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Comparison of Integration Architectures for Process Flexibility in Industrial Processes

Abstract: This paper introduces a software systems architecture and design for an industrial process and its supporting subsystems and components. Material is based on two energy-intensive industrial (EII) use cases: 1) a wastewater treatment plant (WWTP) and 2) a glass manufacturing plant. Both systems include similar components from external partners. Many of these external components are related to energy optimization. A general design based on the use cases is proposed. Decentralization and loose coupling of components are key properties of the suggested design. The proposed design is then compared to the emergent design of the use cases. The deployment and integration of a single component, a process optimization agent (PoA), which adheres to the proposed design, is then explained.

Keywords: energy flexibility, integration, software deployment

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1 Background

The global transition to green energy is changing the energy industry. For example, the European Union has taken a leading role in minimizing carbon emissions [1]. These decarbonization goals for the energy industry have led to a diversification of energy sources in industrial processes. As a result, the electrification of industrial processes is increasing. Increasing electricity demand and intermittent renewable energy generation are reflected as price volatility in the electricity markets. These changes introduce potential for optimization of energy usage. One specific optimization area is the concept of energy flexibility. For example, it may be economically beneficial to consume energy only at a specific time of the day depending on the inherent properties of an industrial process itself and the state of the energy markets and grid requirements.

Additionally, the transition to Industry 4.0 introduces more fine-grained methods and opportunities for optimization. Compared to traditional hierarchical and isolated models of industrial control systems (ICS), the shift towards more intelligent and connected devices enables more detailed optimization of energy usage. For example, a digital twin (DT) could provide real-time data on the energy consumption of an industrial process to other stake holders, who can then utilize this data for optimization models.

On a higher level, both the decarbonization and Industry 4.0 transitions can be seen as the initial phases toward flexible, loosely coupled, and decentralized energy markets. Such markets could allow energy consumers and producers to participate in broader energy markets where stakeholders could be located in different geographical regions. In these markets, purchasing different energy products would be easy, reliable, and economically and environmentally beneficial. For example, decisions to trade different energy products could be based on optimization calculations. These include calculations such as energy consumption, cost optimum calculations and flexibility potential calculations.

2 Aims

On a general level, the objective of this paper is to explore what kind of software system architecture and design would be suitable for a decentralized and loosely coupled energy system. Examples of participants in such a system could be energy consumers and producers, energy market predictors, energy management systems, energy optimization models, and decision support systems. The emphasis of this paper is on identifying the software system integration paradigms, design principles, communication protocols, software stacks, and security models that would be appropriate for such a system.

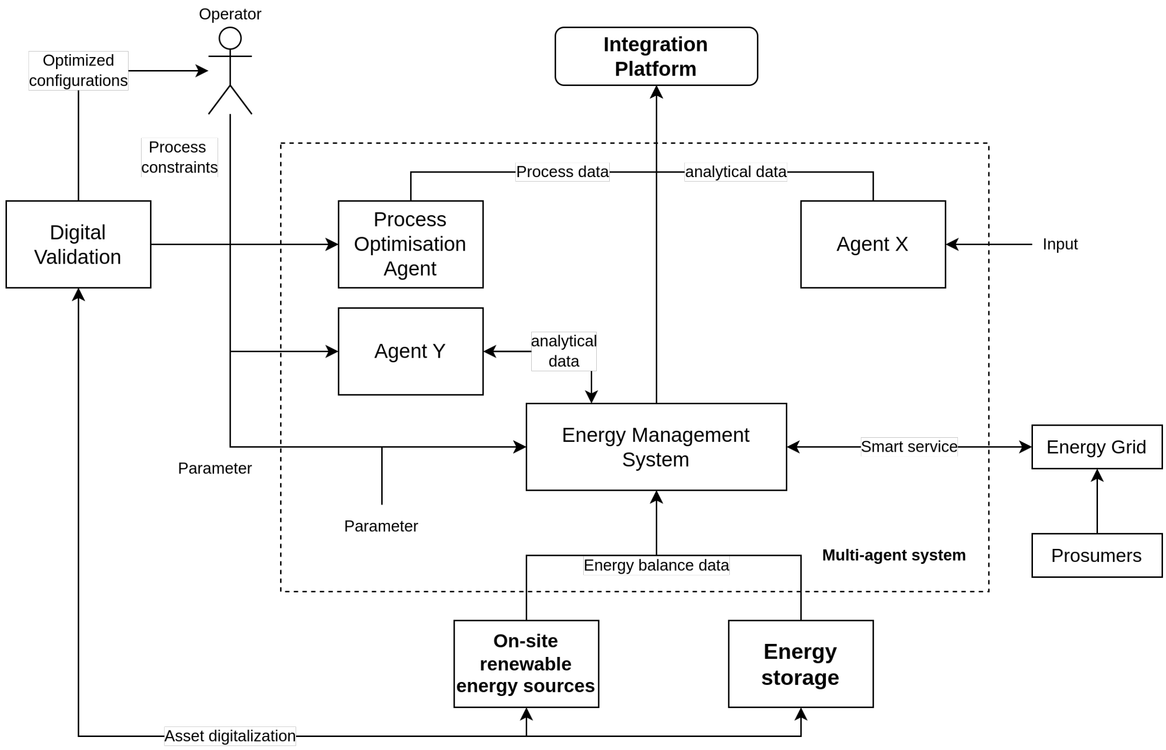

Fig. 1. High-level overview of integration platform based on use cases

3 Materials and Methods

The work in this paper is based on two use cases of energy-intensive industries in the European Union member states. First use case is wastewater treatment plant. Second use case is glass manufacturing. First, a general overview of the desirable properties of a decentralized and loosely coupled energy systems are discussed based on the aforementioned use cases. After this analysis, a suggestion for an architectural design is introduced and its advantages and disadvantages are reviewed. The proposed system is based on the OPC UA PubSub standard [2]. A high-level overview of the different participants, systems and components based on the two use cases is depicted in figure 1.

Then an analysis of the real systems of the use cases is presented and analyzed. The use cases did not have a formal architecture in place beforehand. In other words, the design of the systems emerged during the deployment and integration phases of the components by the different participants.

A comparison of the suggested design with the emergent design of the use cases is then provided. This comparison is valuable, because one of the goals of a decentralized and loosely coupled architecture is to see how a subsystem or a component can be integrated into a system of different design.

One of the key components that is integrated into the environments of the use cases is a process optimization agent. This component relies on flexibility calculations. However, the theoretical background of flexibility is out of scope of this paper. A general framework for the quantification of flexibility in industrial processes is presented in a related paper [3]. On the concept of flexibility itself and identifying flexibility potentials, there is another related paper [4].

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