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Defining Energy Flexibility for Energy-intensive Industrial Processes

Abstract: This paper aims to propose a definition for the energy flexibility of energy-intensive industrial processes. Current research on this topic lacks an ambiguous definition for flexibility. In the literature, flexibility has been reviewed from different viewpoints and, therefore, does not give a comprehensive overall view. This lack of clarity poses challenges for industries to realize the flexibility potential of their processes. The paper begins with a review of existing research on industrial process flexibility, followed by presenting an alternative methodology. Flexibility is categorized into three core components: resources, services, and products. Flexibility resources represent the sources of flexibility; flexibility services provide abstract definitions to utilize these resources for specific purposes; and flexibility products offer mechanisms for trading and contracting services, such as through pricing schemes. To demonstrate the applicability of the proposed definition, two real-world case studies are presented. The first involves a wastewater treatment plant in Greece, where flexibility resources, potential services and relevant products are evaluated as part of a flexibility audit. The second use case focuses on a glass processing plant, analyzing the same aspects to demonstrate the versatility of the methodology. The novelty of this work lies in its structured methodology for defining flexibility and its practical application to diverse industrial scenarios, bridging the gap between theoretical frameworks and real-world operations.

Keywords: Flexibility, flexibility resource, flexibility service, flexibility product

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1 Introduction

The industrial sector has been slow at adapting to changes in the energy system, despite such adaptation needed to meet the target of net zero emissions in the European Union by 2050, as outlined in the European Green Deal [1]. Historically, energy production has been designed to meet the demand. However, the growing penetration of variable renewable energy sources (VRESs) in the power system has introduced intermittency in energy generation, highlighting the necessity for demand-side flexibility. Addressing these challenges requires comprehensive changes to the power system, with industrial sector flexibility identified as a critical component of the solution [2]. In a 2020 report by the International Energy Agency (IEA) it is estimated that less than 2% of global flexibility potential is currently being utilized [3].

Energy-intensive industries (EIIs) are characterized by large energy consumption as a part of their operation [4]. These processes span various activities, including data processing, storage, and transmission in data centers; product manufacturing; food and material processing; and wastewater treatment. Due to their inherently high energy and power demands [5], EIIs present both challenges and opportunities in the context of integrating flexibility into the power system.

This paper seeks to establish a generalized definition of industrial process flexibility that can be applied across diverse use cases. The methodologies proposed for defining flexibility are reviewed, and two example use cases are presented to demonstrate the practical application of the developed definition. The results include characterization of the flexibility resources in the aforementioned industrial processes and an exploration of their utilization potential.

The scope of this paper is limited to active power-related flexibility. Issues related to reactive power, flexibility verification, and services associated with power quality are beyond the scope of this work.

2 Background

Research on the flexibility of energy-intensive industries (EIIs) has gained increasing attention in recent years. In some papers the energy flexibility of industrial processes has been evaluated [5, 6], while in others exploitation of the profit potential of industrial process flexibility in day-ahead (DA) and intraday (ID) markets [7] is discussed. In [8] the role of flexibility in balancing markets has been discussed. A review article examining research on industrial process flexibility up to 2019 [9] highlighted several areas requiring further exploration. These include the impact of flexibility decisions on entire production lines, the development of industry-specific frameworks, and the adoption of simulation-based approaches. Additionally, a notable research gap exists in understanding the information flow of energy flexibility between an EII's energy management system and its process optimization agents.

Flexibility is often conflated with related terms such as demand-side response (DSR), demand response, demand-side management, flexible generation, and energy storage [10]. While these concepts are integral to the broader discussion, they represent specific facets of flexibility rather than capturing its full scope. Consequently, these terms describe distinct areas of flexibility but fail to encompass the concept in its entirety.

Therefore, it is important to form a clear and comprehensive definition of energy flexibility. Such definition must include the identification of flexibility resources, the services these resources can provide, and the various flexibility products available. This approach ensures that the concept is sufficiently broad to encompass its diverse applications while maintaining the precision needed for practical implementation.

3 Aims

This paper aims to establish a clear and unambiguous definition of flexibility and demonstrate its practical application through two example use cases: the wastewater treatment plant (WWTP) aeration process and a glass processing plant. Flexibility is systematically categorized into three key components: resources, services, and products. The characteristics of these categories are analyzed and presented in detail.

