A Multi-Energy Bio-Gas Production Plant Exploiting Electrical Market Services Provision

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Abstract

This paper presents the results to identify optimization strategies to exploit the flexibility provided by a biogas production plant. This plant, located in Murcia (Spain) is one of seven real life case studies of multi energy systems, located in different European countries under analysis in the EU MAGNITUDE project. The facility Murcia Este is a wastewater treatment plant WWTP, with production of biogas as a result from Anaerobic Digestion. The biogas produced is completely exploited to self-sustain the electricity and heat plant demands. The flexibility provision ability is given as ancillary market participation, in particular by manual frequency regulation reserve (mFRR) provision. The model of the plant refers to a base case, consisting of the current configuration and management, and to several possible extensions, improving devices and management strategies. The experimentations carried out are based on weekly data, each one associated to the seasons and to two "critical" weeks. The results show the plant can successfully provide the market service in the current configuration (base case) and in the improvements proposed, for all the six weeks data identified. The improvement which provides the best results is the heat-storage, currently not installed, which ensures an interesting decoupling between the biogas production and the heat demand/service provision.

1 Introduction

The transformation of energy landscape towards decentralized low-carbon energy systems is leading to the redesign of generation devices to supply the demand and upgrade the management strategies.

Utilities are adapting their business models and new energy services are emerging. In this context, decentralized multi-energy systems support the transition from passive consumers to active prosumers with local generation, demand response and energy efficiency measures. The awareness of the need to achieve a strong integration among systems operating across different energy carriers is witnessed by the recent relevance assumed by multi-energy systems [1] and [2].

In recent years, biogas production plants are becoming increasingly popular in European countries to exploit the anaerobic digestion of organic wastes. There is a large number of different sources to supply this type of plant: solid and water urban wastes, agricultural waste etc. These plants represent a well example to close "the circle" of the daily organic wastes produced by human being, in the solid and water form, as well as agricultural activities. Indeed, these are transformed into compost (the solid portion) and fuel (the gas portion). These plants are interesting also in the potential to be fruitfully integrated within a microgrid [3]. The production of biogas from different residual fluxes, such as waste water or solid waste, is a fluctuation medium and a potential producer to assess costs and revenues from the operation of such treatment plants, ideally improving production efficiency.

This paper presents the results to identify optimization strategies to exploit the flexibility provided by a biogas production plant. This plant, located in Murcia (Spain) is one of seven real life case studies of multi energy systems, located in different European countries under analysis in the MAGNITUDE project, founded by the European Commission. This project addresses the challenge to bring technical solutions to identify the possible flexibility options from enhanced synergies between the electricity, heating, cooling and gas networks, supporting the cost-effective integration of variable renewable energy sources and the decarbonisation of the energy system. MAGNITUDE real life case studies of multi energy systems, operate under different regulatory frameworks and geopolitical environments, and involve different sector-coupling technologies, new stakeholders and novel business models.

The facility Murcia Este is a waste-water treatment plant (WWTP), with production of biogas as a result from Anaerobic Digestion. Emuasa and Regenera companies are the project partners that are in charge the knowledge of the case study, while RSE is the project partner that is in charge of the modelling and optimization.

Strategies considered in order to increase the flexibility provision of the multi-energy system are: (i) import/export from the electricity distribution system (EDS) exploiting the day-ahead and ancillary service markets opportunities, (ii) increasing biogas storage capacity and (iii) installation of a heat storage. The different alternatives have been assessed from a technical and economic point of view, but also taking into account the Spanish legal framework.
The paper is structured as follows: in chapter 2 the biogas production plant is introduced with the methodology adopted for the analysis of optimization strategies, in chapter 3 the result of the analysis performed to identify the best strategies is reported. Conclusions propose some remarks on the work carried out.

2. Multi-Energy systems and flexibility

Multi-energy systems are traditionally managed as independent contexts (e.g., electricity, gas and heat). However, the implementation of decarbonisation policy is strongly requiring the integration at physical and commercial levels of the systems operating across several energy carriers. The physical and commercial coupling enables great synergies among the energy carriers but at the same time introduces a higher level of complexity to be managed.

The integration of optimization and control of multi-energy systems at multiple spatio-temporal scales can bring significant socio-economic and operational efficiency as well as environmental benefits [4]. Along with the growing role of distributed energy resources (DERs), the envisioned control architectures are based on a multi-area view. From an operational perspective, the coordinated and seamless control of various energy infrastructures represents a significant challenge, which favours a local view that renders cities quarters, residential neighbourhoods and industrial areas the fundamental building blocks of the integrated energy system.

