Energy for Sustainability International Conference 2019
Designing a Sustainable Future
Turin, 24-26 July 2019

INTEGRATION OF POWER TO GAS AND POWER TO HEAT SYSTEMS INTO THE ELECTRICITY GRID BY THE MEAN OF FLEXIBILITY SERVICE FOR THE AGGREGATORS

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Keywords: Green Energy, Sustainability, Conversion, Storage, Optimization
Abstract *Electricity network is facing growing push to increase Renewable Energy Sources' (RES) share in total energy production while guaranteeing acceptable quality of service and reliability. The issue is more than just an option and it is in fact the matter of passed legislations and defined targets that leaves no space for reverse steps. The targets however come in conflict where grid de-carbonization and therefore RES share increase in turn bring relative uncertainties and thus electrical system reliability would be penalized. Such challenges have triggered wide range of research projects in favour of RES integration to the electricity grid while keeping reliability high.*

In the present research work -the goal of the European H2020 Planet project- we study how the union of the mentioned –partially- conflicting targets, opens a promising market for conversion and storage systems, whose assets could come in service for addressing a vast range of problems in the future electricity grid. We will study orienting on non-preliminary form of energy conversion and storage systems like Power to Heat (P2H) and Power to Gas (P2G), and that how those can alleviate critical issues such as Reverse Power Flow, Power Quality and Over Loadings, while de- carbonizing.

Although P2G unit isn't a very recent technology, but its relatively high cost of investment and maintenance, has restricted drastically its usage regardless of its immediate benefits. We analyse these as flexibility providers to the grid operator in the era of Smart Grid, and show how this strategy brings interesting opportunities, for a multi-products asset.

In the present paper, we review the technical feasibility and efficient strategies to integrate P2G and P2H systems into the electricity system as flexibility providers to the aggregators, as well as the decision-making support system and ICT service architecture to hosting such functionalities. Finally, we discuss the direct impact of the complex system on reducing RES curtailment, avoiding grid congestion and needs for reinforcement and CO_2 emission.

1. INTRODUCTION

In recent years, Renewable Energy Sources (RES) became the pillar for a policy aiming to increase the share of clean electricity generation, and their role will become even more important in the future [3]. The fact that the newly introduced sources are decentralized and intermittent, leads to recognize two trends:

- electricity generation decentralisation;
- progressive loss of generation control and predictability.

Due to the reduced predictability, to guarantee the match between load and generation will be a challenge, that needs good forecasting models (to handle with the slow volatility of the RES, for reducing as much as possible the mismatch in prediction phase),and provision of ancillary services (to handle with the fast and unpredictable variation).

The de-centralization of electricity generation requires equally de-centralized and affordable solutions to eliminate curtailment and decarbonise the EU energy future. Among the possible solutions, the use of alternative carrier networks can help in this sense, having as byside effect the decarbonisation of other energy carriers, in particular gas and heat.

The H2020 project PLANET aims to create this kind of multi-carrier integrated systems, putting together infrastructure (i.e., networks), conversion systems (Power-to-X, PtX) and inertia characteristics (i.e., virtual energy storage, VES) and this paper aims to present some peculiar aspects of the project itself. In particular, Section II introduces the possible electrical network scenarios where the PLANET framework could be applied, while Section III presents a summary of the PtX and VES. Section IV and Section V are focused more on the optimization and architecture aspects of the PLANET Decision Support System (DSS), whereas the Concluding remarks are shown in Section V.

2. DISTRIBUTED GENERATION IMPACT ON ELECTRICITY NETWORK

The presence of RES in the distribution networks can lead to have two conceptually different kinds of problems [5]:

- Non usual operation, with network constraints verified. This is the situation that can occur when, in presence of high penetration of RES, there is injection of power into the transmission system through the HV/MV transformer (i.e., so called *reverse power flow*) , even whether all the distribution system constraints are verified (i.e., voltage and currents falling in the limits). The reverse power flow is not a usual electrical grid operation and, when it is present, the proper protection of the distribution system is not guaranteed, due to the protection scheme currently implemented on the distribution grid [6]. However, this condition (even not normal for the system) does not imply any operational constraint violations, that means that voltages and currents can still fall in the admissible range.
- Operation with non-verified constraints: in this case the network is not secure operated and thus it is necessary an intervention from the network operator. This kind of situations are composed of overloading and over/under voltages, and, fortunately, they are currently very rare. However, due to the increase of uncontrollable RES, these

situations can become more frequent in the future, and proper studies referring to them are necessary.

