USE CASES IN SECTOR COUPLING AS PART OF THE *LINK*-BASED HOLISTIC ARCHITECTURE TO INCREASE THE GRID FLEXIBILITY

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Abstract

Sector Coupling opens up new opportunities to meet fluctuations of renewable energy sources, thereby increasing grid flexibility. The consideration in the *LINK*-based holistic architecture accelerates its practical implementation on a large scale. The standardized architecture structure have three main components: Electricity producer, storage and grid. They operate on a decentralized basis at transmission and distribution levels. Customer Plants that transform from consumers to prosumers operate as virtual vertical integrated utilities. End-Use and Cross-Vector Sector Coupling is integrated into the *LINK*-based holistic architecture via the storage component. Different storage technologies are categorized from the perspective of the power grid. The optimization of the electricity system and other sectors is realised by coordinating and adapting the locally optimized systems. Various use cases for price driven Power to X response are described. The storage integration through the Sector Coupling may positively affect the way ancillary services are provided and traded through market mechanisms.

1. Introduction

Environment protection policies are fostering the deployment of the Sectors Coupling to provide greater flexibility to the energy system so that de-carbonization can be achieved more cost-effectively [1].

The integration of distributed energy sources at several voltage levels creates replicative managing schemes to meet the demand by respecting the technical constraints of the grid. Additionally, the realization of the End-Use and Cross-Vector Sectors Coupling in all voltage levels optimally meets fluctuations of the renewable and distributed energy resources. The essence of it is an increased energy conservation: As soon as the energy reserves of facilities, which consume and feed electricity at the same point of the grid (e.g. water-pumped power plants, and so on) are full, the excess energy available in the electricity sector can be stored or used as alternative energy source in other sectors, Power-to-X (P2X). X represent the energy storage medium like Water (W), Gas (G), Heating (H), Cooling (C), and so on.

Recently, many studies are performed in the field of Sectors Coupling, which have focused on the efficiency of its implementation [2-5]. The chemical energy carriers - like hydrogen and methane – produced via P2X processes -- have the potential for large scale, long-term (seasonal) energy storage capacity [5]. The latter may distinctly increase the grid flexibility.

In this paper we concentrate on incorporating the Sectors Coupling into the *LINK*-based holistic architecture [6].

2. Transformation of power industry structure

Historically, the power industry is perceived as assembly of three main components: Electricity producers included in power plants, Grid and Customers. Electricity storage, almost in form of pumped hydro plants, is traditionally presented as part of the power plants component. The Grid has two main parts: The transmission grid comprising very high and high voltage grids and the distribution grid comprising medium and low voltage grids. Utilities are vertically integrated and own and control electricity producers, transmission and distribution components. Customers consume the electricity offered by the nearest electrical utility. Fig. 1 illustrates the structural transformation of power industry and of the electricity customer. The traditional structure of power systems is shown in Fig. 1 (a).

The decentralization process of the electricity industry was in progress in the 1990s. At that time, from the vertically integrated utilities, various legal entities such as generation, transmission and distribution companies, market operators, political decision-makers, etc., were emerged. Storage, almost pumped hydro plants, were treated as a generation company.

The last 30 years have been characterized by an extraordinary development of various technologies that has a major impact on the structure of the power industry. This changes the perception of the components of the power supply system. In addition to dividing the vertically integrated utilities into different legal entities, there are two other fundamental issues affecting its structure:

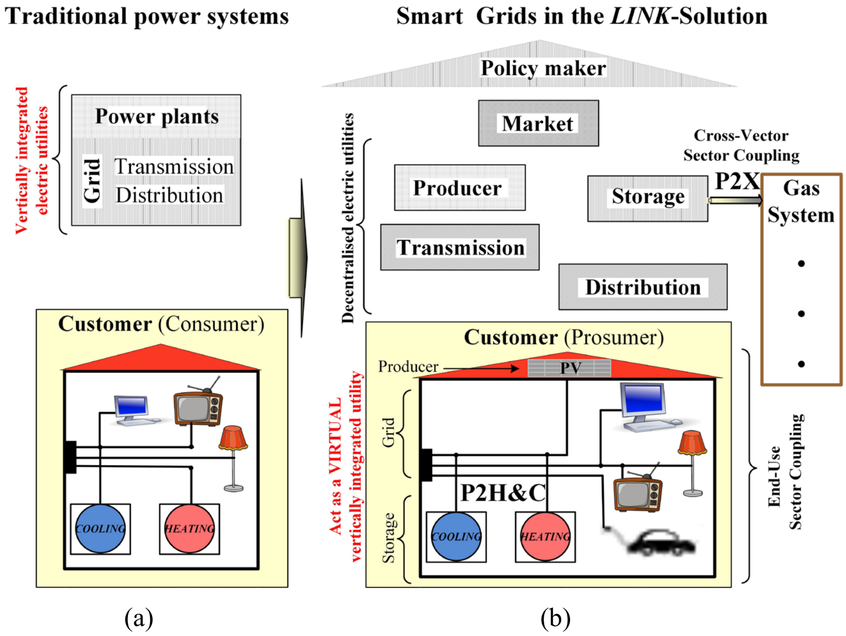

Fig. 1 Overview of the structural transformation of power industry and electricity customers: (a) Traditional power systems; (b) Smart Grids and Sector Coupling in the *LINK*-Solution.

1. Nowadays, storages are undergoing an intensive development process. Diverse technologies are developed and they are available in different sizes, and can be integrated in any voltage level of the grid. The electricity power surpluses might be stored to other sectors, P2X. That means that from the perspective of power system, Sector Coupling is a storage process. Treating storage as part of a power plant is no longer appropriate. It cannot be used to describe P2X processes. Therefore, in the *LINK*-based holistic architecture, the storage is separated from the electricity producer (power plant) component. **Storage is perceived as an own, main component of Smart Grids** [7], Fig. 1 (b).

2. Customers are experiencing radical changes. They are not only the owner of devices that consume electricity, but they also own electricity producers such as PV facilities, and storage devices such as batteries. Additionally, the customer have the option of storing the renewable power surplus on heating and cooling devices (P2H&C) or Power-to-Thermal (P2T). Based on these facts and on the definition of the vertical integrated utility, in the *LINK*-based holistic architecture, **prosumers are perceived as virtual vertical integrated utilities,** Fig. 1 (b). They behave as a black boxes against the power system by exchanging a minimal amount of data. The data privacy is guaranteed [8].

The main principle of the *LINK*-based holistic architecture is the optimization of the whole smart grids by coordinating and adapting the locally optimized Links.

Table 1 Storage categorisation from the grid perspective.

Storage category	Description
Cat. A	The stored energy is injected at the charging point of the grid.
Cat. B	The stored energy is not injected back at the charging point on the grid.
Cat. C	The stored energy reduces the electricity consumption at the charging point in the near future.

3. Storage categorisation

During the storage process, the electrical energy is transformed into other forms of energy, such as: potential energy in the case of pumped hydroelectric energy storage or pressure increasing in Gas Systems, chemical energy in the case of batteries; in thermal energy in the case of cooling and heating appliances; kinetic energy in the case of flywheels and so on. In this paper the storage is treated from the point of view of the power grid. For the latter, the charging and feeding point of the storage in the grid are relevant.

Storage is classified in three categories:

- Cat. A - The stored energy is injected at the charging point of the grid such as pumped hydroelectric energy storage, stationary batteries, etc.
- Cat. B - The stored energy is not injected back at the charging point on the grid such as Power-to-Gas (P2G), batteries of e_cars, etc.
- Cat. C – The stored energy reduces the electricity consumption at the charging point in the near future such as cooling and heating systems (consumer devices with energy storage potential).

4. Sector Coupling in the context of *LINK*-based holistic architecture

The *LINK*-based holistic architecture takes into account the whole power system, i.e. high, medium and low voltage levels) and the customer plants, including the household electrical devices and the market. It reflects the principles of the fractal [7]. Repeating the same structures in ever smaller dimensions offers practical opportunities for the implementation of Sectors Coupling throughout the whole power system and the Customer Plants. Storage-Link is one of the three elements of the architecture that facilitates Sectors Coupling. Fig. 2 shows the coupling of electricity sector with the Gas System through the storage of Cat. B. The End-Use Sector Coupling happens in the Customer Plant_Grid-Link level through P2H&C. While, the cross-vector coupling may happen in the High-, Medium- and/or Low_Grid-Link level. The incorporation of Sector Coupling into the *LINK*-based holistic architecture facilitates the optimization of the electricity and gas sector by coordinating and adapting the locally optimized systems; Links. In the following, the use cases for the price driven P2X response are described.