The methodology involves identifying flexibility resources within the processes, determining potential services these resources can provide, and subsequently exploring possible products by examining the flexibility marketplaces of the process-respective countries as well as novel marketplaces. Additionally, potential challenges in utilizing flexibility in industrial processes and research gaps are discussed.

4 Materials and Methods

In this study, flexibility is categorized into three distinct components: flexibility resources, flexibility services, and flexibility products. This categorization provides a structured framework for evaluating and understanding flexibility in industrial processes. Flexibility taxonomy is visualized in figure 1.

4.1 Flexibility resources

Flexibility resources serve as the source of flexibility, enabling the provision of flexibility services. These resources must possess "the ability to change or modify their routine operation for a limited duration in response to external service request signals, without inducing unplanned disruptions" [10]. Examples of flexibility resources include power system operations, power system assets, loads, energy storage assets, and generators.

4.2 Flexibility services

Flexibility services describe the utilization of flexibility resources for specific purposes. A single flexibility resource may provide multiple services, and the definitions of these services should be independent of the individual resources. This ensures that future flexibility resources can seamlessly integrate, avoiding developmental barriers and enabling fair market participation.

Flexibility services encompass a wide range of applications, such as peak shaving, energy savings, and balance management. Flexibility resources, such as combined heat and power (CHP) plants, can simultaneously provide multiple services. Additionally, the aggregation of multiple flexibility resources can facilitate service provision, further enhancing the overall flexibility of the power system.

4.3 Flexibility products

Flexibility products represent the procurement mechanisms for flexibility services and are typically remunerated. These products are not mandated by grid codes but are developed to address specific system needs. A single flexibility product may be provided by multiple flexibility services and can be utilized to fulfill various technical challenges. For instance, an mFRR product could simultaneously address frequency control and congestion management [11].

The design and development of flexibility products require clear specifications of system operator needs to ensure their effective application. Flexibility products play a vital role in maintaining the reliable operation of the power system. For portfolio optimization, balancing, and congestion management, flexibility products should be designed to enable efficient allocation of flexibility and maximize its overall value [12].

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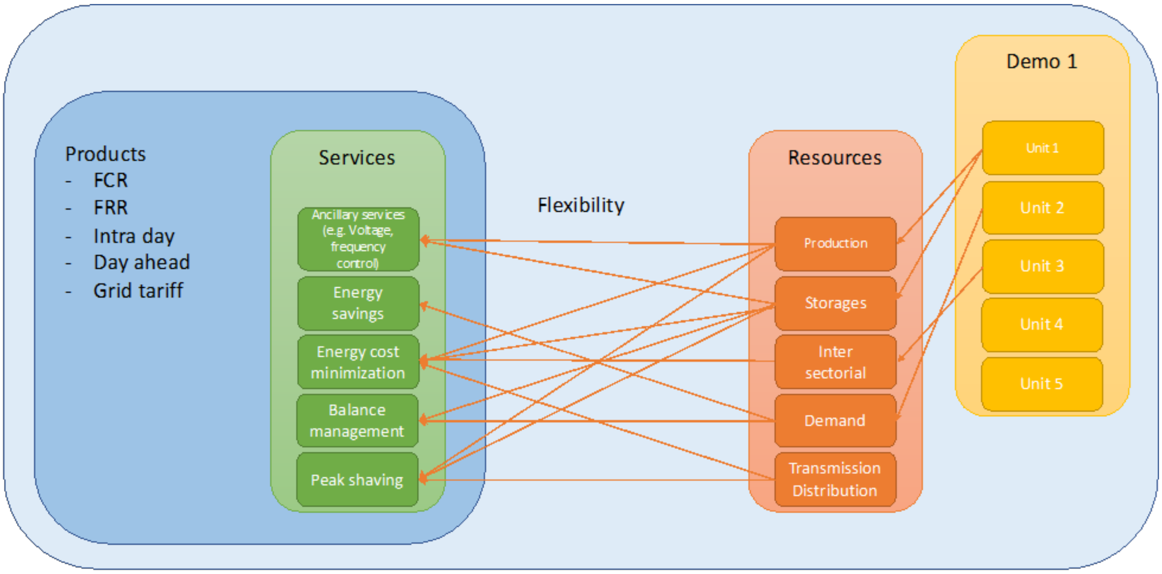

Fig. 1. Visual representation of flexibility taxonomy