Murcia Este wastewater treatment plant (WWTP) (100,000,000 m^3/d) is a "multi energy system" biogas producer from anaerobic digestion. The biogas produced can be stored in 2 gasometers (1,350 m^3 each), or used to feed a set of production units: three combined heat and power (CHP) gas-engines, 500 kW electrical power, and a gas-boiler, 1.6 heat power output. Two of the three gas-engine are always running while the third is kept as back-up and only operated in case of breakdown or preventive maintenance. A gas-boiler is also installed in the plant to ensure sufficient heat production, its nominal power being about 1600 kW. Heat is recovered from the cooling of high temperature engine circuit by means of 1038 kWt water-water heat plate exchanger, supplying 100% of the AD heat requirement. The electricity production is enough to satisfy about 50% of the WWTP demand, contributing to reach the GHG emissions reduction targets of the company and avoiding sulphur dioxide emissions from the combustion of raw biogas flaring. There is a small upgrading plant to produce biomethane for automotive uses (2.5m^3/h), just for on-site needs.

The plant is mainly operated to self-sustain the heat and electricity power demand. Two gas storages provide a certain degree of flexibility allowing to uncouple biogas production from electrical and heat demand. The model of the plant with the biogas generation, the processes related to demand satisfaction and biogas storage ability has been modelled in a mixed integer linear algorithm (MILP) [5]. This allows to identify and assess the best operational strategies for the plant when exploiting the electricity market opportunities.

Indeed, plant flexibility is provided on day-ahead and ancillary service markets with two distinct computational steps. In the first step, the foreseen biogas production is met with the foreseen heat and electricity demands. In this step, 100% of the heat demand and 50% of the electricity demand are expected to be covered by plant self-production. The rest of electricity demand is covered by importing electricity from the distribution system (EDS). Scheduling program of the devices and the amount of electricity imported through the day-ahead electricity market (DAM) is defined/optimized by the first step. The solution is driven by the amount of biogas availability and the (foreseen) market prices, hour by hour.

In the second step of the algorithm, the program elaborated in the first step is tested to verify the possibility to exploit further available flexibility on the ancillary service market (ASM), especially for tertiary frequency regulation provision (i.e., manual frequency regulation reserve – mFRR, as defined in [6]). That is, according to the first step hourly program to import/export electricity on DAM, further margins are identified to buy or sell electricity on ASM as mFRR.

The study carried out consisted of testing the two steps algorithm against 6 weeks data taken on the plant. The 6-week data is organized as follows: one week data for each yearly season, plus two critical weeks of data chosen among particularly critical situations.

The biogas production plant-model, suitable for the application of the two-phase algorithm, was designed using the energy grid methodology [5]. In this methodology the main focus is on the energy carriers involved in the plant management. In the case of biogas production plant, the energy carriers are: gas/biogas, electricity and heat. The methodology sets an energy-layer for each energy carrier. An energy layer allows to describe how the demand is supported by the services and the set of devices operating there, that is generators (Gen) storage (Sto) and loads (Load), plus the contribution of demand not met (λ) minus the losses (ω). Each entity of the model in pastel colours indicates that it is not included in the system. (Bio)Gas layer model includes the anaerobic digestor (AD) which produces biogas processing the sludge obtained from the waste-water treatment. The biogas production can supply the production devices: the three CHPs and the GB, or it can be stored in the gas storage (GS). A sketch of the model set is proposed in the next figure (light grey elements are not included in the plant model). In this energy layer no services are exploited. The electricity layer includes as generator the three CHPs which ensure the supply of the electricity demand.

