Flexibility services from water distribution networks: the demonstration project of Gruppo Acea

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Abstract

This study explores how the inherent flexibility of water systems can provide flexibility services to electricity distribution networks. Flexibility in water distribution networks is essential to ensure efficient operations, taking into account the variability of supply and demand, and it is specifically designed to guarantee service reliability. This flexibility is achieved through storage tanks and backup pipelines, which balance supply and demand fluctuations by operating remotely controlled pumps based on monitored quantities. By leveraging controllable assets, water systems can modulate electricity consumption and offer flexibility on the markets for electricity distribution network services, which are currently being tested in several European countries. The paper focuses on the Italian demonstration activity promoted under the European project BeFlexible, aimed at developing a systematic approach to assess the flexibility potential of water distribution networks for electricity system services, without compromising water supply security and ensuring a profitable business model for both water and electricity distributors.

1 Introduction

Flexibility services are essential for the future Electricity Distribution Network (EDN) due to the expected increase in renewable resources and the electrification of the transport and heating sectors. Despite the fact that these changes will require significant investments in the grid infrastructure, local resources can provide the necessary flexibility to address these challenges, reducing the need for extensive network reinforcements and supporting the stability of the electricity system through regulation reserves. To effectively manage local flexibility, dedicated markets should be established [1], aligned with the planning and operational procedures of the system operators. This approach will improve congestion management and ensure a well-functioning local flexibility market, despite the diversity and interdependence of existing systems [2].
Integration of water distribution networks with power systems presents a significant opportunity to enhance the flexibility of the grid. Traditionally, water facilities have been viewed as static loads on EDN, but emerging research emphasizes their potential to provide valuable flexibility services [3]-[8]. Water facilities, including potable water and wastewater treatment plants, are substantial energy consumers, often accounting for 2-4% of national electricity use and most of this consumption goes toward pumping operations [4][6]. By strategically managing the operation of pumps and storage tanks, it is possible to shift energy consumption to coincide with times when the electricity network requires load reduction [5][8].
Recent projects and studies, such as FLOWERS in the South West of England [8] and HYDROFLEX in Belgium [5], have explored these concepts, demonstrating the feasibility and benefits of leveraging water treatment systems for demand response and energy flexibility [3][5][8]. This can involve actions such as modifying pumping schedules, adjusting water treatment processes, or using storage to shift loads in response to signals from the electricity network [7][8]. However, to realize this potential, it is necessary to address technical, regulatory, and commercial challenges to unlock flexibility from water systems [8][9].
The European project BeFlexible [10] aims to increase the flexibility of the energy system by improving cooperation among electricity operators and involving energy-related stakeholders. This will be achieved through the validation of large-scale demonstration initiatives on cross-sectoral services, including the synergies between the EDN and

integrated water systems. This specific experimentation will be held in Italy and, as for the aforementioned projects, aims to demonstrate how intelligent management of water infrastructure can support electrical grid operations. Key participants include Areti, responsible for analysing the flexibility potential of water systems, Acea Group companies (GORI, Acea Ato-2, Acea Ato-5, and Acquedotto del Fiora), and Ricerca sul Sistema Energetico, which contributes to defining use cases and models.

2 Flexibility available by leveraging on controllable asset of water systems

This paper explores the concept of "cross-sector flexibility boosters", focusing on how Integrated Water Systems (IWSs) can enhance the flexibility of electrical grids. BeFlexible examines the business and system use cases by analysing the technical processes, benefits, and information exchange involved in leveraging water distribution network assets for grid support.

2.1 Business Use Case: Capitalising on Flexibility

BeFlexible proposed several business use cases aimed at promoting the participation of users in providing flexibility to the electricity system. One of them is specifically focused on developing new methods to increase cross-sector flexibility by using the inherent potential of IWSs to offer services to the EDN [11]. This use case involves:

- IWS operator: responsible for managing water resources from source to consumer and wastewater treatment, it studies the behaviour of assets to quantify their flexibility potential.
- Electricity Distribution System Operator (eDSO): responsible for delivering and managing electricity to consumers, the eDSO provides tools and devices to monitor the flexibility offered by IWSs.

The proposed use case outlines a detailed process for exploiting the flexibility potential of IWSs. First, the process involves defining the portion of the system to be studied, monitoring, and analysing key hydraulic parameters such as flow rate and hydraulic head, and matching water demand with the energy consumption of the studied IWS portion to forecast future water demand. Meanwhile, the eDSO, to enable water resources in the local flexibility market, provides them with a device [12] aimed at monitoring electricity consumption and the activation signal, later, the actual flexibility provision, to be recorded in a dedicated flexibility register [13]. Using a measurement campaign and the continuous monitoring process, the eDSO evaluates the baseline consumption profile of the assets, which is used to quantify the volume of flexibility available and delivered [2]. To accomplish this objective, the eDSO relies on the availability of monitoring and controlling functionalities of the IWS assets responsible for the provision of flexibility, the most recent smart-meter technology, and an accessible flexibility register.

