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Unlocking European Grid Local Flexibility Through Augmented Energy Conversion Capabilities at District Level †

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Abstract: Pentagon is research and innovation project that investigate the potential of wider deployment of energy conversion technologies and strategies at district-level, with the aim to foster flexibility in the low-voltage and medium-voltage grid. Multi-vector smart districts can be the key enablers of future smart grids, provided their flexibility capabilities are augmented with adequate energy conversion technologies. Object of the research are two key technologies: a highly efficient power-to-gas installation sized for coupling with typical district heating plants and a multi-vector multi-scale district energy management platform for the combined monitoring and management of all district energy carriers.

Keywords: energy conversion; Power-to-Methane; Internet of Things; multi-vector energy management; district heating; energy flexibility; penetration of renewables

1. Introduction

PENTAGON is a new Horizon 2020 EU-funded project which sees the participation of 10 partners. It aims at paving the way for a new generation of eco-districts, leveraging on enhanced energy conversion systems and a high level integrated management platform simultaneously acting on different energy carriers. The core of the project is formed by the development of two ground-breaking technologies: (i) An innovative power to gas technology at the district level; and (ii) An intelligent, versatile and service based IoT (Internet of Things) platform for holistic, multi-vector energy management.

Power to gas is one of the most promising future smart grid technologies because it has the potential to solve the problem of renewable energy curtailments.

To bring these technologies closer to the market, PENTAGON will follow a three-step validation strategy that relies both on focused technology deployment in experimental facilities for 'live' assessments on a small scale and on more extensive simulations to assess the impact at the low and medium-voltage grid levels, considering different levels of renewable energy systems penetration [1].

2. Challenges

Europe's electricity system is in a period of profound change characterized by a shift from centralized fossil fuel power generation supplying passive households, businesses and industry, to distributed and decentralized power generation system where households, businesses, and industry are active participants in the grid by offering renewable energy characterized by high value of flexibility.

Moreover, Europe has committed to ambitious 2030 energy and climate objectives consisting of 40% greenhouse gas reductions, 27% renewable energy increase and 27% energy efficiency increase [2]. To respond to these challenges and to meet its targets, Europe needs to develop and mature the next generation of competitive technologies and services for the electricity distribution grid at medium and low voltage levels, which are clearly going beyond the state of the art and will be ready to integrate the market in a five to ten years' period. These technologies and services should enable advanced solutions for demand-response, smart grid, storage, and energy system integration while respecting the needed stability and security in the context of an increasing share of variable renewable energy sources in the electricity grid.

This issue can be addressed by adding flexibility to electric loads, installing significant smart storage equipment and taking advantage of energy conversion. Finally, effective management at district level, taking into account all energy vectors (electricity, gas, thermal), is crucial to make high penetration of renewables sustainable.

3. Impact

Pentagon will focus in particular on the achievement of four key impacts related to increased penetration of renewables, increased flexibility at local level, enablement of new local flexibility markets and five years' post-project horizon commercialization of key technological results.

3.1. Renewables Penetration

PENTAGON will enable higher penetration of renewables in distribution grids through enhanced synergies between electric, gas and thermal networks, leveraging power to gas technology and power to heat district-level strategies.

Smart tri-generation (electricity, gas, heat) districts are considered as first-class enablers to future grid flexibility and, in this respect, aims at critically enhancing their flexibility capabilities through the focused integration of power to gas conversion technology and the leveraging of intrinsic building power to heat capabilities. Power to gas technologies can actually allow for the transformation of electricity into methane that can then be reused or injected in the gas network and thus address current limitations, such as alleviating the need for renewable electricity production curtailment. However, the maturity and efficiency of these technologies are not yet sufficient to ensure their cost-effectiveness.

The relevance of the Power-to-Gas technology is confirmed by available forecasts, which suggest a wider uptake of the technology by 2020. One of the reasons is that gaseous storage (i) has a low marginal cost of storage; (ii) is comprised mostly of inexpensive components and (iii) offers the benefit of bulk storage without an unwieldy footprint.

3.2. Flexibility Management

Revenues generated from district flexibility to increase by 15 to 20%, thanks to multi-scale multi-vector energy management with holistic consideration of energy production, load and storage. Model Predictive Control (MPC) and Multi-Agent System (MAS) optimization strategies have been successfully developed and deployed for electrical and heat flow management in the frame of ongoing EU projects (Ambassador and Resilient, 2013–2017), allowing for the implementation of advanced optimization schemes at district level. The aim of these optimization schemes are to allow for the full exploitation of district and building flexibility capabilities, relying on flexible loads and storage capacities. MPC and MAS are complementary in the sense that they factor in different assumptions on the constraints that apply to the management of district energy resources. While MPC assumes that all resources can be controlled and implements a centralized optimization strategy, MAS rely on dynamic, decentralized and hierarchical negotiation. Therefore, MPC is more adapted to situations where the district resources are owned and managed by a single entity (which mostly align with the local authority managed, publicly owned smart district), while MAS will be more adapted to situation where multiple stakeholders are involved (typically the aggregator/

supplier/DSO interaction scheme). These platforms rely on predictions of electrical consumption and renewable energy production based on weather forecast and adaptive prediction models.

