Energy-Aware Production Management for Storage-Augmented Production Facilities

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Abstract. The last decades have witnessed a fundamental change in electricity supply and demand across the world. While both energy generation and consumption have increased worldwide by around 50% between 1993 and 2012, the share of renewable energy in the total amount of energy supply has increased as well and is expected to grow further in the years to come. The highly distributed allocation and the hardly controllable intermittency of renewable energy resources strongly contrast with traditional energy generation, and thus create major challenges for the management of present and future energy systems. The most relevant challenge today is that energy generation from renewable sources only rarely matches energy demand over time. As a result, modern energy systems need flexibility in managing differences between energy generation and demand. Industrial production accounts for a large share of the total energy consumption and more and more becomes a source of renewable energy generation itself. Airbus and Tesla, for instance, equipped their new production facilities with a substantial amount of renewable energy generation facilities whose energy generation often exceeds internal consumption. Industrial production has potentials for flexibility by actively managing its energy demand over time. Thus, production and production management should not be considered a simple, non-controllable load in the future, but rather an active member of the overall energy system. However, centrally controlling the production facility for short-term flexibility operation may become computationally infeasible. For this reason, this paper proposes a framework that proposes a distributed control arrangement. The framework considers five subsystems of components in industrial production facilities: the production system, auxiliary systems featuring production-bound and unbound systems, energy conversion systems and local energy generation systems. Each subsystem is equipped with a local flexibility controller and coordinated by a central controller.

1 Introduction

Over the last decade, energy systems have experienced a fundamental change towards a significant share of energy originating from renewable, intermitting sources [1]. As a result, maintaining the balance between electricity supply and demand has become a complex task in modern energy systems, and ensuring system stability is no longer the responsibility of the supply side alone. Demand Response (DR) leverages flexible loads on the demand side to provide needed balancing power ([2-6]), and it is becoming one of the main pillars for the smart grid paradigm. Flexibility is the technical ability of a load to adapt its consumption when needed. DR embraces the flexibility by price-based and incentive-based programs. Price-based programs aim to influence the electricity consumption pattern of end-users through electricity prices that change over time. In contrast, incentive-based programs resort to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized [7].

For adopting short-term DR measures (e.g. within an hour), the system operator is often permitted to directly reschedule, reduce, or disconnect loads to prevent critical periods, when the stability of the power grid is at risk. However, the direct control of loads by a third party interferes with consumer privacy and internal operations and it may prevent consumers from participating in DR. Other solutions that would enable timely load adjustments, but that do not require direct access to loads, could therefore lead to a higher DR potential.

Industrial consumers and in particular their production facilities (PF) are of special interest for DR research for three reasons. Firstly, around 42.5% of world-wide electricity consumption could be accounted to industrial usage in 2014 [8]. Due to this high share in the total energy consumption, this group of consumers has a particularly high potential for DR. Secondly, industrial consumers bear a large potential for flexibility in load management in their complex and large organizations [9]. Thirdly, tapping these potentials requires a deep interference with internal operations, which requires advanced communication and coordination techniques often available in PF.

This paper supports tapping industrial PFs' potential for offering its short-term flexibility to system operators. To this end, this work formulates a framework for researchers to identify participants and structure decision problems for better handling complexity within distributed control arrangements.

2 Development of the framework

Based on the work of [10] on decision-relevant subsystems in a PF for energy planning and based on own considerations, we developed the framework described in this section as an integrated, energy-aware view on PF for offering its short-term flexibility (see Figure 1). PF include various elements starting from production systems itself back to local energy generation facilities that contribute to short-term energy flexibility, which will be described in the following.