The two above cases can be fix through the introduction of proper conversion systems aiming to create a multi-energy system. At that point, it is possible to evaluate a strategy for optimizing them into a normal operation scenario[i].

3. CONVERSION AND STORAGE OF ENERGY TO NON-PRIMARY FORM (OTHER VECTORS)

3.1. Power to Gas

Power-to-gas (P2G) conversion is a class of energy conversion technology that has recently been
gaining interest for introducing additional flexibility in the entire chain of the electricity grid [7]. Largescale pilot facilities are already operational in test environments in order to validate their technical merits and investigate the arising business cases (for more information see the demo sites of the project [5]). The term P2G actually could indicate both the production of hydrogen, or the production of methane, called Synthetic Natural Gas (SNG). With the purpose of use synergically different carrier networks, the second options seems to be more appropriate, because allows to produce a product that can feed directly the gas network, without introducing additional difficulties neither for the network operator and the final user. From conceptual point of view, the gas network (an infrastructure already existing) is a long-term, (almost) limitless storage infrastructure: in Europe, the gas infrastructure (high pressure) is composed of 2.2 million kilometres of gas pipelines in Europe [4], with a good potential of storage due to the "line packing" of the grid (indicating the intrinsic capability of the grid to store additional gas). The conversion chain is composed of electrolyser and methanation process. Even though the technology is already known, its optimal integration in the future energy system to synergistically collaborate with the electricity and natural gas grids has not been resolved yet.,

3.2. Power to Heat

The Power-to-Heat (P2H) technology exists as commercial products since decades. Due to the consumption existing in EU for space heating/cooling and water heating (about 40% of the total residential energy consumption [1,2]) the share of energy that could be handled through them is very high. Their good dynamic characteristics, associated to a source of thermal inertia could guarantee an effective way to manage the intermittent sources, by introducing in the system additional flexibility.

From conceptual point of view, P2H can be divided in two main types of applications:

[i] It is worth to note that the "normal operation" condition has been reached thanks to the presence of conversion systems, but it is possible further optimize their use.

- Centralized Power to Heat (CP2H) applications, where the interaction is between the electricity grid and the local District Heating (DH). The interaction among the two infrastructures is made through large-scale heat pumps, which allow to efficaciously convert electricity in thermal energy to be provided to DH networks. The source of thermal inertia is provided both from the DH itself and from additional large-scale thermal storages that can be employed to face heat peak power required by buildings when the grid cannot to satisfy the peak loads;
- Local Power to Heat (LP2H) applications, which cover all the decentralised application (e.g., the interaction is between the one feeder of the electricity grid and a building) based on the use of small heat pumps. The inertia in this case can come from the deployment of traditional thermal storage or by using Phase Change Material (PCM) thermal storage. However, an alternative with respect to them is the exploitation of the thermal inertial of the building, i.e., VES, which constitutes a virtual energy network that both enhances energy end user involvement through energy management and provides significant demand flexibility potential. It is worth to note that the very distributed nature of VES makes it as a prime candidate to face the issues caused by decentralised RES on the electricity distribution grid. Using this storage capacity requires the capability to monitor and control the equipment involved (heat pumps, storage) by taking into account both the optimal demand profiles for the distribution grid and the customer comfort/health requirements. Even though its potential is enormous, VES has not been yet exploited at scale due to the lack of technologies up to now to make its impact comfort-neutral for the energy consumers, who does not want to sacrifice living/working conditions to save energy or provide grid services.