3.3. Smart Grid District

Empowering European smart district managers to successfully implement local energy aggregation businesses, allowing for the generation of additional revenues from district flexibility trading and reduced energy costs for local consumers. The business roadmap of PENTAGON is largely based on an inspirational study 48 commissioned by partner Blaneau Gwent County Borough Council (BGCBC) that aims at framing a sustainable local energy supply and aggregation business, with the objective to reduce the costs of energy for local consumers. There are several reasons why PENTAGON would like to build upon this BGCBC 'Energy Catalyst' roadmap. First of all, this specific business case (local authority acting as local flexibility manager) is fully in line with the most recent market frameworks for the distribution grid flexibility management: The Universal Smart Energy Framework, for instance, emphasizes the central role of aggregation in flexibility trading.

One objective of Pentagon is therefore to enable Local Authorities like BGCBC to endorse the role of local flexibility manager, with the aim to create a sustainable local business in the frame of future smart distribution grids. Secondly, the revenues generated by this flexibility trading will enable empowered Local Authorities to decrease the cost of energy for the locals and contribute to the social improvement of the community. Eventually, this Local Authority as Local Flexibility Aggregator business case is widely replicable all over Europe. Actually, the key market drivers for PENTAGON solutions are the current growing trend towards the transition to smart cities and the same trends for district heating.

3.4. Power to Methane

Power-to-Gas, is a very promising energy system since it produces gas with a lower environmental impact than fossil gas and at the same time offers a flexible controllable load for electric grid stabilization. Its application can be used to mitigate the fluctuations that can occur in local areas with high shares of renewable energy sources. In order to be considered as green energy, Power-to-Gas has to be based on renewable energy, i.e., renewable electricity.

The state of the art for the Power to Methane technology reaches efficiency of 60% in large scale of plant which is well below the efficiency of competitive technology as Power to Hydrogen. Aim of the PENTAGON project is to increase the efficiency until the current limit, until the 75% [3].

The production of methane with this technology has two steps: first hydrogen is produced through an electrolyser exploiting electric energy, as in Power-to-Hydrogen technology. In this first step, an efficiency of approximately 80% can be reached. The second step, is the methanation. This requires, in addition to the electrolyser with rectifier, power electronics and balance of plant equipment used in Power-to-Hydrogen, an additional reactor (Sabatier reactor) where hydrogen is combined with carbon dioxide to form methane and water, in a highly exothermic reaction. If the transformation is completed to 100%, the efficiency of this second step is 78%. The remaining 22% of energy is released from the methanation reactor in the form of waste heat [4]. If catalytic methanation from a thermochemical process is used, the waste heat is available at 300 °C, i.e., at a temperature high enough to generate steam even at elevated pressures. The latter may be used as input for a Solid Oxide Electrolysis Cell (SOEC) with the consequence that the electrolyser needs less energy and the plant efficiency being much higher [5].

This concept, present in literature but never experimentally realized, will be performed in the PENTAGON project as shown in Figure 1, in order to boost the efficiency of the entire system with a view to apply it within the scope of an eco-district heating production plan, adapting the existing SOEC technology to the needs of a Power-to-Methane plant into an environment of a Power-to-Gas plant in small scale.

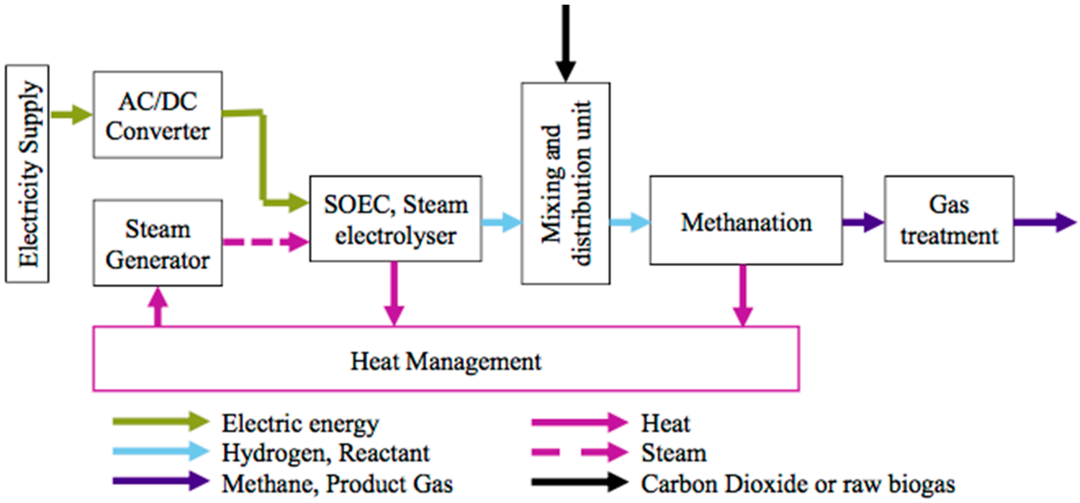

Figure 1. Schematic of diagram of Power to Methane with Solid Oxide Electrolysis Cell.

4. Conclusions

The solution for a high penetration and efficient integration of energy renewable systems, in a district network, must be performed throught the management of different energy vectors. Electric energy, thermal energy and storage solutions are actors in a multi-scale synergic strategy which focuses in the flexibility of the buildings. The PENTAGON project arrived today at its first year of life is working in this way modelling the pilot networks (electric, thermal and gas) with aim to simulate the potential performance of distributed loads, storages and renewable productions in the holistic consideration of all energy carriers involved.

PENTAGON will also posture toward future market uptake of the solution delivered through an evidence-based exploitation roadmap for next generation European eco-districts, particularly aimed at local authorities and Energy Service Companies. In this activity relevant role will be the contribution of R2M Solution in the exploitation of results.

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