the Oil & Gas sector, but also mining plants, metal industries or chemical plants for instance. These generation assets are usually operated in a suboptimal way, the only concern being the safety of the process. The gist of this work will be to determine an optimal use of these assets for the industrial plant operator, considering interactions with the electricity markets.
Laying on the mathematical description of this optimization problem, a model was built up following a double target. First, to develop a standard architecture that would easily be translated from one case to the other. Then, to assess how high the expected savings could go and what would the induced strategy be. This model has been applied to a refinery case study, where the expected earnings rose up to 8 M€ per year. It accounts for 1% of the turnover. The figures obtained show that this is a relevant business concept. Following this trend, other energy-intensive case studies are being considered, from cement plant to paper plant.

Keywords: Energy management; Electricity markets; Asset management; Optimisation.

1. Introduction

For historical reasons, many large industrial sites produce their own electricity. Whether it is because the site was isolated when built up or the local network wasn't reliable enough to ensure a regular production, the industrial hence detains the responsibility to manage its own production unit. This

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situation mostly involves energy-intensive industries, as iron/steel or other metal industries, foundries, paper mills, cement plants, chemical plants – and in particular petro-chemical plants including refineries –, or even glass industries. Hence, we have here a situation where the production units are managed by local operators, and where the main goal of these operators is to ensure the industrial site's production. We understand that the decision process for meeting the demand will then often be based on the operators experience and safety concerns, which can easily lead to sub-optimal solutions. In particular, this can lead to a situation where many production units are used below their nominal capacity, leaving a potential unused for energy savings, earnings or environmental purposes [1-3].

We want to determine an optimal use for these electricity generation assets. We will consider these producers taking a role on the electricity markets. Indeed, as these capacities are currently used in a sub-optimal way, interactions with the markets appear to be an interesting way to try to manage them in a more profitable direction that would hence generate extra-earnings. Our problem statement is the following:

> Considering an industrial site with electricity generation assets, considering interactions with the spot markets (sales and purchases) and taking into account operational constraints and constraints from the Transmission System Operator (TSO), what earnings could the industrial get from an optimal use of its assets?

2. Generic Model

2.1. Objective

We will want our model to provide the two following outputs:

- the amount of these potential earnings, to see if this option is relevant or not, and maybe worth investing into;
- the guidelines on how they would be achieved. Although it isn't meant to be a genuine piloting tool, we must show that our solutions are realistic. Hence, our model must still give an idea of how these earnings would be made, what the production curve of each machine would look like.

2.2. General architecture

The model we develop will be based on the architecture displayed Figure 1. The electricity will be produced by either gas or steam turbines, and we shall hence consider both steam and electricity flows. Given the characteristics of the machines and the production planning of the industrial site, we will expect our model to determine the optimal production level of each machine. Comparing the cases with and without interaction with the electricity markets, we will deduce the extra-earnings we generate.

This model lays on a mixed binary-continuous linear optimization problem. The flow variables are continuous, and the decision variables will be the sales and purchases on the markets and the gas purchases [4]. The objective function can hence be written in the equation involving prices (p), commission fees (p_{fee}) and quantities exchanged on the market (q):

$$\max \sum_t \left(p_{elec,t} - p_{fee}\right) \cdot q_{sales,t} - \left(p_{elec,t} + p_{fee}\right) \cdot q_{purchase,t} - p_{gas,t} \cdot q_{gas,t} \quad (1)$$

with the following assumptions:

- the production of the regular output of the plant (for instance, refined products in a refinery) is guaranteed;
- the use of the machines follows operational constraints [5]. Specifically, we will consider the inertia of

steam turbines and boilers, and hence we will set an upper bound to the fluctuation of the output of these machines over one hour [6]. This is described in the equation:

$$\forall i \in \text{machine}_{\text{steam}}: |q_{i,t} - q_{i,t-1}| \leq \alpha \cdot P_{max,i} \text{ with } \alpha \in]0;1] \qquad (2)$$

- the electricity market considered are the day-ahead markets, and are simply modeled as an input price for each hour [7];
- in order to interact with the electricity markets, the industrial plant will have to comply with constraints from the TSO, such as the participation to the back-up mechanism;
- the yields of the machines are assumed to be piecewise-continuous. The flow variables will hence be divided between several pieces, this will require binary variables:

$$\forall i \in \text{machine}, \forall t: q_{i,t} = \sum_j q_{i,t,j} \qquad (3)$$

This optimization problem is then encoded, using the Python language and the Gurobi solver [8].