2.2 System Use Case: Evaluating Flexibility Capability

The experimentation promoted by BeFlexible delves deeper into the technical aspects of assessing and using IWS asset flexibility, specifically focusing on calculating the potential flexibility of an IWS to make it available for the electrical grid. For this purpose, a specific use case is dedicated to examining the potential for load shifting from water facilities and its impact on power system operations. The suggested approach aims to optimize the operation of the system, reduce running costs, and contribute to lowering congestions on the electricity network. The analysis outlined in [14] is further broken down into the following key phases, which align with the one adopted in previous projects [8].

Mapping the Topology: Creating a detailed representation of the water network within the system. This involves identifying the key components, their interconnections, and their characteristics.

Registering Flexibility Equipment: Documenting the specifications of all equipment that contributes to the flexibility of the IWS. This includes pumps, valves, storage tanks, and any other relevant assets.

Enabling Data Collection: Setting up a system for periodic and automated data collection from water pumps and other flexible assets. The data collected includes flow rates, pressures, water levels, and energy consumption.

Forecasting Water Demand: Predicting future water demand based on historical data, consumption patterns, and other relevant factors. Accurate demand forecasting is essential to optimize the operation of the IWS and determine the available flexibility.

Matching Demand with Electrical Consumption: Aligning the forecasted water demand with the energy consumption of the selected portion of the IWS. This analysis helps define the relationship between water use and energy requirements, which is crucial to identifying periods where flexibility can be offered to the electrical grid.

Quantifying Flexibility Potential: Calculating the total amount of flexibility that IWS can provide to the electrical grid. This involves considering various operational constraints, such as water quality and pressure requirements, and the need to maintain a reliable water supply.

By following this structured process and key phases, the considered use case aims to provide a comprehensive evaluation of the flexibility potential of water distribution networks and their ability to support the electrical grid, offering benefits to both the system operators:

- IWS operator: Optimizing flexible water components leads to reduced energy costs, new revenue streams, and operation within hydraulic constraints.
- eDSO: Increasing the liquidity of local flexibility market to efficiently manage grid congestions while ensuring cost-effectiveness.

3 Flexibility potential of water systems

Gruppo Acea manages the integrated water service in five Italian regions, covering all stages of the supply chain. It is committed to safeguarding sources, sustainable resource management, and ensuring potable water in homes and cities. It invests in the future with technological innovation and raising awareness of responsible consumption. The current strategic objectives of Acea's Industrial Plan include the protection of water resources, improving service quality and efficiency through smart water meters, reducing losses, rationalizing purification plants, and sectionalizing the network. In addition, they aim to improve technical quality indicators and ensure water supply security.

Following the phases illustrated in section 2.2, the flexibility potential has been estimated for four water distribution facilities and one sewage lifting plant. According to their available and controllable assets, a portion of their energy demand can be shifted in time with the aim of reducing power consumption within peak hours of the electricity network.

Fig. 1 illustrates the typology of flexibility that can be delivered by the IWS assets, which can be described as:

- Baseline power consumption (red dashed line): expected power consumption pattern without any adjustments, which serves as a reference to evaluate the variations caused by the flexibility service.
- Power flexibility/reduction (green shaded area), where power consumption is intentionally reduced to alleviate stress on the electrical network.
- Rebound effect (orange shaded area), located before/after delivering the flexibility service and aimed at preparing the system to the power reduction (or compensating its effects), without endangering the IWS operation requirements.

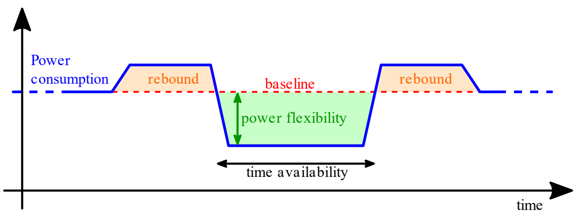

Fig. 1 Illustrative power profile used to define the electrical flexibility potential of IWS assets.

Section 4 describes the case studies that are considered within the BeFlexible project and involve five different plants. According to the analysis reported, the flexibility potential has been achieved thanks to remote control of the water pumps, which power consumption can be arbitrarily modulated according to the capacity of water storage. The analysis also highlights the impact on flexibility potential derived from the availability of additional water sources (gravity-fed and backup interconnections with neighbouring water distribution networks).