5. Price driven P2X use cases

Fig. 3 shows the generalised use case for the price driven P2X response. It has four main players: the market agent, the Grid-Link operator (GriLiO→TSO, DSO or customer), the storage operator of the respective category (StO_Y, where Y can be A, B or C), and the operator of the respective sector X (OX, where X can be Water Power Plant, Gas and so on). The interaction between different players is described by means of the use case: Price driven P2G response, Fig. 4. P2G is classified in the Cat. B of the storage. The operator of the storage Cat.B, who for ex. is responsible for H_2 production, receives from the Market Agent a notification for low electricity price. Consequently, he sends a request to the operator of the Gas System (GasO) to increase for e.g. the H_2 production. After having checked the availabilities in the Gas System, GasO approves the request of StO_Cat.B. The latter sends a request to the operator of the Grid-Link (GriLiO) where the charging point is located. After having verified the effectiveness of this action in its own Link, the GriLiO approves the request and the StO_Cat.B procures the P2G.
Fig. 5 shows the use case: Price driven P2W response. P2W is classified in the Cat. A of the storage. In this case, the StO_Cat.A also operates the Water Power Plant (WPPO). After being informed by the market agent about the low electricity prices, WPPO sends a request to the GriLiO (TSO)

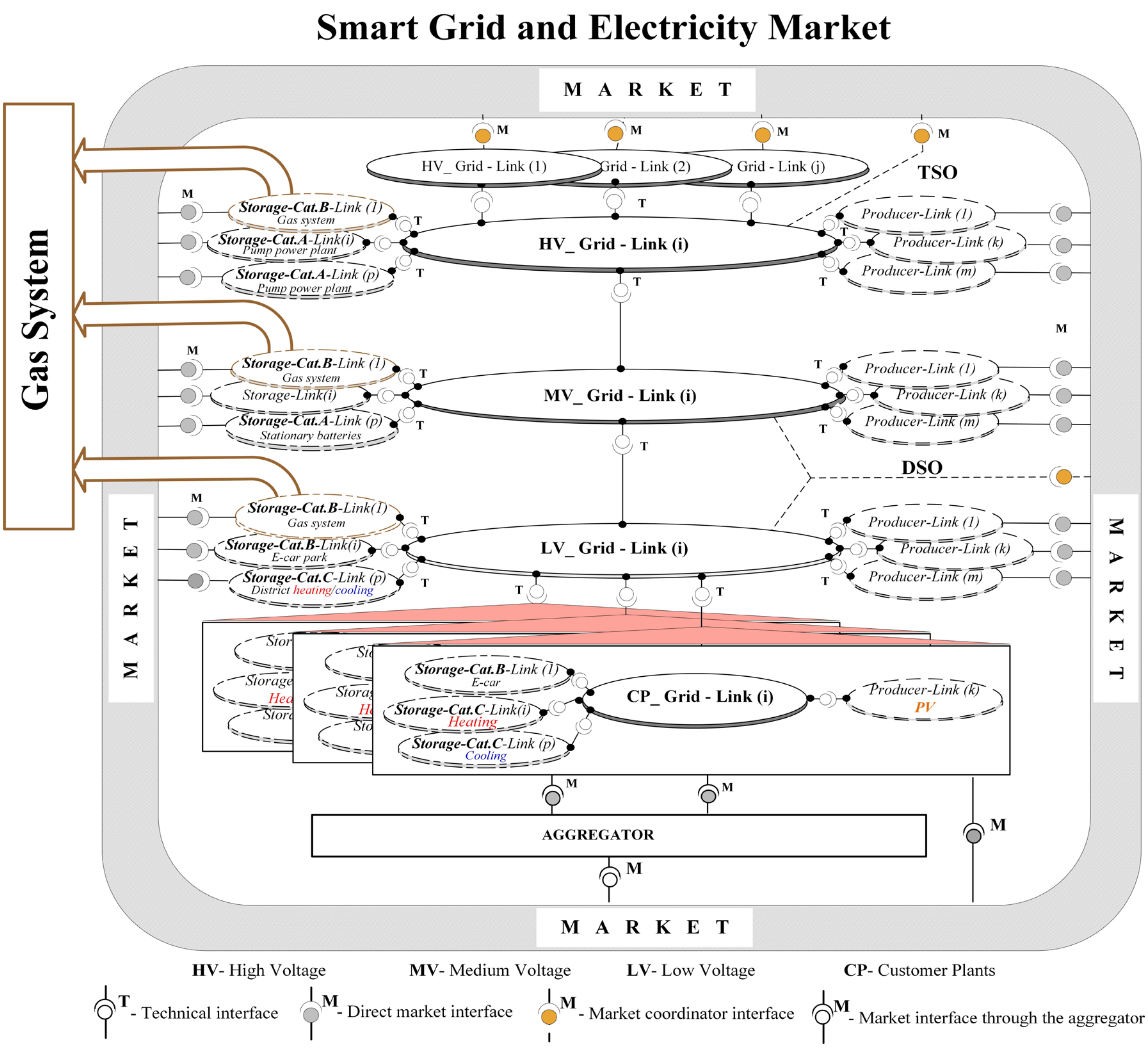

Fig. 2 *LINK*-based holistic architecture coupled with the Gas System.

