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Empowering Prosumers in the Energy Transition: The REEFLEX Approach to Flexibility Markets and Improved Grid Management

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Abstract

In the dynamic environment of the electricity system, characterized by a notable influx of renewable energy sources and the electrification of loads, the significance of prosumers (consumers who possess the ability to both consume and produce, store and distribute their own energy) has grown increasingly crucial. The shift towards renewable energies, while advantageous for reducing carbon footprints and promoting sustainability, introduces a degree of variability and unpredictability into the grid. This variability presents challenges for grid operators who are responsible for maintaining the stability, balance and efficient functioning of the electrical system. To tackle these challenges, prosumers can assume a pivotal role by offering their flexibility in energy production and consumption (the ability to alter electric energy generation and demand patterns based on external signals) to support Distribution System Operators (DSOs) and even Transmission System Operators (TSOs) in managing the grid.

Flexibility markets have emerged as an innovative solution for harnessing the potential of prosumers in stabilizing the grid. Through engaging in these markets, prosumers have the ability to offer valuable flexibility services to grid operators. This not only assists in the management of the grid, but also presents an opportunity for prosumers to generate additional incomes, resulting in a mutually beneficial situation for both grid operators and prosumers. Nevertheless, navigating the intricacies of flexibility markets can prove to be overwhelming for many prosumers, as they must grapple with comprehending market mechanisms, regulations and the technical facets of effectively managing energy assets.

The objective of the REEFLEX project is to enhance the accessibility of flexibility markets, thereby facilitating the involvement and advantages for all types of prosumers. To achieve this, REEFLEX is dedicated to creating a collection of tools that streamline the management of electrical facilities and controllable assets for prosumers. These instruments are carefully designed to enable efficient management of energy resources and effortless participation in flexibility markets, thus overcoming a significant obstacle to prosumer engagement.

Within the REEFLEX project, a cloud platform is being developed, which is poised to incorporate a wide range of tools aimed at revolutionizing the landscape for prosumers within the flexibility markets as well as facilitating the participation of other actors such as aggregators or BRPs for example. These tools cover various functionalities across the entire flexibility management/operation/activation/valuation value chain: calculators that elucidate the possible flexibility options and their cost for different types of prosumers, mechanisms to determine the most advantageous flexibility market for each participant, calculating the flexibility requirements of the Distribution System Operator (DSO), activation of P2P markets for energy trading between prosumers, NILM algorithms to gain in-depth knowledge of the consumption components of a prosumer, etc. .... These elements underscore the project's comprehensive approach to bolstering grid stability and efficiency. Among this suite of innovations, the algorithm for optimal management of microgrid assets of prosumers facilities emerges as a foundational component.

This specific algorithm serves as an illustration of the forward-thinking approach of REEFLEX, which is designed to meticulously examine the intricacies of energy production and consumption patterns among prosumers. Through the assessment of various manageable assets and careful consideration of factors such as energy prices, fluctuations in demand, the availability of renewable energy and storage capabilities, it develops personalized strategies for effectively operating prosumer grid systems and participating in flexibility markets. The design of this algorithm embodies the core mission of REEFLEX, which is to simplify the complexities surrounding energy asset management for prosumers, allowing them to make the most of their resources with minimal requirement for extensive market knowledge or direct manipulation of assets.

The entire suite of REEFLEX tools serves as evidence of the project's dedication to promoting a durable and effective energy ecosystem. Through equipping prosumers with the necessary resources to proficiently

manage their energy assets, REEFLEX not only amplifies the stability and efficiency of the power grid, but also enables individuals and communities to actively contribute to the ongoing energy transition.

Introduction

The electric grid of the future is poised for transformation driven by the urgent needs of energy transition towards sustainable sources [1]. This transformation is catalysed by the proliferation of distributed energy resources (DERs) such as solar photovoltaics, wind turbines and energy storage systems, along with the increased digitization inherent in smart grid technologies. As the grid evolves from a centralized to a more distributed system, the roles and operations of Distribution System Operators (DSOs) are also undergoing significant changes to accommodate the dynamics of modern energy demands and the integration of renewable energy sources.

