A Perspective on the Future Retail Energy Market

Michael Hoefling, Florian Heimgaertner, Benjamin Litfinski, and Michael Menth

University of Tuebingen, Chair of Communication Networks,
Sand 13, 72076 Tuebingen, Germany
{hoefling,florian.heimgaertner,menth}@uni-tuebingen.de,
benjamin.litfinski@student.uni-tuebingen.de

Abstract. Electrical energy will be more expensive and less predictable in the near future. A leading factor in this trend is the mass deployment of renewable energy sources. In this paper, we sketch the structure of the electrical energy grid and explain why power supply will be more demanding in the future. More volatile energy prices and small energy suppliers will create more activity on the retail energy market (REM). We present a perspective on the future REM that calls for communication support to satisfy the information needs of the market participants.

Key words: Smart grid, retail energy market, market structure

1 Introduction

Power generation is currently changing from a centralized system with predictable and controllable outputs to a system integrating distributed energy resources (DERs) including weather-dependent renewables. Such renewable energy sources are hard to predict and impossible to control [1,2]. There is strong societal pressure to protect the environment, explore cleaner alternatives to fossil fuels, improve energy efficiency, and reduce carbon emissions. The downside is that we will face variations in supply, with periods of higher or lower renewable energy offers. The deficit must be compensated by other, more expensive energy sources to avoid outages. This will affect future markets for electrical energy.

In other words, future prices for electrical energy will fluctuate more than today. Nevertheless, a normal household will still be able to buy electrical energy for a fixed price per period from a retailer, but at increased cost. Consumers may be better off buying power directly from prosumers or DERs than from retailers on the retail energy market (REM), thus taking advantage of lower prices at certain times, and possibly shifting parts of their demand to other times of day, which is a desired behavior [3].

Today, DERs like photo-voltaic (PV) panels or wind farms sell their generated power for a fixed, subsidized price. When the fixed-price contract model expires, they may sell their energy on the REM, too. As a consequence, the future REM for electrical energy will have many more participants and see more volatile prices than today, creating the need for new trading infrastructures [4,5,6].

2 Structure of Power Grids

Power grids are hierarchically structured. They can be divided broadly into three different domains: power generation, power transmission, and power consumption. In addition to the domains, there are four different voltage levels: extra high-voltage (EHV), high-voltage (HV), medium-voltage (MV), and low-voltage (LV). Substations transform between the voltage levels. Figure 1 shows the structure of a typical power grid.