For each case study, a simple model (illustrated in Fig. 2 and inspired by existing studies [3]-[7]) is used to calculate the flexibility potential by evaluating the combined behaviour of water management assets. This model can be applied to all case studies that feature different storage capacities and pumping systems, as well as varying profiles of water in- and out-flow.

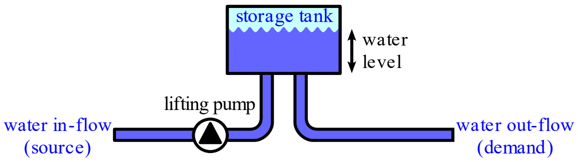

Fig. 2 Basic model of a potable water management plant, composed of a lifting pumping system and a storage tank.

The investigation consists of evaluating the variation of the water level of the storage tank with respect to the naturally variable water in- and out-flow. In a simulated environment, modifications are introduced into the control parameters that manage the assets of the water system, with the aim of verifying if the stored water remains at acceptable levels from the perspective of the IWS infrastructure and water demand. In the same environment, the IWS can evaluate the effects of turning down one or more pumps without compromising the IWS operation and/or the water supply.

In this case, the reduced energy consumption can be made available for the provision of flexibility services to the electricity grid. Further investigations will assess whether the flexibility target can be achieved by completely shutting down one or more pumps for a period of time or by using systems (e.g., inverters) to modulate the lifted flow rate and, consequently, the absorbed power.

A similar model can be applied to evaluate the flexibility potential of sewage lifting plants, which, like potable water systems, typically consist of storage tanks and pumps.

4 Case studies

4.1 Gori(1) case study – potable water plant

GORI manages the IWS of the entire territory of the Sarnese-Vesuviano District Area in the Campania Region, which covers an area of about 900 km² with a population of approximately 1.47 million inhabitants. For the case study, one portion of this water network is selected as the case study, which is one of the most important and strategic facilities managed by GORI: it is the second most energy-consuming facility in the territory, with an average annual output flow of 2,700 l/s, providing 38% of all resources introduced into the managed district. It is characterized by:

- Connection to the 20 kV EDN.
- Contractual power: 7.250 MW.
- Annual consumption: 14 GWh.

The selected water plant has the possibility of remotely controlling the pumping system, which guarantees the modulation of the consumption from the EDN. Thanks to the presence of a 30,000-m water storage tank, power reduction and increase can be operated without affecting the 2,700 l/s requested by the water distribution system. Without further investments, the current operating strategy of the considered water plant can deliver:

- Power flexibility: 1 MW (load reduction).
- Time availability: 3 h.

In case of re-design of the operating strategy of the considered plant, further flexibility can be delivered by optimizing the water level of the tank and by exploiting alternative water sources (which are already available, but currently used only in case of emergency).

4.2 Gori(2) case study – sewage lifting plant

GORI also investigates the flexibility potential of a second facility, which consists of a sewage lifting plant located in Portici (province of Naples), equipped with a high-capacity storage tank (about 1,200 m^3). The power supply characteristics can be listed as follows:

- Connection to the 20 kV EDN.
- Contractual power: 800 kW.
- Annual consumption: 1.5 GWh.

The plant asset can be controlled remotely, and it is designed to manage a highly-variable flow rate, which is strongly dependent on weather events. It ranges from an average flow of approximately 440 l/s to a maximum flow rate that can reach 1,500 l/s. Due to the availability of the sewage storage tank, the pumping system can be temporarily switched off without compromising the operation of the plant. Considering these two extreme cases, the achievable flexibility consists of:

- During low-flow-rate periods
  - Power flexibility: 0.5 MW (load reduction).
  - Time availability: 45 min.
- During high-flow-rate periods
  - Power flexibility: 0.5 MW (load reduction).
  - Time availability: 13 min.

4.3 Ato-2 case study

Acea Ato-2 manages the IWS of 112 municipalities belonging to Central Lazio, which covers an area of approximately 5,000 km^2 with a population of about 4 million inhabitants. The managed water network extends for a total length of 16,380 km and is divided into a primary supply network that extends for 1,976 km and a distribution network of about 14,404 km. Also in this case, one of the most energy-consuming plants is selected for the demonstration activity, with an average annual output flow of 1,500 l/s. It is characterized by:

- Connection to the 20 kV EDN.
- Contractual power: 2.125 MW.
- Annual consumption: 1.45 GWh.