The transition to a smart grid is essential in addressing the critical challenges faced by DSOs, including the management of increased grid complexity, maintaining reliability. and ensuring efficiency in the face of fluctuating energy supplies and demands. Smart grid technologies empower DSOs thanks to the development of Information and Communication Technologies with advanced monitoring, control capabilities and enhanced automation facilitated by real-time data communications and IoT technologies [2]. These advancements are vital in managing the intermittent nature of renewable energy sources which, while beneficial for reducing carbon footprints and promoting sustainability, introduce variability and unpredictability into the grid and are key to involve prosumers in the management of the grid since it allows prosumers to help solving grid needs in a decentralized manner that few years ago was impossible to achieve.

One of the principal challenges in this evolving grid landscape is maintaining balance and stability. As traditional baseload power generation is progressively replaced or supplemented by variable renewable energy (VRE), the importance of flexibility in energy use becomes paramount. Flexibility in this context refers to the ability of grid participants—increasingly prosumers [3] —to modify their energy generation or consumption patterns in response to grid needs or (through) economic signals. This flexibility can manifest through peak shaving, load shifting and participation in demand response programs [4], which are critical for smoothing out the variability caused by high penetrations of VRE.

It is also important to consider that the energy transition towards decarbonization of society involve electrification of loads that previously relied on fossil fuels such as domestic heating or car mobility. This electrification process put extra stress on the grid as increase in consumption and grids may not be prepared to deal with this new scenario, generating congestions and power quality problems such as voltage deviation. In this context, flexibility from prosumers assets also helps to organize efficiently electric consumption without having to rely on grid expansion and other infrastructure investments.

However, the participation of prosumers, particularly small and medium-sized entities, in flexibility markets is not without constraints. These participants often face significant barriers, including a lack of technical expertise to manage and optimize energy assets, insufficient understanding of market mechanisms and the regulatory and economic challenges of interfacing with traditional grid operations. Small-scale prosumers, in particular, may find the initial technological investment and the complexities of regulatory compliance daunting. Also, flexibility markets may set a minimum power threshold as an entry requirement and the vast majority of small-scale prosumers are not able to reach it without participating in broader flexibility schemes through other agents such as aggregators or retail electric companies.

1. REEFLEX approach to empower prosumers in flexibility markets

The REEFLEX project [5] stands at transforming how prosumers interact with Local Flexibility Markets (LFM). By empowering and facilitating the participation of all types of prosumers, REEFLEX addresses the growing need for flexibility within the energy grid, which is increasingly characterized by the variable nature of renewable energy sources.

The primary objective of REEFLEX is to establish a range of feasible interoperable solutions and services which enhance the engagement of energy consumers in demand side flexibility (DSF) markets. These tools and services are constructed upon the establishment of a centralized interoperable platform, linking various stakeholders in the multi-sector energy framework, facilitating their entry into diverse flexibility markets (local, national, European) and offering a selection of tailored interactions and services from the catalogue to meet their energy requirements.

The tools under development in the REEFLEX project are grouped into three pillars:

- P1, Interoperability and data exchange platform. Development of a central platform, enabling the connection and interoperability of all devices, accounting for synergetic, cross-sectoral networks, improving data secure and privacy exchange through these assets.
- P2, Optimal management and flexibility potential. Mobilizing demand response and new services thanks to the standardization of smart assets connected through IoT and the development of a set of solutions aiming at achieving optimal management of microgrids in accordance to end users' demands.
- P3, Connection and interactions with flexibility markets. Establishing easy connections to any flexibility markets, reducing entry barriers and transaction costs.

Pillar 1: Interoperability and data exchange platform	**I1.1)** Data exchange, handling and interoperability **I1.2)** VERIFY: Web-based platform enabling LCA/LCC of projects **I1.3)** USE: Platform enabling uniform evaluation of projects **I1.4)** Flexibility potential classification for any given asset
Pillar 2: Optimal management and flexibility potential	**I2.1)** Second-life batteries as flexibility assets **I2.2)** Predictive flexibility potential and operation of distributed devices **I2.3)** NILM techniques for large consumers' load disaggregation **I2.4)** Innovative inverters for storage systems and electric vehicles (V2G) **I2.5)** Optimal management of the grid
Pillar 3: Connection and interactions with flexibility markets	**I3.1)** End-users' potential flexibility calculation and aggregation **I3.2)** Calculation of DSO flexibility needs **I3.3)** Optimal market selection **I3.4)** P2P and bilateral energy exchange trading