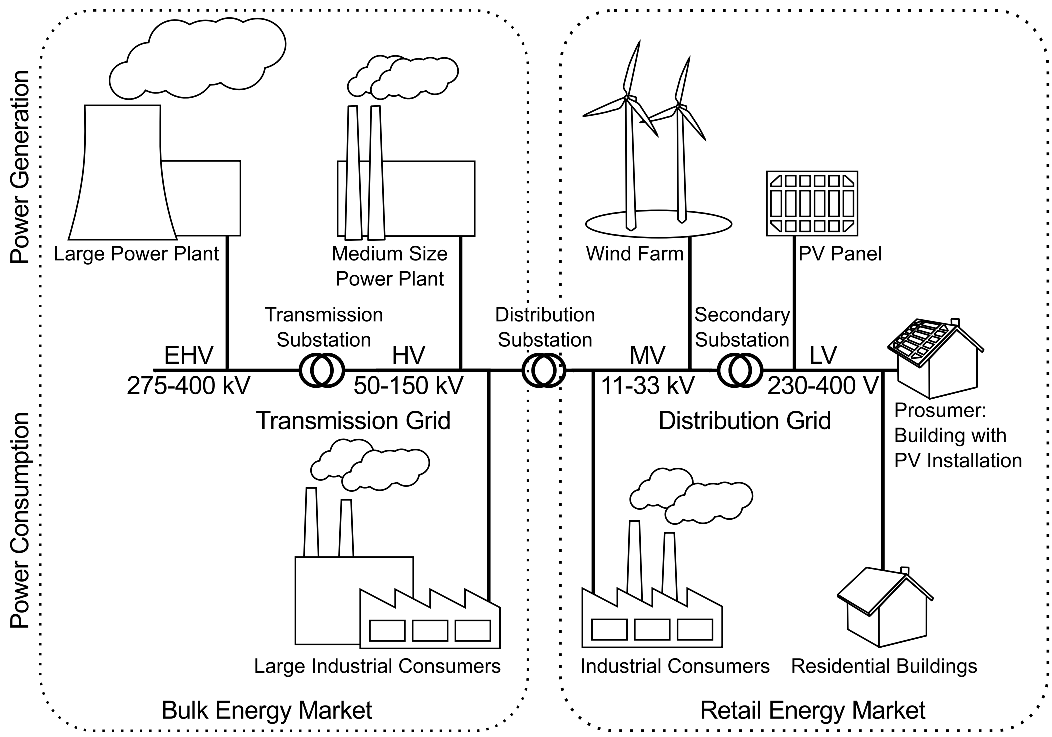

Fig. 1. The structure of a typical power grid including the general boundaries of the electrical energy market. Power is generated at the top, transfered over the transmission and distribution grid, and consumed at the bottom. Prosumers are positioned in-between the generation and consumption domain as they are part of both domains. Voltage levels decrease from left to right, i.e., from EHV level to LV level.

The *power generation* domain consists of power plants, e.g., coal, nuclear, or hydroelectric plants, but also DERs, e.g., wind farms or PV panels. The transmission grid transports power over long distances, sometimes even across international borders. The distribution grid facilitates regional distribution of power. Combined, both grids form the *power transmission* domain. The *power consumption* domain covers all service locations consuming power, e.g., industrial consumers and residential buildings. Prosumers are special entities since they belong to both the power generation and the power consumption domain. They may produce power and feed-in to the grid, but they may also consume power. The normal power flow is unidirectional: top-down from the generation domain to the consumption domain, and from left to right in the transmission domain, i.e., from EHV level to LV level. With the increasing number of DERs, bidirectional power flow inside the transmission domain is possible, e.g., from LV to MV level.

3 Today's Bulk and Retail Energy Market

We now take a closer look at today's electrical energy market and its market mechanisms. From an economic point of view, electrical energy is a commodity which can be bought, sold, and traded. Depending on which participants interact with each other on what voltage level, we differentiate between two markets: bulk energy market (BEM) and REM. Figure 1 illustrates the boundaries of BEM and REM. In practice, there is no sharp border between both markets.

The *BEM*, sometimes referred to as wholesale market, consists of three major participants on the EHV, HV, and MV level of the power grid: suppliers of energy, retailers, and large consumers. Competing suppliers of energy offer their electrical energy on the BEM to retailers or large consumers of electrical energy, e.g., aluminum plants. Large consumers buy electrical energy through the BEM directly. Energy trading normally takes place on trading platforms similar to the stock exchange. However, BEM transactions are also possible without involving a trading platform. An example for a BEM trading platform is the European Energy Exchange (EEX) [7], which spans Germany, France, Austria, and Switzerland. Typical time scales for BEM transactions on the EEX vary between hours and years.

The *REM* consists of two major participants on the MV and LV level of the power grid: retailers and clients. *Retailers* buy electrical energy on the BEM, and resell it through the REM to clients not participating in the BEM. *Clients* buy or sell electrical energy on the REM. Examples for clients are consumers, prosumers, and DERs. The

REM enables clients to choose their electrical energy supplier from competing retailers. In contrast to the BEM, energy on the REM is not traded directly between all participants but indirectly through the retailer. That is, clients can buy or sell energy only through retailers.

All transactions between consumers of energy and suppliers of energy on the REM are called retail energy transactions (RETs). Today's RETs include three consecutively executed phases: retailer selection by clients, delivery of electrical energy, and accounting for the delivered electrical energy. While the meaning of each phase is self-explanatory their exact realization in today's REMs is subject to country-specific legislations. Today's RETs are based on fixed-price contract models, i.e., a client buys or sells a certain amount of electrical energy at a fixed price per energy unit for a specified period on the REM. The time scale of today's RETs is given by the accounting period of the electricity contract, e.g., one month, one year, or even longer. However, no generally agreed fixed time scale for today's RETs is given in the literature.

