

Template for SAMA Reports

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Abstract

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Chapter 1

Introduction

1.1 Background

Background

Definition of flexibility

The challenges due to renewable penetration:

Traditional flexibility from supply-side has limitations due to

The increasing demand can be fulfilled in various means, including conventional methods like generation (gas turbine), transmission (grid extend), which normally requires vast investments on infrastructure. With the development of technologies in ICT and batteries, new options are becoming increasingly feasible

The push and pull from market demands and technology availability is leading the policy makers to review or even revise the regulatory framework which were established based on the to allow non-discriminatory participations of those new technologies.

Uncapping the potential

1.2 Technologies: options for system flexibility provision

- supply-side flexibility
 - Conventional power plant response
 - Curtailement of variable renewable
- Energy Storage System (ESS)
 - Battery Energy Storage System (BESS)
 - Pumped Hydro Energy Storage (PHES)
 - Compressed Air Energy Storage (CAES)
 - Flywheel
- Demand Response (DR)
- Other
 - Electric Vehicle to Grid (V2G)

Electricity to Heat (E2H)

Power to Gas (P2G) / Power to Hydrogen (P2H)

1.3 Applications, benefits and business models

1.3.1 In liberalized market

Needs of different players

Player * Market * Application

Energy Markets

Ancillary Service Markets

1.3.2 In vertically integrated market

1.4 Scope and research questions

The target audience of this thesis is the management at Landis+Gyr on a high corporate level.

The ultimate goal is to provide references to support the audiences' strategic decision makings regarding flexibility management.

In order to achieve this, we conducted qualitative studies and developed quantitative models to identify: 1) the value of markets for flexibility management

•

The goal of this thesis is to:

developed a robust modeling tool with moderate complexity so that it can not only provide results in current environment but can be also reused or easily revised to provide results in case of changes in the future.

based on the tool, make quantitative as well as qualitative analysis to provide references

Purpose: providing references for strategic decision makings regarding flexibility management.

In order to make the analysis robust and reliable, we have built a techno-economic models which include the bottom-up dynamics of some key elements regarding the electricity markets and flexibility technologies.

However, it shall be noticed this thesis is not intended to serve for:

project developers to design a flexibility system or make operating (including bidding) strategies of the system

policy makers to redesign the electricity market structure, rules or other policies

grid planners to understand the needs and options of flexibility in order to achieve system reliability with lowest costs

Since the concept of flexibility management is related to a great variety of technologies, applications and Landis+Gyr is positioning globally in various markets, the scope could be very broad. Nonetheless, in order to produce viable and reliable results with a solidly established techno-economic model, we have to make compromises. According to the relevance to Landis+Gyr's business, the scopes are defined as:

The potential business model of Landis+Gyr is either to supply products to the customers to help them enable flexibility or to directly sell them flexible MWs as a service. In this case, we want to understand the value of each MW we enabled or sold. We assume Landis+Gyr will not directly participate and trade in the power market, as it is going to place Landis+Gyr at the rival side of some customers in that market.

The value of flexibility will definitely vary according to the purpose, users' portfolio and operating strategies.

Chapter 2

Literature Review

As is clearly revealed by the literature review, there exist abused research articles generally on this topic of flexibility management. However, there exist very few academic works that serve the needs of our target audiences who are the management of technology vendors. The deviations of interests result in gaps that make it difficult to directly use the existing works. These gaps include:

- Most of the researches are based on one specific technology and one specific market, as usually a utility company or a grid planner is operating in one market regime and a technical professional is focusing on one technology. However, our target audiences are likely to be interested in various markets and technologies.
- Scope
- Method - proof of concept

Conventionally, their decision makings are supported primarily by commercial consulting firms who relied much on qualitative analysis or quantitative data-analytics. Even when sometimes it is possible that those firms have developed model with fundamental and physical approach, the model is always customized and not public

most of the researches are focusing one specific technology and one specific market, due to the nature of their target audiences. However, the management of a technology vendor will likely to be interested in various markets and various technologies.