The selected water plant has the ability to remotely controlling the pumping system, which guarantees modulation of the consumption from the EDN. Thanks to the presence of a 35,000-m storage tank and gravity-fed (pump-less) water sources, electrical power reduction can be operated without affecting the 1,500 l/s flow requested by the water distribution system. Without further investments, the current operating strategy of the considered water plant can deliver:

- Power flexibility: 60 kW (load reduction).
- Time availability: 4 h (from 14:00 to 18:00).

4.4 Ato-5 case study

Acea Ato-5 manages the IWS of Southern Lazio – Frosinone. It serves a territory that covers a total of 86 municipalities. The infrastructures managed in the territory include 1,235 km of supply network and 4,977 km of water distribution network, for a total length of 6,212 km with 202,195 users. In this case study as well, one of the most energy-consuming plants is selected, featuring an average water delivery rate of 200 l/s. It is characterized by:

- Connection to the 20 kV EDN.
- Contractual power: 1.125 MW.
- Annual consumption: 5.8 GWh.

Although the ability to remotely control the plant asset is available, its original design is optimized to meet the demand for water without the need for tanks and alternative sources. For this reason, the current configuration does not allow variations in the operation strategy for pumps and other assets; therefore, flexible electricity services cannot be delivered. Acea Ato-5 is currently assessing the refurbishment of the selected plant to interconnect it with neighbouring water distribution networks. These investments would improve redundancy in the water supply service and increase its reliability. Furthermore, the interconnections enable the provision of energy flexibility services, and the revenues from participating in local and global ancillary services markets would increase the profitability of the planned investments.

4.5 Acquedotto-del-Fiora case study

Acquedotto del Fiora is the IWS manager at the 6th Optimal Territorial Conference "Ombrone" (the largest in the Tuscany region – within the province of Siena and Grosseto) which includes 55 municipalities, covering an area of 7,586 km^2, with a total resident population of 392,990 inhabitants. Nevertheless, the area is subject to significant tourism, therefore, the actual population can exceed 643,000 inhabitants during the months of maximum presence. The managed water distribution network extends over a total length of 8,396 km. The selected plant is one of the most important and strategic facilities managed by Acquedotto del Fiora, being the most energy-intensive facility of the area, which, with an average annual withdrawal of about 5 Mm^3, provides 27.4% of all the water resources withdrawn from the wells. It is characterized by:

- Connection to the 15 kV EDN.
- Contractual power: 2.286 MW
- Annual consumption: 6.1 GWh.

The selected water distribution system is fed by two different sources: a well-based water plant and a gravity-fed source. The groundwater capture system is equipped with a 250 m lifting system and which use is strongly influenced by the availability of gravity fed water resources. Furthermore, the pressure of the water is managed by using booster pumps that can be controlled (together with the groundwater capture system) to modulate the overall power electricity consumption without compromising the demand due to the exploitation of a storage tank (9,900 m^3).
Two different operational conditions were considered: *inactive* and *partially-active* water plant (wells). In each of these conditions, the level of flexibility varies according to seasonality and is primarily dependent on the availability of gravity-fed water resources (which do not rely on the operation of the water plant). Therefore, depending on the season and productivity of gravity-fed sources, two different availability levels can be drawn for the provision of flexibility services to the EDN:

- Level 1 – *inactive* water plant
  - Power flexibility: 0.45÷1.00 MW (load reduction).
  - Time availability: 2.5÷3.5 h.
- Level 2 – *partially-active* water plant
  - Power flexibility: 0.15÷0.65 MW (load reduction).
  - Time availability: 4.5÷7.5 h.

4 Conclusion and future activities

One of the key advantages of cross-sectoral use cases in water distribution networks is their inherent flexibility, which is rooted in the essential security constraints of water distribution. This flexibility can be exploited to provide significant benefits to the electricity network, often at little or no additional cost. There are cases in which a IWS could negotiate with the eDSO on advantageous connection agreements instead of receiving direct remuneration in return for flexibility services [9].
Moreover, IWSs that currently lack sufficient flexibility (e.g., the case of Ato-5) can undergo targeted investments to enhance their adaptability. The cost-effectiveness of these use cases of course relies on the combined necessity of foresee measures to guarantee the water distribution service (additional tanks, backup sources, etc.) and the flexibility demand for the planning/operation of the EDN. Furthermore, it is important to acknowledge that certain factors (e.g., seasonal variations and specific operational constraints) impact on the availability of this flexibility reserve and, therefore, must be carefully managed.
Although the research field, as noted in the bibliography, is relatively recent, the literature has already proposed comprehensive and tailored cost-benefit analysis methodologies for water-related use cases. In fact, there are highly detailed models [7], for which practical applications have also been documented [7][15]. The authors are currently working on their implementation and physical experimentation within the BeFlexible activities.

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