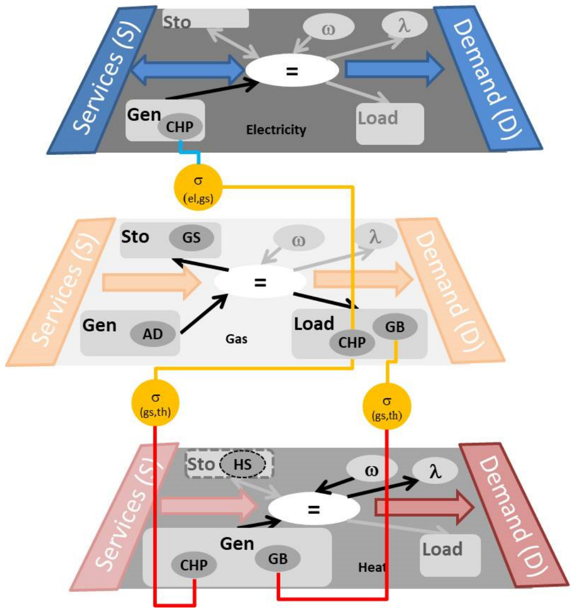

Figure 1 : Biogas production plant energy lattice model

Here electricity services from DAM and ASM support to feed the demand. The heat-layer includes the generator units CHPs and GB satisfy the heat demand. The overall energy-balance of the energy layers defined can require a given flexibility which is obtained exploiting heat-losses and heat-demand-not-met as slack elements. Yellow nodes represent the conversion factor from one carrier to the other ensured by the specific device. For instance, CHP provides a conversion factor from gas to electricity, and a conversion factor from gas to heat, as the co-generative nature of gas-engines taken into account.

3 Experimental results

The model of the plant set is tested in order to quantify the amount of flexibility provided as ancillary market products [6]. The flexibility of the plant is tested in its base case configuration, as depicted in Figure 1, and with several (possibly) improvements. These include the introduction of a heat storage (HS) and doubling the gas-storage capacity. The first improvement means to decouple the biogas production from the heat demand, while the latter means to increase the ability to decouple biogas production from electricity and heat demands. Foreseen cases are set in the Table 1. The different plant configurations have been tested against 6-week data taken from the plant operation during 6 weeks in 2018. One week was identified as representative for each yearly season, that is: winter, spring, summer and autumn; in addition two critical weeks were identified: one in October and one in November. One week was identified as representative for each yearly season, that is: winter, spring, summer and autumn; in addition two critical weeks were identified: one in October and one in November. These data have hourly resolution and include: the sludge flux produced by AD, the biogas flow input to production units (i.e., CHPs and GB), the electric and heat loads.

Table 1: Plant improvement configurations

acronym	device impr.	manag. impr.
Base Case (BC)	-	-
BC + mFRR	-	mFRR provision
BC+mFRR+HS	heat storage	mFRR provision
BC+ doubled GS (DGS)	doubled gas-storage capacity	-
DGS+mFRR	doubled gas-storage capacity	mFRR provision
DGS+mFRR+HS	doubled gas-storage capacity, heat storage	mFRR provision

Data also include the DAM and mFRR Spanish market prices taken in the six weeks identified. Tariffs for services and taxes to purchase electricity are roughly assumed to be 50% of the sell price.

The results of the analysis for the plant base-case during the winter weekly program is proposed in the next figures. In the first one is proposed the biogas production and consumption coupled with the trend of gas energy stored (GS-soc, GS-state of charge).

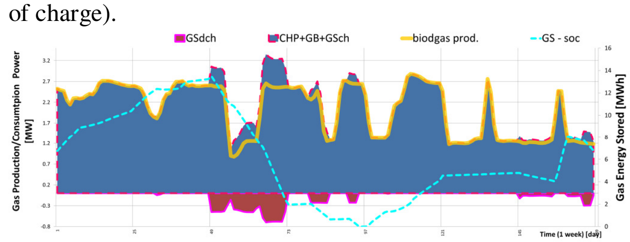

Figure 2: Base-case biogas production/consumption.

The next figure shows the electrical balance.

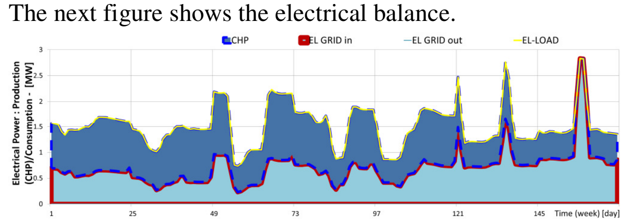

Figure 3: Base-case, electrical balance

The last figure concerns the heat production and demand, with the details about losses and demand not met.

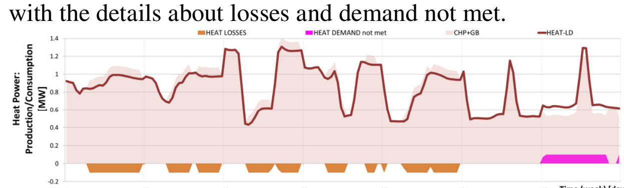

Figure 4: Base case, heat balance

The electrical flexibility the plant shows in the winter week program is proposed in the Figure 5. The proposed improvements to the plant device are mainly aimed at increasing the amount of flexibility. The tests carried out are mainly assessed from the daily production cost point of view. The idea is to get the best plant configuration and management strategy that are able to ensure the best result from the cost reduction. That is, the economic advantage arising from the participation to the ancillary market service, and in particular to mFRR in both sides upward and downward.