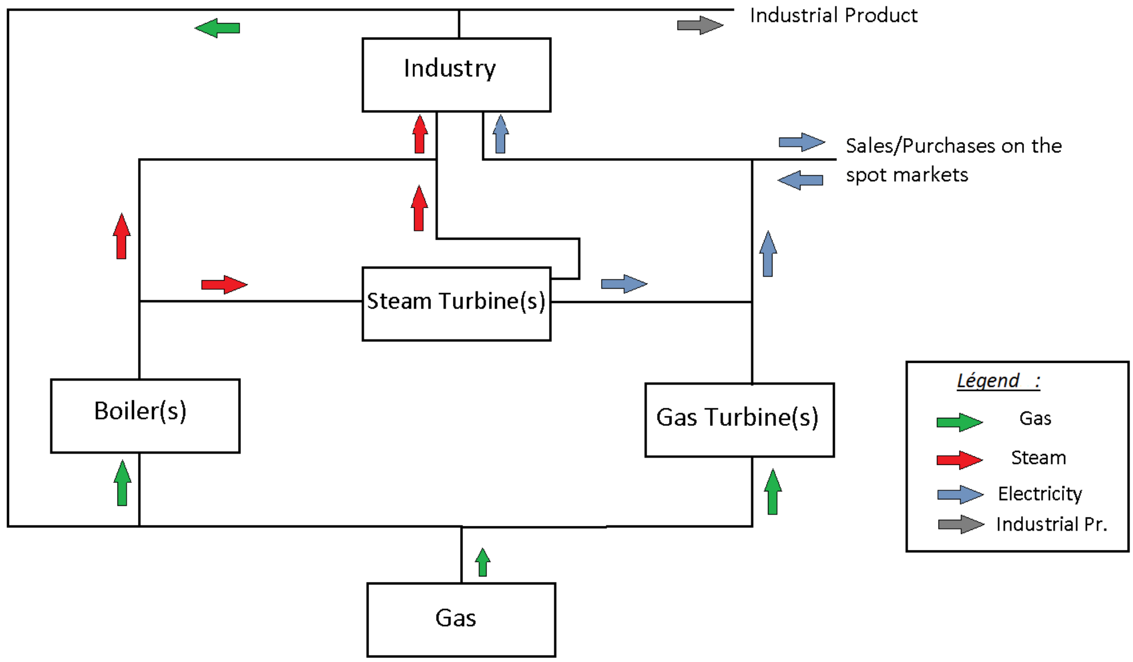

Fig. 1. General architecture

3. Case Study

3.1. Refinery

We first apply our model to a refinery, which characteristics are given in the table 1. The annual production of the site is 8.5 Mtons of refined products, and the annual steam and electricity consumption rises respectively to 3,000GWh and 420GWh. Although this subject seems rather fitting for developing countries, we will use the day-ahead prices from France as an easy-going solution. Our point here is to test the model rather than carry on a thorough analysis of the numerical results.

Machines	Number	Nominal power (MW)
Boiler	1	600
Gas Turbine	1	40
Steam Turbine	2	15

Running the simulations over a week length, we obtain the results displayed in the Figure 2. Depending on the month, and hence the level of electricity prices on the markets, the weekly savings vary between €140,000 and €180,000. With the low electricity prices we find in Europe these days, we end up with a situation where we will more often purchase instead of producing locally, rather than overproducing to sell. Aggregated into a year, we end up with annual savings around 8.5 M€. Rather than the rough figure, that obviously depends on the assumptions and the context we are working on, the order of magnitude (M€) is the important element here. Considering the overall turnover of the refinery, these savings account for almost 1%. This tells us that, on the one hand there are some genuine earnings to obtain through this optimization, and on the other hand we confirm that the industrial process at stake here cannot be jeopardized by our optimization.