4 Future Retail Energy Market

In the future REM, any participant will be able to trade energy. Instead of a fixed-price contract model, consumers will have dynamic pricing based on predicted supply and demand [3]. Electricity trading intervals will be on the order of minutes or hours, i.e., significantly shorter than today's accounting intervals [6]. As a consequence, the future REM will have many more participants and see more volatile prices than today. New trading infrastructures are necessary as enabling technology [4,5,6]. In the following, we briefly introduce the structure of the future REM, mention the concept of coalitions, and eventually sketch future RETs.

4.1 Market Structures

In the literature there exist various definitions of future market participants and their functions [2,4,6,8,9,10]. We provide a unified view thereof in Figure 2. The figure shows what a future REM may look like compared to today's REM. Besides additional participants, cash and energy flows, and communication flows will change. The future REM can be divided into five classes of participants: clients, aggregators (AGGRs), energy supply managers (ESMs), distribution system operators (DSOs), and regulators (not shown in the figure).

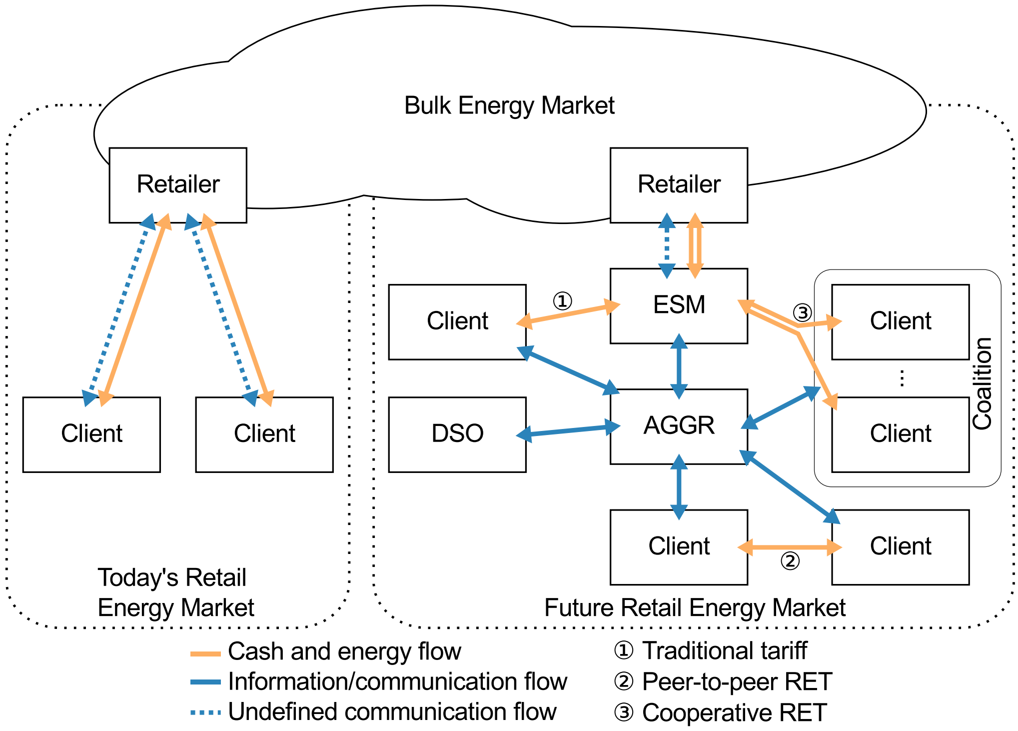

Fig. 2. Cash, energy, and communication flows in today's and the future REM. In today's REM, clients can only sell or buy energy through retailers. Trading between clients is only possible indirectly using retailers. In the future REM, in addition to traditional tariffs (1), AGGRs enable clients to directly trade their energy with each other (2). Groups of clients may form coalitions and participate in collaborative RETs (3), e.g., to maximize profit. ESMs guarantee energy balance inside distribution grids, while DSOs verify physical constraints of RETs.