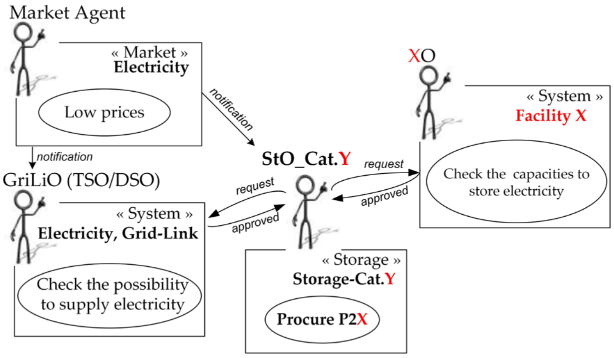

Fig. 3 Generalised Use Case: Price driven P2X response.

to increase the electricity consumption. After having verified the effectiveness of this action in its own Link, the TSO approves the request and the WPPO procures the P2W.

Fig. 6 shows a typical use case of the End-Use Sector Coupling: Price driven P2H/C response. The GriLiO is the customer, who should have installed the House Management Unit (HMU) [8]. The latter takes over the coordination and the optimization of the processes within the customer plant.

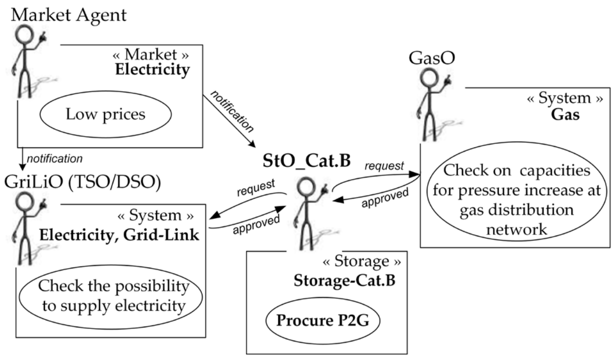

Fig. 4 Use Case: Price driven P2G response.

6. Conclusion

The *LINK*-based holistic architecture, which includes the power system and the market, facilitates the Sector Coupling at both stages: End-Use and Cross-Vector Sector Coupling. The optimization of the electricity system and other sectors is realised by coordinating and adapting the locally optimized systems. The storage integration through the Sector Coupling may affect (in positive manner, if properly managed) the way ancillary services that are provided and traded/valorised through market mechanisms.

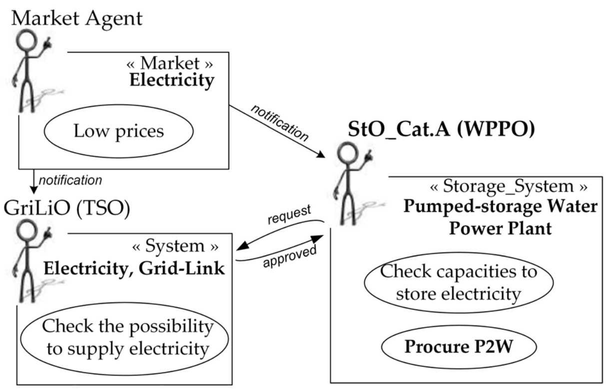

Fig. 5 Use Case: Price driven P2W response.

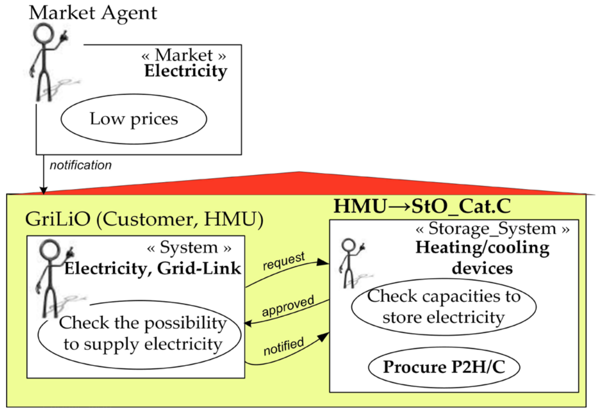

Fig. 6 Use Case: Price driven P2H/C response.

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