The Emergence of Consumer-centric Electricity Markets

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***Abstract*—After substantial changes in the generation mix brought by renewable energy capacities, and their impact on power system operation and electricity markets, it may now be the turn of electricity markets themselves to go through a profound evolution. The increasingly decentralized nature of power system management, combines with digitization, are favoring the emergence of so-called consumer-centric electricity markets in their various forms. We give here a high-level introduction to these markets. Based on recent developments and prospects from such structures, we believe that they will be a major component of future electricity markets.**

***Index Terms*—Electricity markets, prosumers, decentralized organization, peer-to-peer.**

I. Introduction

THE ENERGY TRANSITION towards a more environmentally friendly and sustainable energy system has reached a stage where renewable energy capacities deployed in certain countries and regions of the world are dominating the generation mix. China and other countries around the world are for instance installing new wind and solar power generation capacities at a pace that could not have been imagined (even though somewhat desired) even 10 years ago. This energy transition is more profound and fundamental than replacing generation capacities only, for instance due to a change in the centralized and top-down approach to power system management, to the electrification of the transport sector and to the liberalization of electricity markets (as illustrated in Figure 1). Lately, one is observing a rapid change in the way societal and industrial actors perceive how electric energy is to be produced, exchanged and consumed. For instance, large corporations like Facebook, Google and Apple are committing to procure 100% renewable energy for their operations. In a broader context, visions for sustainable future societies necessarily rely on greener energy [1]. Besides technology-based innovation, consumer engagement may be core to the energy transition. This led some to coin the term of “energy citizen” [2], a term that refers to the social commitment of individuals towards better energy usage.

If power systems and their management are to be more decentralized, and electricity markets liberalized, it is not far-fetched to think that all agents of these power systems could (and should) be able to interact directly and readily engage in energy transactions. This is especially relevant as the share of prosumers (i.e., agents that are able to both produce and consume electric energy) is increasing, also supported by residential and community storage systems. Alternative scenarios for future electricity market design accounting for these prosumers were recently covered in [3]. Such paradigm change is in fact extremely powerful since yielding a flexible platform for power system management, allowing for a wealth of new business models within the electric energy sector and beyond, e.g., with transportation and for integrated energy systems. This change is also supported by the need for consumers to become more flexible and proactive, in order to support integration of variable renewable power generation [4]. Consequently, we refer to this alternative organization as consumer-centric electricity markets, which in practice may take the form of peer-to-peer or community-based structures.

The idea of a direct interaction between actors of the power system has been around for a long time, but it was limited to the case of large actors engaging in bilateral contracts, in view of the high transaction costs involved. For its generalization to all actors of the system, the concept of multilateral bilateral trading (which we call peer-to-peer nowadays) was conceptualized and discussed nearly 20 years in [5] where the challenges stemming from the linkage with power system operation are stressed heavily. Today, advances in Information and Communication Technology (ICT) allow to think all agents may be able to seamlessly interact, negotiate and settle at very low transaction costs.

Our aim here is to give an overview of this transition towards this novel form of electricity markets, to explain how and why they are emerging as a viable and complementary approach to current electricity markets, and to eventually review promises and challenges with such peer-to-peer and community-based electricity markets. The paper is structured as following. Section II introduces the motivations, enablers and barriers related to consumer-centric electricity markets. Their organization and functioning is presented in Section III. The wealth of business models that may be thought of under this novel market paradigm is discussed in Section IV. Finally, Section V gathers a set of conclusions and perspectives regarding future electricity markets and their new consumer-centric component.

II. Motivations, Enablers and Barriers

The first enablers for peer-to peer and community-based electricity markets are of technological nature. Certainly the

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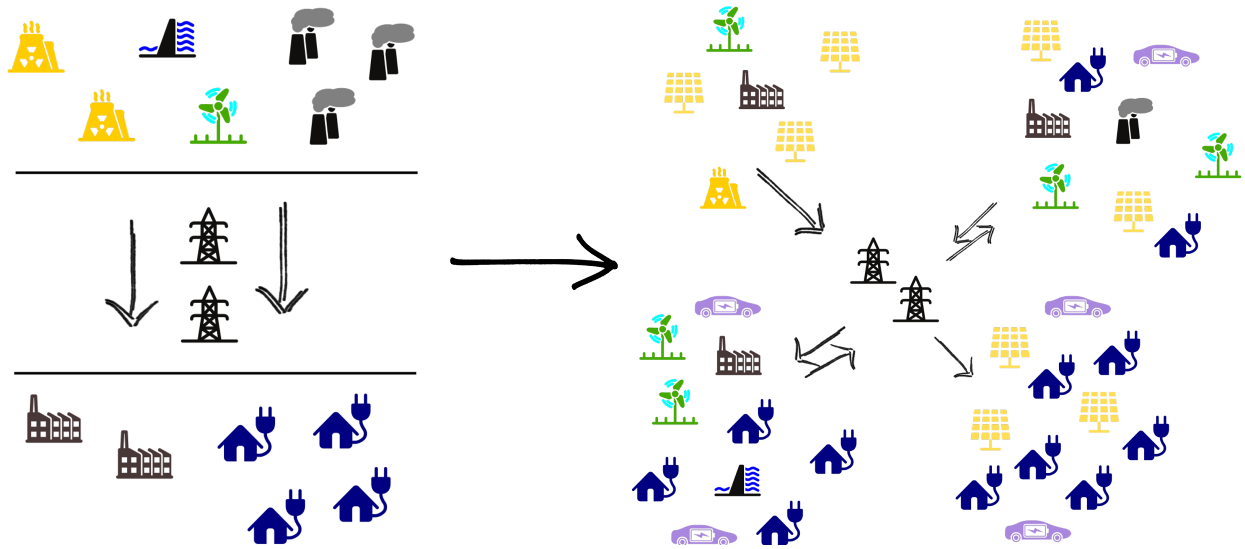