Clients in the future REM cannot only buy and sell electrical energy from or to retailers, but they can also trade their electrical energy directly on the REM. They have to provide proper forecasts of their energy demand and supply, possibly based on weather forecasts if their power production is weather-dependent.

AGGRs supervise demand supply matching (DSM). They mediate between clients for DSM inside the distribution grid, and between clients and ESMs for DSM between the distribution grid and the transmission grid. AGGRs are the only authoritative entity in the future REM to initialize and supervise auctions, and they prevent trades that cannot meet physical constraints.

ESMs are responsible for balancing the energy in the distribution grid. For example, if the energy demands of distribution grids exceed their internal production, ESMs acquire additional electrical energy on the BEM to ensure proper energy supply in the distribution grids.

DSOs are control instances of distribution grids. They operate distribution grids and validate the outcomes of auctions, so-called power transaction plans. That is, if the outcome of an auction would lead to an unstable grid configuration violating physical constraints, the auction is invalidated and AGGRs may be asked to restart the auctions.

Regulators are independent authorities that determine or approve the electricity market rules, and monitor RETs to ensure compliance with regulations and rules.

4.2 Coalitions

Normally, each client acts as an individual participant in a RET. The minimum achievable profit by a single client is given by the so-called *self-value* [11]. The self-value depends on client-specific parameters, e.g., estimated weather-dependent energy production, or the geographical location of the client. The future REM introduces client coalitions to maximize client profits [11,12,13,14] or to create efficient virtual power plants [15]. Client coalitions are temporary groups of clients, not necessarily geographically close to each other, pursuing short-term common economic interests. Coalition formation is a distributed process which enables clients to find and agree on potential coalition partners. During coalition formation, each client calculates its self-value and disseminates it to all other clients through the AGGR. Coalition decisions are then made based on the self-values, i.e., each client independently determines whether a coalition with one or more clients matches its economic objectives.

From the market's perspective, coalitions are virtual clients with their own self-value participating in RETs. A virtual power plant is an example for such a client coalition, i.e., prosumers and DERs are aggregated into a virtual equivalent of a large power plant. Coalitions are included here because they are an active research area, but RETs are possible without coalitions as well, i.e., coalitions are an optional feature. We will use the term clients interchangeably for both clients and coalitions.

4.3 Future Retail Energy Transactions

The future REM supports three different types of future RETs: traditional tariff, peer-to-peer (P2P), and collaborative. Traditional tariff RETs are comparable with today's RETs based on fixed-price contracts. However, communication flows for traditional tariffs differ as shown in Figure 2. Clients communicate with retailers through AGGRs and ESMs. P2P RETs [4,16] are direct transactions between two clients which have been coordinated using the AGGR. Collaborative RETs [12,13,14,15] are transactions between coalitions and clients, or coalitions and coalitions.

In contrast to today's RETs, the retailer selection phase is replaced by a two-stage process consisting of *coalition formation* and *auctions* in future RETs. Coalition formation is optional as described in Section 4.2. The auction phase between clients is initialized and coordinated by the AGGR. That is, each client sends its demand and supply prediction to the AGGR which then matches the received demands and supplies. The outcome of the auction is a *power transaction plan* which is sent to the DSO for approval considering the physical constraints of the distribution grid. If the approval is successful, the AGGR sends a binding agreement to the clients. After the delivery of electrical energy, the accounting phase matches actual demands and supplies with their originally predicted values. Clients which did not fulfill their demand or supply prediction are penalized.

5 Conclusions

The evolution of power grids to smart grids leads to new technical, political, and economical challenges. In this paper, we presented a perspective on the future REM based on an extensive literature study. In Germany, projects like SESAM, DINAR and BEMI [5,8] already address energy control, management and trading. To enable the future REM, new trading infrastructures are needed. The FP7 project C-DAX [17] works on an information architecture for which the future REM is a use case. Further investigations of existing and future problems need interdisciplinary efforts of electrical engineers, computer scientists, and economists.

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