The economics of flexibility solutions in power systems, especially electric energy storage (EES), is an active topic in research. It has drawn great attentions from the academics, investors and policy makers.

2.1 Purpose and stakeholder

2.2 Modelling methodology

2.2.1 Overview

Engineering vs system Linear vs nonlinear Deterministic vs stochastic problems Solving techniques

2.2.2 Engineering model

Price taker perfect forecast stochastic or dynamic programming Hybrid system Service mutualization

2.2.3 System model

2.3 Affecting factor

2.3.1 Techno-economic characteristics of power system

Generation

Generation mix (Renewable integration) Fuel Prices

Climate and weather

Transmission

Grid topology Transmission capacity

Consumption

Merit-order model

[?]

[?] [?] [?] [?] [?] [?] [?] [?] [?]

2.3.2 Statistic model

[?]

2.3.3 Perfect forecast

[?] [?] [?] [?] [?]

2.3.4 Power market design and policy regulation

Player and competitive landscape

Renewable Support Scheme

Power Market Design

Market structure and rules: nodal, interval, reserve market Access

In general, the seven ISOs/RTOs require companies that service loads (i.e., the energy requirements of end-use customers) to provide reserves in proportion to their loads. (ref to Project Report: A Survey of Operating Reserve Markets in U.S. ISO/RTO-managed Electric Energy Regions)

Balancing market design [?] [?]

Ownership and dispatch

Direct policy support

Capacity market Feed-in premium or tariff Other program

2.4 Value of results for reference

2.4.1 Demand for flexibility in power system

2.4.2 Profitability of flexibility solutions

Chapter 3

Power Markets and The Role of Flexiblity Management

This chapter introduces some key concepts of power market elements and how the role of flexiblity management is determined by them. We adopted a generalized method to extract the key variances in power market structures that have impacts on value of flexiblity management. The purpose of this chapter is to provide the managment of a technology vendor who plan to expand their business in a variety of geographies a comprehensive and comparative view on flexiblity managment in different power market regimes.

3.1 Power market frameworks

Started in the 1980s and facilitated in 1990s, liberalized power markets has been the mainstream worldwide, especially in developed countries where the constructions of power infrastructure have been largely completed. [?] Nowadays, there are many maturely existing liberalized power markets. However, since different preconditions exists in different countries due to historical, political and climatical reasons, the structure of their power markets tend to be very heterogeneous. Moreover, with the development of technologies, for instance the renewable penetration and rise of demand response as well as electricity storage, power markets face pending or undergoing restructuring, make them a rapidly changing field of the economy. [?]

These spatial and temporal variances bring great challenges to our study as the business models of flexiblity managment and values out of them depend extensively on the power market structure. Hereby we reviewed and analyzed the existing mechanisms of how power makets can possibly enable the value creation of flexiblity management. Proposing novel market mechanisms is out of the scope of our study.

3.1.1 General stucture of power markets

3.1.2 Key attributes of power market stucture

3.2 Overview

Power exchange / Power pool

Capacity or not

Locational pricing or not

3.2.1 Energy market

3.2.2 Ancillary service market

3.2.3 Capacity remuneration mechanism

3.3 Power market design and structure

3.3.1 PJM

3.3.2 Germany

3.3.3 Australia

3.4 Regulatory and market framework for flexibility resources

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Chapter 4

Case Studies

4.1 Analyzing the power market structures and business opportunities in select cases

The superset of I is the set of selected energy market segments in different geographies:

$$I \subseteq \begin{cases} \{Day Ahead, Real Time\} & PJM \\ \{Day Ahead, Intraday, Balancing\} & Germany \\ \{Real Time\} & NSW \end{cases}$$

The superset of I is the set of selected reserve market segments in different geographies:

$$J \subseteq \begin{cases} \{RegA, RegD, SR, NSR, DASR\} & PJM \\ \{PCR, SCR+, SCR-, TCR+, TCR-\} & Germany \\ \{Lower, Raise\} \times \{REG, 6SEC, 60SEC, 5MIN\} & NSW \end{cases}$$

4.1.1 PJM

Organization of PJM power markets

Marketplaces Timeline

Players

A Load Serving Entity (LSE), as is defined officially by PJM, is "any entity that has been granted authority or has an obligation pursuant to state or local law, regulation, or franchise to sell electric energy to end-users that are located within the PJM RTO. An LSE may be a Market Buyer or a Market Seller"[?]. Therefore, LSEs refer to all market participants in PJM who have rights and obligation to act in all the power marketplaces of PJM, including the energy, capacity and ancillary services markets.

