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Leveraging consumers' flexibility for the provision of ancillary services*

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Introduction

The output of most renewable sources is intermittent and can only be predicted with limited accuracy. Therefore, the increasing penetration of variable renewable sources leads to an unprecedented level of stochasticity and non-linearity in power system dynamics. Such complexities cause various operational challenges for power systems operators by requiring more ancillary services (AS) resources.

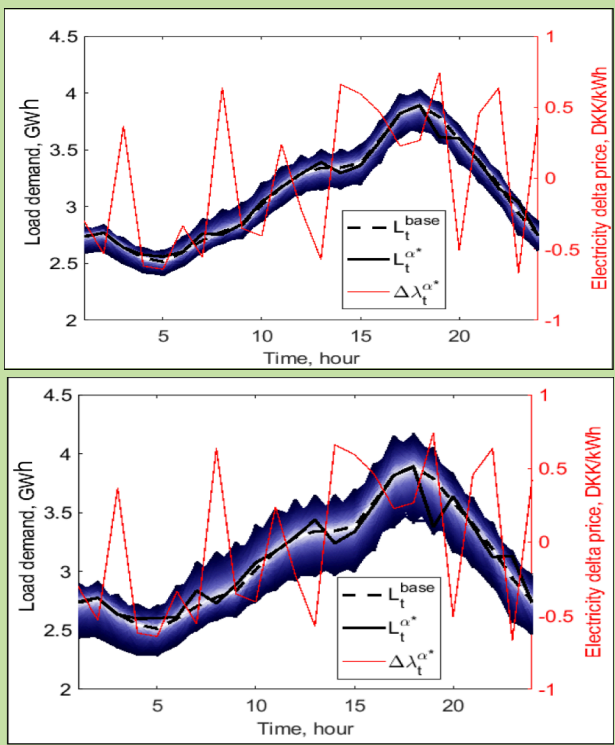
Demand response (DR) can be a valid solution to leverage demand flexibility to provide services to the grid. To optimally exploit consumers' flexibility, it is important to account for consumers' different preferences and constraints. Specifically, studies must approach the heterogeneity of loads and understand what influences consumers' behaviour.

Unfortunately, no study in the technical literature has discussed the aggregate potential of consumers' flexibility, and estimation studies have been carried out only for specific types of loads. This PhD thesis intends to fill this gap by proposing methodologies to **estimate the potential of consumers' flexibility**. Moreover, we proceed in the research by developing an **innovative framework that can exploit consumers' flexibility** at different grid levels.

Estimating consumers' flexibility

We investigate and estimate the aggregate consumers' flexibility potential at an aggregate level as a mixed-integer linear program (MILP), considering different categories of rational consumers (which are equipped with **individual controllers**) and a DR program based on **time-varying electricity prices**.

Our model accounts for different **dynamics** and the **stochastic nature** of consumers' behaviour, including chance-constrained (CC) programming. This way, it is possible to quantify the aggregate consumers' flexibility for different **confidence levels** β.



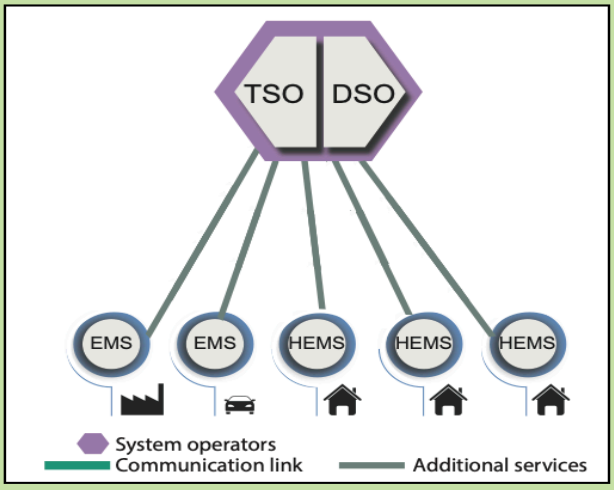
Flexibility achieved for different time-varying prices by CC optimisation for β =0.95 (top) and β =0.50 (down): baseline consumption, flexibility for the reference price, and the time-varying price component.