4. DECISION SUPPORT SYSTEM

Planning and operation of new storage/conversion components to address electricity distribution system issues however, requires a comprehensive analysis including economical and technical aspects. The feasibility of such scenarios hangs upon first, on the physical systems especially electricity grid and the impact of considered configuration on several indicators each from a different nature, potentially. Therefore, decision makers need a tool that brings several calculations, transfer functions/models and services together, within a solid and performant computation service.

The EU-founded H2020 PLANET project, has been launched to provide solutions for power system stability through synergy with other networks, and a Decision Support System (DSS) specialized for assisting decision makers to draw a conclusion over certain deployments, either from technical, environmental and economic impacts. One can analyse arbitrary/futuristic scenarios in which expecting growing RES power production causes reverse power flow, extreme voltage deviation and congestion that forces the grid operator to upgrade physical infrastructure.

The DSS accommodates various model/transfer function e.g. electrical system, conversion/storage units and virtual energy storage, each containing further micro models.

4.1. Architecture

Within PLANET project, an ICT platform to integrate various entities through models, algorithms and a powerful simulator, communicating via a middleware channel, to handle monitoring and controlling data flow, as well as unifying data standards forming PLANET CIM. This DSS is accessible by the mean of an ad-hoc intuitive user-interface, without need of expertise knowledge, so suitable as a multi-disciplinary system. An optimization module – Storage and Conversion Coordination Engine (SCCE)- hosts algorithms that make operations smarter. High-level architecture of the PLANET is depicted in the Fig. 1.

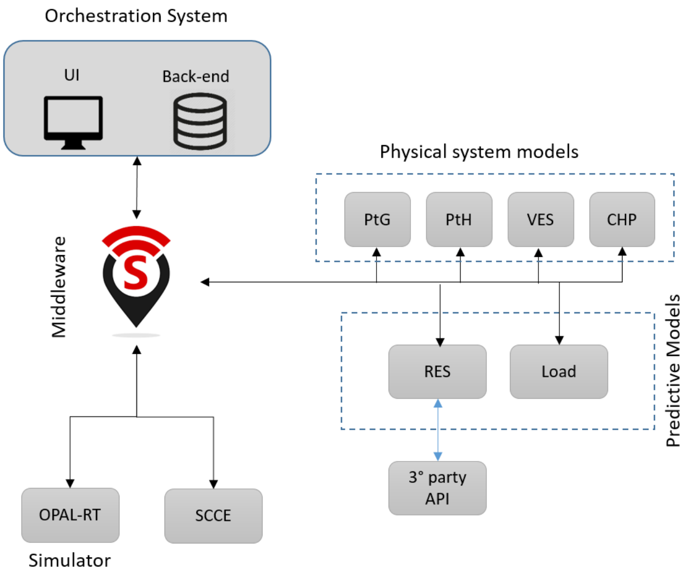

Figure 1. PLANET high-level architecture.

The SCCE in provision of abnormal condition in the electricity system, e.g. excess of local power generation as shown in Fig. 2 and congestion -that explicitly ends up with reverse power flow- instructs new set-points for available flexibilities within the area of control. Decision algorithm is based on heuristic such as Greedy and Dynamic Programming search methods with a configurable dispatch according to the specific problem, and designed to be fast enough to correspond needs of real-time control. This engine incorporates also Artificial Intelligence (AI) routine for prediction motives and also to accelerate of the computations.

5. CONCLUSIONS

In this paper, we briefly introduce PLANET project rationale, offered potential solutions and implementation to cope with the problems that are raising in the electricity system due to high penetration of variable RES power generation. The PLANET brings Power-to-X vector conversion/storage integration into practical evaluation, and furthermore designs a system to address analytical needs, from both technical and business decision makers' perspective.

ACKNOWLEDGEMENTS

This research received support from the EU project Planet founded from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 773839. The authors thank Antonis Papanikolaou, from Hypertech (Greece), and Yannis Damousis, from CERTH (Greece), for their reserch contribution in the Planet project.

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