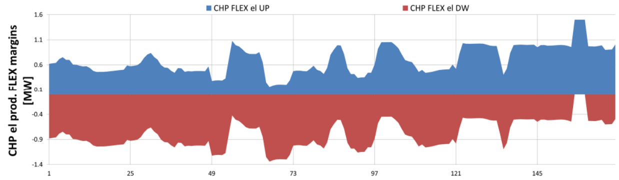

Figure 5: Base-case CHP electrical flexibility UP and DW

In the upward case getting the remuneration for exporting extra power to the grid and in the downward case reducing the need of power production. In the next figure the results gained.

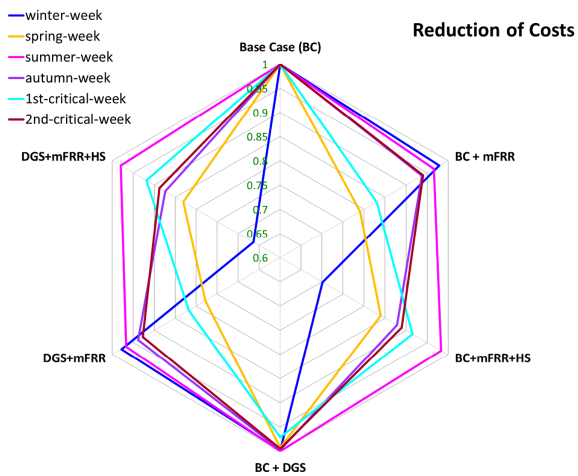

Figure 6: Weekly costs program analysis

The results gained propose different feedbacks about mFRR provision with the identified plant improvements. The graph in Figure 6 shows the effects of mFRR provision during winter, summer, autumn and two critical weeks. This does not provide relevant benefits unless the HS is introduced. In spring and 1st critical weeks the provision of mFRR provides benefits when the gas storage capacity is doubled.

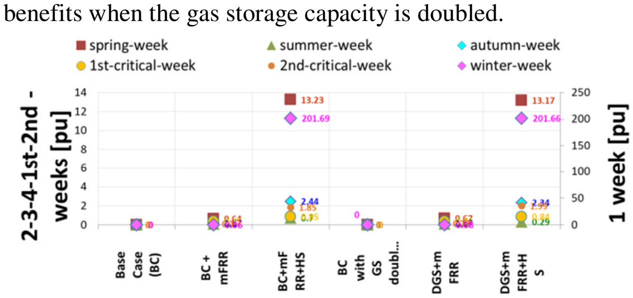

Figure 7: mFRR provision compared to electricity exchanged in DAM

In these cases the heat storage introduction does not provide relevant benefits. For 2nd critical week it seems there is a general reduction of the cost with respect to BC. In figure 7 it is proposed the detail about the amount of electricity due to mFRR with respect to that due to the DAM for all the identified cases.

6. Conclusions

The paper proposed the assessment of main flexibility capacity/potential of a real biogas production plant. This study was carried out in the MAGNITUDE project founded by the European Commission under contract n. 774309. This is one of seven real case studies taken into account in this project. The analysis was performed in the current plant configuration and in several possible extensions consisting of heat storage introduction, gas storage doubling capacity, as well as some management improvements. The results shown a good ability of the plant to meet *mFRR* service provision. This is documented through the reduction of costs achieved in the overall identified improvements.

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Bibliography

[1] P. Mancarella, "Cogeneration systems with electric heat pumps: energy-shifting properties and equivalent plant modelling," *Energy Convers Manage,* p. 1991–9, 50 2009.

[2] P. Mancarella, "Smart multi-energy grid: concepts, benefits and challenges," San Diego, US, 2012.

[3] A. Piacentino, C. Barbaro, F. Cardona, R. Gallea and E. Cardona, "A comprehensive tool for efficient design and operation of polygeneration-based energy mgrids serving a cluster of buildings. Part I: description of the method," *Appl Energy,* vol. 111, pp. 1204-21, 2013.

[4] P. Mancarella, "MES (multi-energy systems): an overview of concepts and evaluation models," *Energy,* vol. 65, pp. 1-17, 2013.

[5] E. Corsetti, A. Del Corno and M. Riello, "A Methodology to Support the Flexibility Maximization for Multi-Energy Systems to Provide Services to the Electrical Distribution System," in *CIRED 2020 Berlin Workshop*, Paper 388, Berlin., 2020.

[6] L. Cauret, R. Belhomme and et al., "D3.1 – Benchmark of markets and regulations for electricity, gas and heat and overview of flexibility services to the electricity grid," Magnitude, contr. n.774309, 2018.