In order to develop these tools and achieve the project objectives, a consortium has been formed comprising all actors involved in the flexibility value chain, from flexibility providers to flexibility buyers for a better operation of their electricity grids. Technical partners with extensive experience in this type of projects are also involved. A list of REEFELX project partners is given below [6]:

- Prosumers who are going to provide flexibility from their premises:
  - Sociedad Municipal Zaragoza Vivienda SL, ZAVI
  - Holbæk Kommune, Holbæk

  - Cnet Centre For New Energy Technologies SA, EDP-NEW
  - Smart Energy Lab – Association, SEL
  - Abilix Soft LTD, ABILIX
  - Temsa Skoda Sabanci Ulasim Araclarianonim Sirketi, TEMSA
- Develoers of technology, of manageable systems:
  - Betteries Amps GMBH, BETT
  - Arcelik A.S., ARC
  - Enerbrain SRL, ENERB
- Aggregators and ESCOs that will take small prosumers by the hand and bring them to the market:
  - Sistemas Urbanos De Energias Renovables SL, URBE
  - Watt And Volt Anonimi Etairia Ekmetalleysis Enallaktikon Morfon Energeias, WVT
  - Hive Power SA, HIVE
  - Que Technologies Kefalaiouchiki Etaireia, QUE
  - Kainotomia Idiotiki Kefalaiouchiki Etaireia, INNO
- Regulatory experts:
  - Yugoiztochnoevropeyska Tehnologichna Kompania Ood, SETECH
  - Lietuvos Energetikos Institutas, LEI
  - University Of Piraeus Research Center, UPRC
- Market operators:
  - OMI-Polo Espanol SA, OMIE
- DSO:
  - Azienda Elettrica Di Massagno SA, AEM
- Research centres:
  - Fundacion Circe Centro De Investigacion De Recursos Y Consumos Energeticos, CIRCE
  - Ethniko Kentro Erevnas Kai Technologikis Anaptyxis, CERTH
  - Ubitech Limited, UBI
  - Suite5 Data Intelligence Solutions Limited, SUITE5
  - Scuola Universitaria Professionale Della Svizzera Italiana, SUPSI
  - Fundacion CARTIF, CARTIF
- Communication and exploitation experts:
  - Rina Consulting SPA, RINA-C
  - Smart Innovation Norway AS, SIN

REEFLEX places significant focus on showcasing and replicating these solutions in seven distinct countries with varying energy constraints to guarantee interoperability [7]: Spain, Greece, Switzerland, Bulgaria, Portugal, Denmark and Turkey.

2. REEFLEX framework

The REEFLEX platform is designed with a multi-layered approach to streamline flexibility management in modern energy systems. The platform comprises three distinct layers: the local operation layer, the data layer and the business layer. The local operation layer focuses on the optimal operation of microgrids, connecting directly to flexibility assets and utilizing AI techniques to enhance automation and efficiency. This layer integrates key innovations to manage flexibility assets locally while minimizing transaction costs. The data layer serves as the central backbone, providing high-quality data to support analytics and business optimization functions. It includes AI-driven intelligence services, privacy and

cybersecurity measures, and mechanisms to enhance data quality, ensuring robust and secure data management.

The business layer of the REEFLEX platform is dedicated to interfacing with flexibility markets, forecasting flexibility needs, and suggesting optimal market selections. It facilitates the trading of flexibility assets by identifying the best bids and offers based on current market prices, thereby optimizing economic returns. Additionally, the platform includes a comprehensive consumer engagement framework aimed at informing and training all stakeholders, from residential consumers to industry managers and regulators. This engagement process ensures that technological solutions are user-centric and widely accepted, enhancing the overall impact of the REEFLEX project in advancing grid flexibility and efficiency.