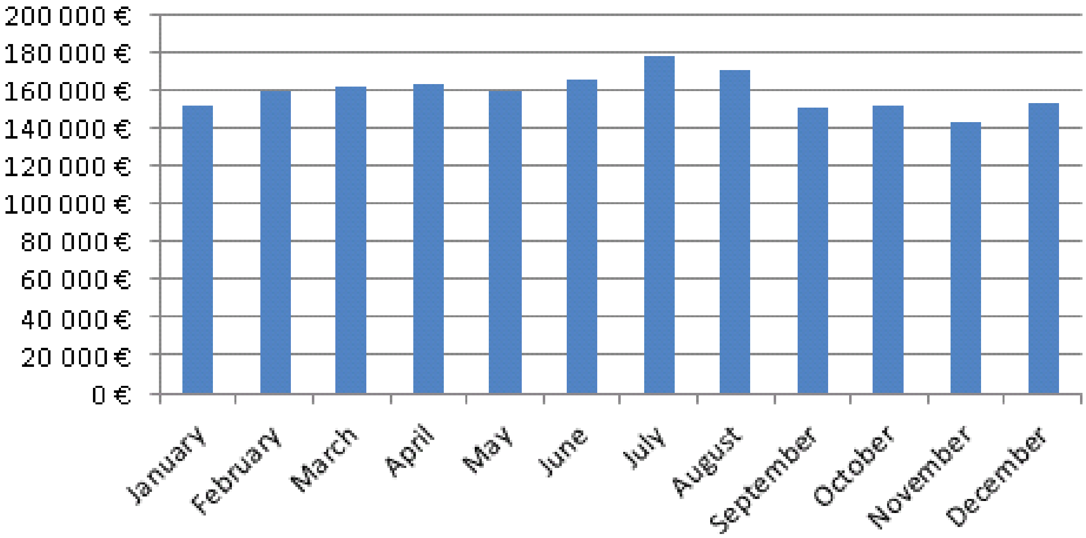

Fig. 2. Refinery, weekly savings.

Displayed Figure 3 is an example of an output of our program, the production planning for each machine on the July week. We see that the needs of the site are met through purchases on the week-ends, where the prices are at the lowest. The production of the turbines hence drops. However, the minor peaks that still appear during these days are met through a modulation on the gas turbine, more flexible.