Ancillary Services AS4.0

AS4.0 consists of an alternative solution to the current market-operation structure for AS provision, to optimally exploit consumers' flexibility for AS provision at **different voltage levels.**

It allows system operators to exploit consumers' price responsiveness according to grid needs, by **varying the electricity prices** offered to consumers.

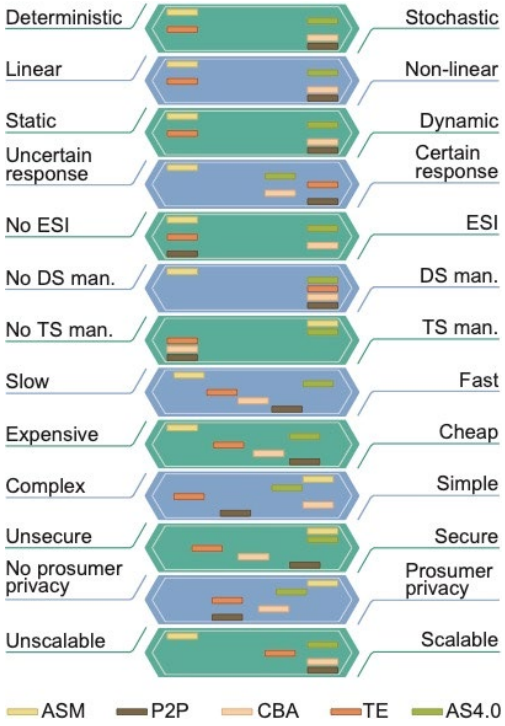
Consumers can automatically and **individually react to these prices** and minimise their own cost.



Conceptual block-diagram of the AS4.0 approach. Abbr: Home energy management system (HEMS).

Strengths of AS4.0

By exploiting the entire fleet of flexibility resources through EMS and time varying prices, AS4.0 has significant advantages compared to alternative AS provision methods.

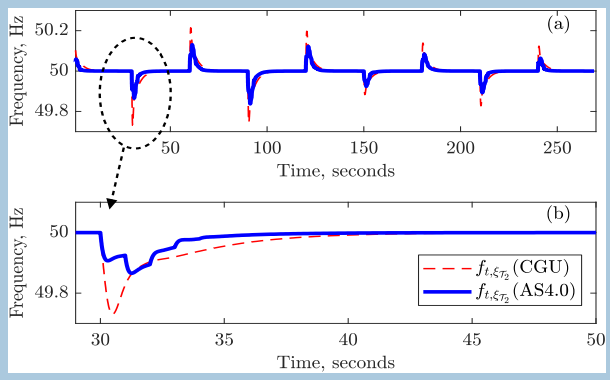


Comparing the current AS market (ASM) with main features of Peer-2-Peer (PTP), Control-based Approach (CBA), Transactive energy (TE) and Ancillary Services 4.0 (AS4.0). Abbr: Energy System Integration (ESI).

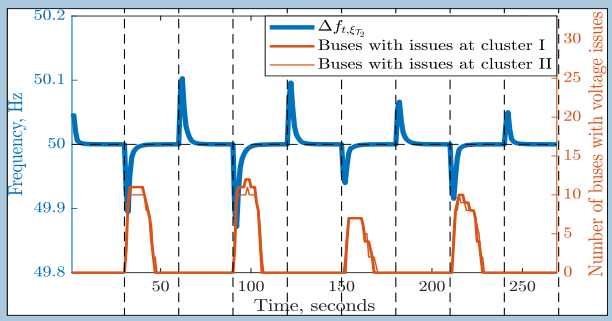
Effects of AS4.0 on power systems

Frequency performance improves significantly for the case of AS4.0 with respect to settling time and overshooting, **reducing the frequency deviation by 52%** compared to the conventional AS provision solution (CGU).

The number of buses with voltage issues also **decreases over time,** and TSO operation is not compromised by the DSO operation of voltage regulation.



Frequency profile of the system. (a) Overall frequency. (b) Zoomed-in part to see dynamics. Abbr: Conventional generation unit (CGU).



Number of buses with voltage violations along with the system's frequency.

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