3. Optimal microgrid management

Optimization algorithms are critical in the realm of microgrid management as they provide a systematic approach to manage the local energy production, storage and consumption of energy within a microgrid. These algorithms take into account various factors including energy demand forecasts, renewable energy generation, energy prices and the physical and technical constraints of the microgrid's components. The primary goal is to obtain the most appropriate management strategy in order to minimize operational costs, maximize energy efficiency and maintain grid stability.

The optimization algorithms for the management of the asses in microgrids has been implemented in several applications. The specific algorithm discussed in FLEXICIENCY [8], [9] project and EV-OPIMNANGER project [10], which are also representative of those used in the REEFLEX project, illustrates a general optimization framework that is adaptable to various microgrid configurations, whether residential, commercial, or industrial environments. The advantages of this management methods are the key where the algorithms management effectively different assets, from traditional and flexible loads to advanced battery storage and renewable generation technologies.

Main challenges Addressed by Optimization Algorithms
Optimization algorithms play a crucial role in demand response management. Energy consumption and production is adjusted in real time through metering instantaneous parameters and predictive scheduling of incoming energy consumption and demand. As a result, the system is able to respond to grid demands or economic signals by modifying the

predictive baseline power schedule. This flexibility can help in balancing the supply-demand equation, thus stabilizing the grid and preventing outages.

The increase of renewable energy has carried out a new problem of irregular energy flow regarding when the energy is obtained and when is it used. Energy storage is the solution to this problem but, with the integration of systems like BESS and EV charging stations, managing the storage and timely release of energy becomes essential. Optimization algorithms ensure that energy storage systems operate within their optimal parameters, reducing wear and tear and extending their lifespan. They manage charge and discharge cycles based on energy availability and demand, optimizing the use of stored energy and reducing reliance on external power supplies.

The intermittent nature of renewable energy sources like solar and wind can pose challenges to grid stability. Optimization algorithms help in effectively integrating these sources by predicting energy generation and adjusting the microgrid operations accordingly. This includes minimizing curtailing generation when necessary to prevent overloading the grid and maximizing the use of generated energy when production peaks.

Optimization Algorithm flexibility

The optimization applications under development have several factors that make them very attractive to the management of smart grids. The development of the algorithm implemented in CIRCE, to be used in REEFLEX project, has shown several flexibilities in different aspects:

- Flexibility in microgrid configurations. Thanks to the mathematical equations that defines the real electrical microgrid circuit, the developed algorithm can be implemented in several circuits, whether they are grid-connected, isolated, connected in DC, AC both.
- Independence in the number and technology of the circuit components. The structure of the algorithm allows the configuration of different technologies for energy generation, storage and consumption. The system can have photovoltaic power generation, battery energy storage, hydrogen generation and EV chargers, among others. It is also possible not to connect all elements or, on the other hand, to connect more than one of the same technologies. In conclusion, the algorithm is independent of the number and technologies of the circuit, configurable by an input file.
- Multiple users connected to the grid. The system can have both several users and a single user. That will define the final destiny of the energy generated and it can be distributed with different criteria. However, the algorithm itself calculates the optimal energy distribution for all the users and all the loads connected regardless of the final number of users.

In addition to the physical flexibility in terms of available system devices, one of the main advantages of the flexibility of the algorithm is the availability to run it in different environments. It can be used remotely in the cloud by uploading the necessary calculations and connecting it to other devices in the system. At the same time, it is possible to use it in local gateways where the calculations are performed on the devices themselves. Despite the limitations that these scenarios may have, due to the limited number of resources available, with limited memory capacity, this algorithm has no problem operating on these platforms.

Example of an Operational Strategy

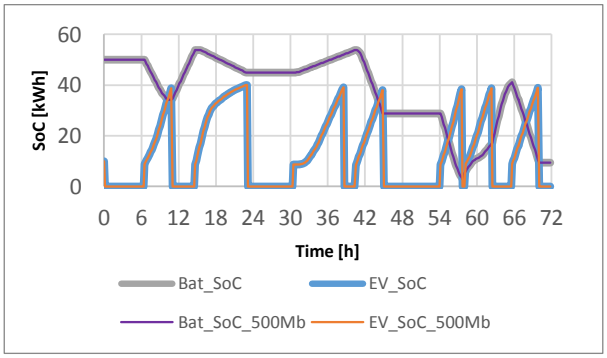
One of the scenarios tested with the optimization algorithm corresponds to an isolated petrol station with a solar generation system, battery energy storage, electric vehicle charging and a hydrogen system with electrolyze and fuel cell. The optimization algorithm developed uses a comprehensive model that includes:

- PV System Constraints: Prioritizes the use of solar energy by minimizing associated operational and maintenance costs. The possibility of curtailment is included.
- Battery Storage Constraints: Manages battery operations to extend life and efficiency, incorporating limits on charging and discharging.
- EV Charging Constraints: Balances the need for rapid charging with grid capacity and stability. It depends in EV time availability and the power limits of the charger.
- Hydrogen System Constraints: Manages hydrogen production, storage and usage, ensuring efficient operation of electrolysers and fuel cells.
- Grid Connection Constraints: Controls the interaction with the main grid, managing energy import and export based on contracted power and variable energy costs.

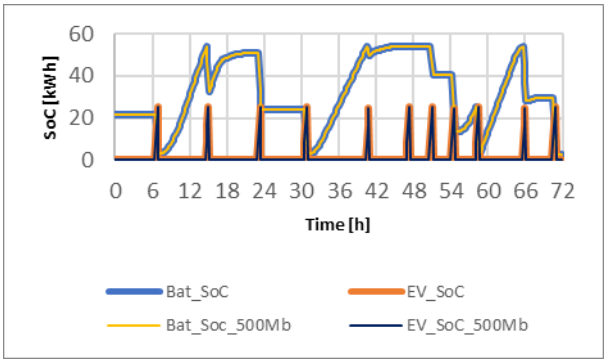
These constraints are part of a mathematical model that also incorporates flexibility options, allowing the algorithm to adjust operations based on variable energy prices and demand signals from flexibility markets. The initial case under examination corresponds to an isolated grid instance with a battery State of Charge (SoC) exceeding 80% and a limited quantity of charging vehicles. The second case has an initial battery SoC below 40% and the number of electric vehicle charges is double that of the previous case.

The results obtained within the test demonstrated the flexibility and stability of the implemented algorithm. The data presented in the following table indicates that both the duration of the simulation and the results of the objective function remain consistent regardless of the location where the algorithm is deployed, even when the calculation capacity is restricted by a memory constraint. Moreover, the predictions for the charge of the vehicles and the use of batteries generate the same forecasts, as the graphs below demonstrate.

		Objective function	Simulation Time
Case 1 SoC_init = 80 % EV_charged = 6	Memory limit, 500 Mb	-103.84 €	14.38 s
	No limit	-103.84 €	10.36 s
Case 2 SoC_init = 40 % EV_charged = 12	Memory limit, 500 Mb	-90.98 €	29.88 s
	No limit	-90.98 €	20.69 s



Case 1



Case 2

4. Conclusions

In the dynamic electricity system, prosumers play a crucial role in the face of increasing renewable energy sources and electrification of loads. The renewable energy shift benefits sustainability but adds variability, posing challenges for grid operators. Prosumers can help by offering flexibility in energy production and consumption to assist in grid management. Flexibility markets enable prosumers to provide valuable services to grid by participating, benefiting both parties. Prosumers can generate additional income by engaging in flexibility markets. Understanding market mechanisms, regulations and technical aspects can be challenging for some prosumers, mainly smaller ones.

The aim of the REEFLEX Project is to improve the availability of flexibility markets, which in turn facilitates the engagement and benefits for all categories of prosumers. In order to realize this goal, REEFLEX is committed to developing a set of resources that simplify the supervision of electrical infrastructures and controllable assets for prosumers. These tools are meticulously crafted to enable effective management of energy assets and customer involvement in flexibility markets, thereby surmounting a significant hurdle to prosumer participation.

One of the most important algorithms to be developed in the framework of the REEFLEX project is the optimal operation of microgrids, as it allows maximum use of the flexible, manageable resources of each prosumer. The optimization algorithm shown in this article, one of several being developed in the project, will be tested in the project on various execution platforms, in the cloud and on physical platforms or gateways. For this reason, in these initial phases of the project, the stability of the solution is being tested by emulating different execution environments with positive results.

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