The production system (PS) (see Figure 1), at the center of a PF, may contribute to flexibility through various measures. Since energy consumption varies across different production stages and across machines at the same stage, the total energy consumption is controllable, firstly, either by adapting the sequence of jobs or by changing the allocation of jobs to machines at any of the stages. Secondly, delaying individual production steps or even interrupting on-going processes can further change total energy consumption [11]. In addition, in continuous production processes, adapting process parameters (such as the production rate or processing temperature) might significantly influence energy consumption. Changes of the production schedule, however, influence inventory levels and throughput times. Physical inventories would become equivalents to energy storages in this case. In recent years, energy-aware production planning has become increasingly popular and thus, besides traditional production planning objectives, energy-related objectives such as energy consumption, energy costs or greenhouse-gas emissions have more and more attracted the attention of researchers and practitioners ([12] and [10]). [13], for example, presented an algorithm for a market-based DR program in a discrete manufacturing facility. For a given incentive for load reductions, the proposed algorithm reschedules the production plan to lower energy consumption in the respective period. As a result, production output is lowered and the tradeoff between revenue from production and provided flexibility is optimized. Another example of providing flexibility in the PS is presented in [14].

Next to the PS, we group all auxiliary processes with local consumers that are not part of the PS and not related to the main production process. In this group, we distinguish between production-bound auxiliary systems (PbAS) and unbound auxiliary systems (UAS) (see Figure 1). This differentiation is useful as units in PbAS depend on the schedule of the PS, and determining flexibility in PbAS requires knowledge about the production schedule. UAS, in contrast, can be managed independently of the PS. An example for PbAS are electric vehicle (EV) fleets in intralogistics. [15] investigated the flexibility potential of infrastructure for charging the EV fleet at a container terminal. The EV fleet runs with additional battery-charging stations; the state-of-charge of the batteries and their availability at the charging stations depend on the schedule for unloading ships. Studying the charging of batteries and the unloading of ships independently might thus result in infeasible solutions.

EV fleets, however, can also be considered independent of the production process and thus be part of UAS (see Figure 1). [16], for instance, investigated the role of the electric storage capacity of an (employee-owned) EV fleet available for charging to compensate mismatches between supply from local RES at a discrete manufacturing line. In comparison with similar stationary batteries, EV fleets offer some advantages as they do not need additional investments and offer an alternative use in traction applications. A further example of UAS are heating, ventilation and air-conditioning (HVAC) systems of the PF which typically allow modification without affecting their thermal service due to thermal inertia of the entire system [17].

The fourth and fifth subsystems we identified for providing energy flexibility are internal energy conversion systems (ECS) and local (renewable) generation systems (LGS) (see Figure 1). We distinguish between three sources of energy. Most valuable to the PF are applied energy sources, such as electricity, gas, pressurized air, and heat, which can directly be used in the PS. Some of these energy sources are not grid-bound and need to be converted from final energy sources such as electricity and gas in the ECS beforehand. Primary energy sources such as wind and solar energy are converted into electricity in the LGS beforehand. Nevertheless, both systems offer flexibility potential either through internal storage potentials or, in the case of LGS, by simply curtailing production. One example for energy conversion units are combined heat and power plants that convert gas into heat and electricity. Another example is compressed air (CA) which is converted from electricity by compressors. Pressurized (air) tanks can additionally be used as storages. An integrated ECS and PS control strategy using CA to increase self-sufficiency of a PF with local RES was presented by [18]. By means of a combined control of CA production and PS, the authors were able to improve the self-sufficiency ratio by around 6 percentage points through an adequate sizing of a CA tank. When combined with a gas turbine, pressurized air can be converted back to electricity. The overall efficiency of the converting electricity to CA and back to electricity, however, is rather low compared to battery technologies and additionally, further investments would be required. [19] formulated a similar optimization problem for the complete ECS.

Centrally controlling the PF for short-term flexibility may suffer from long model development time and huge computational efforts due to many interdependencies. We suggest a distributed control arrangement with decentralized flexibility controllers (FC) for each of the subsystems described above and a central flexibility controller taking the role of a market maker coordinating the other subsystems. An example concentrating only on PS can be found in [20]. The authors presented a distributed control arrangement for a continuous manufacturing system. To handle complexity, every machine in the serial production line has a local controller following a cost function including local costs at machine-level and collaborating costs induced from surrounding and affected machines. To set priorities in solving the control problem between local controllers, the problem is solved iteratively starting with the slowest machine.

The above mentioned concept can be applied at the PF level. The decentralized FCs determine local flexibility potential. The central FC collects information on flexibility potential and coordinates decentral, subsystem FCs in multiple iterations to generate an efficient and feasible, but not necessarily optimal solution. Additionally, the central FC communicates the monetary flexibility offer to the system operator and implements control inputs in case offers are accepted.