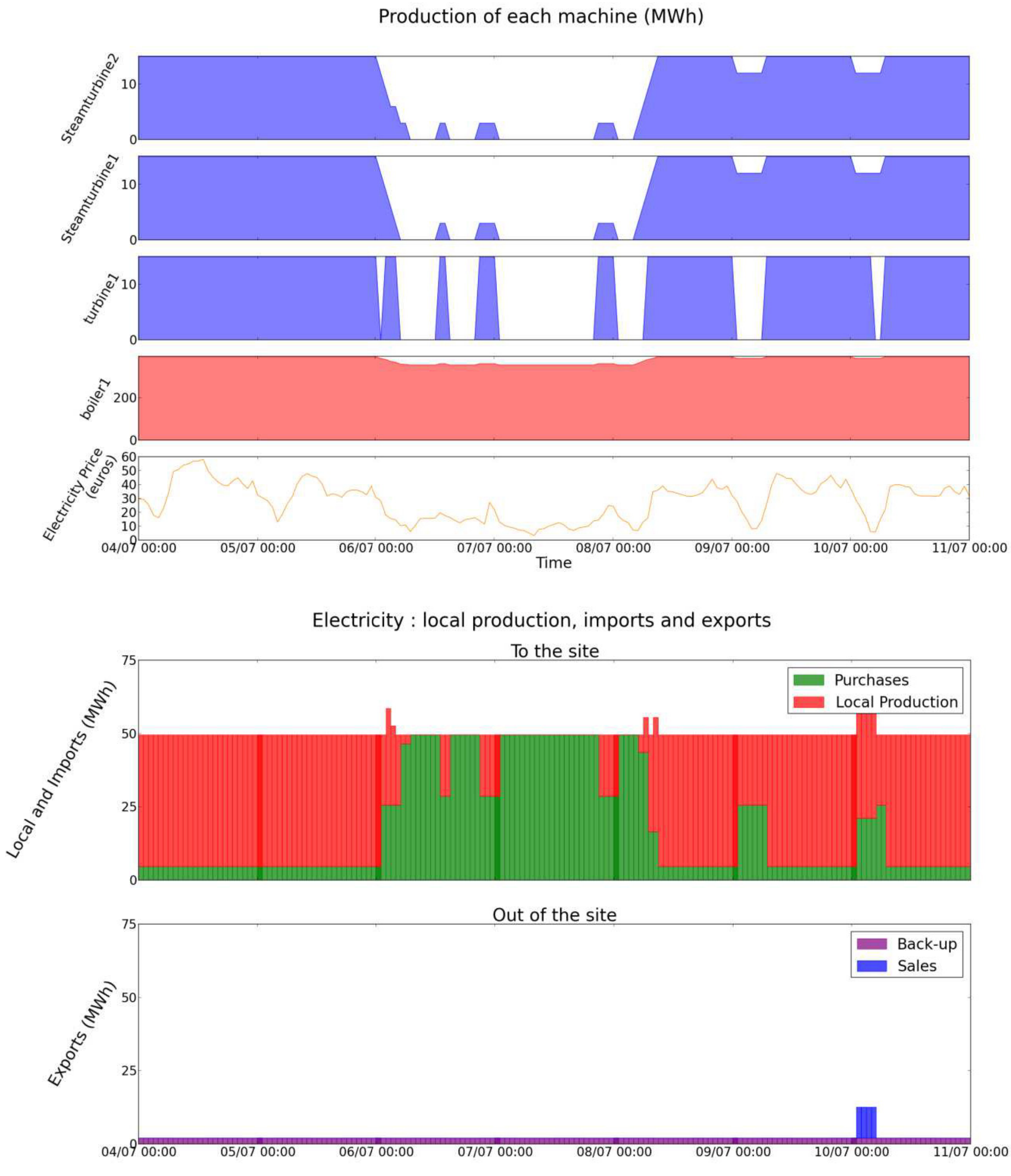

Fig. 3. Model outputs, July week.

3.2. Cement plant

Similarly, we have then tested our model to the waste-recovery system of a cement plant. The system, merely composed of two boilers and a steam turbine, collects waste heat during from the preheater and cooler during the production process. The key difference between this case and the refinery one is that here the input flow, the waste heat, is fixed, whereas we could before choose the level of our gas purchases. However, this can still be brought back to our generic problem, using a gas price of 0. Doing so, we end up here with annual savings around 2.5 M€. Considering an investment cost for the heat-recovery system of 14M€, the Return-On-Investment rate is 5.6 years.

4. Conclusion and forthcoming

We have translated our optimisation problem into a generic model, that has proved to be adaptable to our two case studies. The order of magnitudes of our annual savings, in M€, seems interesting, but must obviously be handled cautiously. Further developments are under progress, ranging from the paper plant to the (whisky) distillery.

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Biography

Vincent Mazauric has been with Schneider Electric since 1995, currently in charge of Scientific Affairs and Patent Policy. From 1988 to 1991, he was with the French Agency for Aerospace Research (ONERA) and joined the Center for Extreme Materials (Osaka, Japan) from 1992 to 1994. He received a PhD in Solid State Physics (Paris, France) and is post-graduated in Electrical Engineering (Grenoble, France), Pure Mathematics and Theoretical Physics (Paris, France). He is Fellow of the Japanese Society for the Promotion of Sciences and Expert-evaluator for the R&D Framework Programs of the European Commission. He received the 2013 Applied Electromagnetics and Mechanics Award. He is closely involved in sustainability and climate-energy initiatives and policies within the United Nations Framework Convention on Climate Change, the Commission Environment & Energy of the International Chamber of Commerce, and the ParisTech Chair "Modeling for sustainable development".