A new MILP model for integrated lot-sizing and energy supply planning with onsite renewable energy

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With the increasing concern on climate changes and global warming, industrial companies, one of the largest carbon emitters, are urged to reduce the carbon emissions of their manufacturing processes. The recent energy crisis also caused a sharp rise in the price of conventional energy resources and strong pressures on energy supply. One of the solutions to deal with these two challenges is to power, at least partially, manufacturing processes by electricity generated on site from renewable sources. However, the intermittence of the renewable energy sources as well as the time-of-use pricing policy frequently employed by energy providers make it necessary to accurately track the timing and amount of energy consumption, on-site generation and trading. This means that an integrated production planning and energy supply planning problem should be investigated.

The present work focuses on simultaneously planning the industrial operations and energy supply of the system depicted in Figure 1.

The production system comprises a single machine producing several types of products to satisfy an external customer demand. Backlogging is not allowed and demand must be met on time. In case finished products are produced in advance, they are kept in inventory, which is penalized by inventory holding costs. The machine may be either idle, carrying a changeover between two products, preserving its setup state for a given product or manufacturing a single type of product. Changing the setup state of the machine from one product to another one requires to carry out changeover operations, which incurs sequence-dependent changeover costs and times. The industrial production planning to be solved is thus a multi-item single-machine lot-sizing problem with sequence-dependent changeover costs and times.

Energy is consumed during changeover operations, manufacturing and preserving. The amount of energy consumed during a changeover is sequence-dependent, the one consumed during manufacturing is proportional to the number of items produced and the one consumed for preserving the machine setup status is proportional to the length of time spent in this state. No energy is consumed when the machine is idle. As for the energy supply system, it comprises three main elements : on-site power generation devices producing a time-varying amount of green electricity from renewable energy sources, an on-site energy storage system and the main electricity grid with which electricity may be traded at a time-varying price. Note that the one-site generated green electricity is assumed to be free and that trading energy with the grid incurs losses due to the electric transformer. This means that consuming the on-site generated green energy to power the manufacturing process will be in most cases more profitable than trading energy with the main grid.

We propose a new MILP model for this problem. It relies on a two-level time structure : a coarse time discretization to track the demand satisfaction (typically using periods corresponding to 8-hours shifts or days) and a fine time discretization to track the energy consumption,

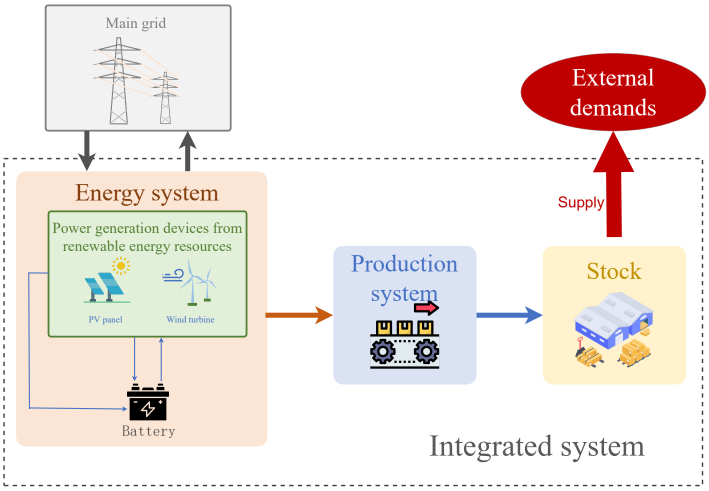

FIG. 1 – Integrated energy supply and industrial production system

generation and trading (typically relying on 1-hour or 15-minutes time intervals). This fine time discretization is also used to plan the industrial production. The production planning problem is thus modeled as a Proportional Lot-sizing and Scheduling Problem (PLSP), a small-bucked lot-sizing model in which at most two different types of product may be produced in each micro-period. As our problem involves changeover operations that may overlap several planning micro-periods, we propose to extend the formulation recently introduced in [1] to take into account sequence-dependent changeover costs and times and to integrate the energy supply planning into the model. Note that a similar integrated problem was studied in [2]. The authors proposed to use three distinct time structures : one to track the demand satisfaction, one to build the production plan and one to track the energy supply. However, their model, based on an extension of the General Lot-sizing Problem (GLSP), leads to a large-size MILP formulation involving many big-M constraints and poses thus computational difficulties.

Numerical experiments were carried out on randomly generated instances to compare the quality of the energy supply and production plans obtained by our PLSP-based model with the one of the plans obtained with the GLSP-based model introduced in [2]. Our preliminary computational results show that for small-size instances involving 3 products and 16 micro-periods, the problem can be solved to optimality much faster by using the PLSP-based model than by using the GLSP-based model. Moreover, the cost of the production plan obtained with our model is the same as or even better than the one obtained in the GLSP-based model (since the GLSP-based model does not allow changeover overlapping two macro-periods). For medium and large instances involving up to 5 products and 96 micro-periods, the solver can hardly find a feasible solution when using the GLSP-based model, while it finds a relatively good feasible solution when using the PLSP-based model.

Références

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