3 Outlook

Energy consumption and an active participation in grid operations have become topics of interest in today’s management of production facilities. This paper introduced a framework for an energy-aware view on PF to manage flexibilities with a distributed control arrangement. In future research, we will further detail operations of the decentral, subsystem FC units and how their interaction with the central FC should be organized.

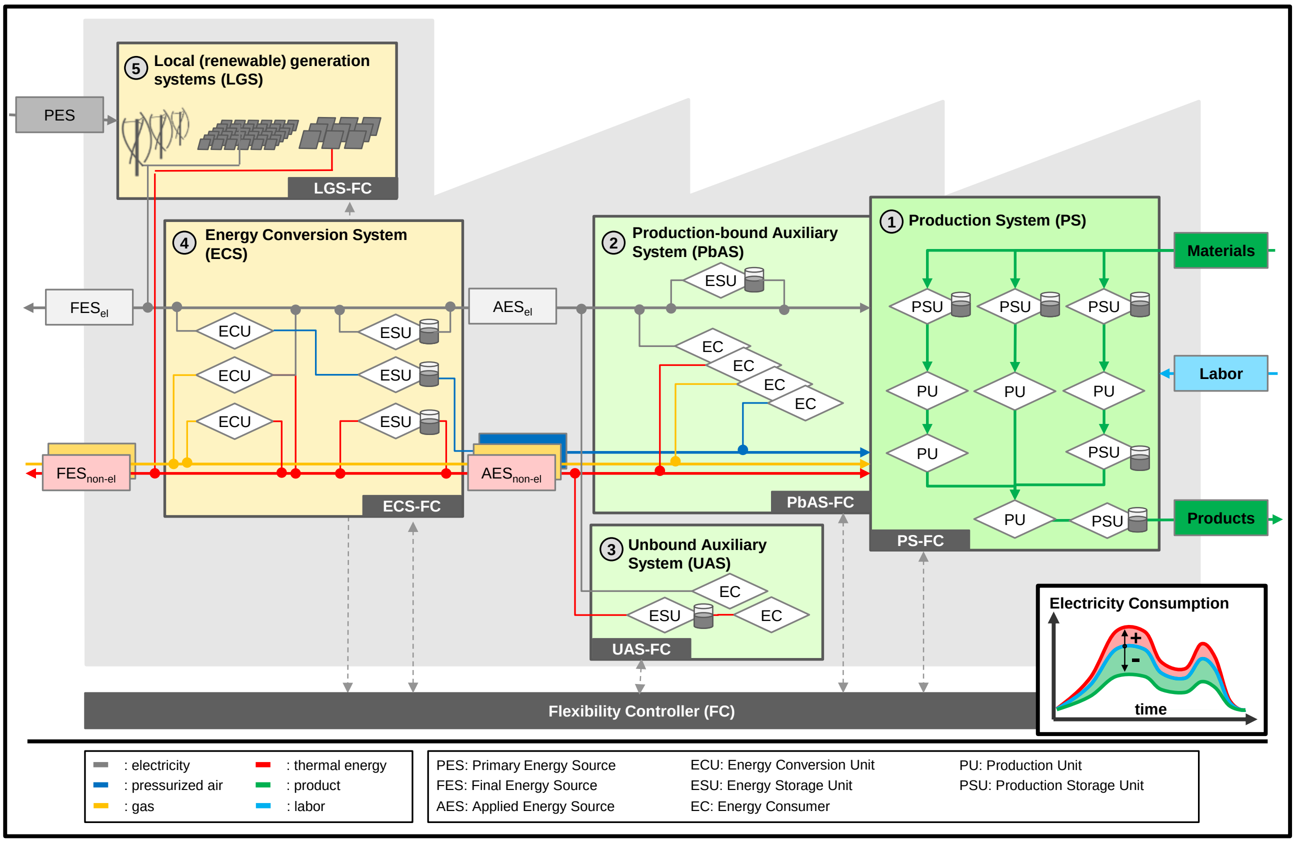

Figure 1: Flexibility controller in an energy-oriented PF

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