Curtailment Service Providers (CSPs) are members in PJM markets specializing in demand response. A CSP is an intermitted agency that provides the end-user DR to the wholesale market. [?] [?] The role of the CSP is actually a legacy product from the liberalization of retail markets in PJM. Once the retail competition began, PJM allowed LSEs to provide DR not only for their own customer but also for customers of other LSEs. The role of the CSP was created to facilitate the liberalization and competition. [?]

Balancing mechanism

submit offer - rebid - update information up to 65 mins - deviation charged with real-time reviewed the participation, violating -> suspend activity, enter enforcement

LSE obiligate to purchase (or self-schedule) reserve, obiligation as a proportion to its contributing flow to the grid. [?] This incents liquidity in the market with competitions on both buyer's and seller's side. However, the obiligation does not reflect their actual needs.[?]

CSP intermitted agency allowed to voluntarily respond to the LMP

PJM DR

PJM DR is the umbrella for all distributed energy resources, including DR, behind-the-meter generations, storage, etc. since PJM does not specify how the load is reduced. However, PJM DR program does not allow energy injection beyond the meter and receive wholesale compensation.[?]. This issue is currently under discussion in Special Market Implementation Committee meetings.

DR emergency fast changing over years [?] Since the DR in the wholesale market as a supply recouse will cause double payment issue where a customer may receive wholesale energy revenue and retail cost savings for the same MW of load reduction, PJM states that DR participation in the retail market on the demand side would be more ideal. And they are discussing to revisit the mechanism. Therefore, this value is not fully modeled in our study.

LSE buyer or seller in Energy, and reserve market

Identify business model

Accounting

The real-time market price is applied for all deviations from day-ahead planned schedule, including Regulation, Primary and Supplementary Reserves.

$$\pi_t^{e,j} = \pi_t^{e,i} \quad i \in \{Real\ Time\}, j \in \{RegD, RegA, SR, NSR, DASR\}$$

The capacity prices of reserves are computed using a complex algorithm, taking into account a list of specifications of the resrouce, e.g. the performance & historical performance, benefits factor, milleage, etc. The detailed calculations can be found in appendix. As outputs, we will get deterministic values for $j \in \{RegA, SR, NSR, DASR\}$, and the upper and lower bounds, $\bar{\pi}_t^{r,j}$ and $\underline{\pi}_t^{r,j}$, for $i \in \{RegD\}$.

4.1.2 Germany

$\pi_t^{e,i}, i \in \{Balancing\}$, is the the price for balancing energy (reBAP), which exist only in Germany

$\pi_t^{r,j}$ and $\pi_t^{e,j}$ are based on principle of pay-as-bid. The weighted-average values are available in the datasets.

Prices for balacning energy are unified across TSOs and determined according to the balancing energy price settlement system (BK6-12-024) developed by Federal Network Agency (FNA) as of 01/12/2012.

$$reBAP = \frac{\sum netimbalanceenergycost}{\sum netimbalanceenergyvolume} \quad (4.1)$$

4.1.3 Australia-New South Walse

The unit prices of reserve products, $\pi_t^{r,j}$ and $\pi_t^{e,j}$, are not available in datasets published by AEMO. Only weekly summary for total payment and recovery are provided. Due to the limits of available data, we are only able to perform calculations of total potential revenues, rather than thorough studies as in the other two geographies.

4.2 Accounting rules and data preparation

4.3 Results and discussion

Appendix A

Excess Data

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Bibliography

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