Fig. 1. Power systems are in transition from a top-down hierarchical setup to a decentralized setup. Future markets have to accommodate and adapt to this new reality.

deployment of distributed generation capacities supported the idea of rethinking electricity markets, but most likely it is the recent advances in ICT that make us believe new forms of markets could be designed and operated at low transaction cost. There has been a strong push over the last decade or so towards the proposal of various framework for the coordination of large numbers of heterogeneous components in future power systems. Most notably these framework proposals include transactive energy (see, e.g., [6]) and the energy internet (see, e.g., [7]). In both cases, even though these proposals are mainly for coordination purposes, these may be readily seen as supporting the proposal of new market mechanisms.

Besides these framework proposals, many are now considering the possibility of decentralized forms of electricity markets as blockchain has gone from the backbone for bitcoin transactions only to a generic decentralized platform for registering and settling transactions based on the so-called smart contracts. Numerous announcements are regularly made about engaging into blockchain-based experiments, from Maersk for the tracking of their shipping containers, to the Massachusetts Institute of Technology (MIT, Boston) to manage credentials and issue diplomas. Blockchain is a distributed ledger system, in the sense that instead of having a central entity being responsible for settling and archiving, this task is decentralized and relying on a number of entities that work in parallel with their own copy of the ledger. Blockchain-based platforms should in principle allow managing system without third-party supervision. For power system management, this would come with its advantages but also its caveats. A gentle introduction to blockchain, and to how the backbone of bitcoin is foreseen to have a bright future for many applications, can be found in [8]. Some argue that blockchain could be the true enabler for rethinking management of natural resources [9] including renewable energy [10].

Beyond the technological aspects, the prospect of truly establishing decentralized market structures has the potential of being a game changer for electric energy. The main benefit may be societal since allowing for better involvement of actors of the system at all levels. Especially, the fact that small actors at the residential level can directly and flexibly decide on how to source and share energy with others will increase their awareness level and motivate their contribution to the energy transition. By allowing for such direct interactions, it is highly likely that community-based systems will emerge. There is evidence that community involvement help with the local integration of renewable energy capacities and generation [11]. Ideally, we would like to find a balance between these local and community-based initiatives and the reliance on a top-down approach as we have today that requires significant grid infrastructure investments, as also foreseen by [12].

Even if they are relevant enablers and motivations for the proposal and deployment of peer-to peer and community-based electricity markets, there also are a number of barriers that exist today. For instance, the few systems that have been demonstrated so far for direct exchange of energy cannot involve monetary transactions, as in most countries that have regulated on integration of distributed renewable energy resources it is deemed illegal to directly sell the energy produced from these distributed capacities to others. This contrasts with the case of large renewable energy generation projects, for which Power Purchase Agreements (PPAs) allow for direct transactions between energy producers and consumers. In practice this means that actual demonstrations and projects have settled on the idea of using dedicated virtual and crypto currencies for their exchange. A well-documented and relevant example is that of the NRGcoin [13]. Possibly the most significant barrier to the deployment and adoption of these consumer-centric electricity markets relates to regulation, which is based on a long history of relying on a hierarchical and top-down approach to power system operation and market organization. Things could evolve rapidly though, as for the French example where a law passed early 2017 to support self-consumption

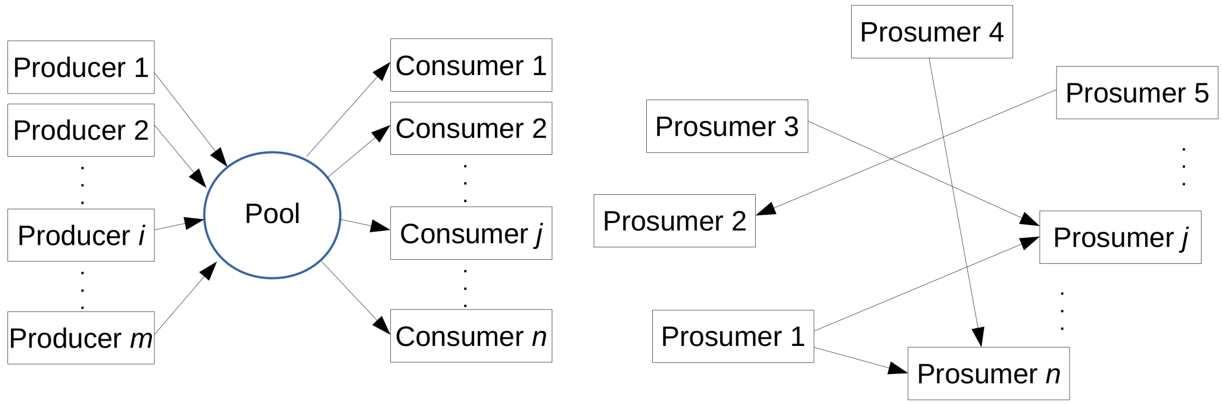

Fig. 2. Alternative organizations for electricity markets: from pool-based (left) to peer-to-peer (right) setups.

of renewable power generation as a community [14]. There to contain it to manageable levels, communities are to be located under the same electric bus and with a maximum installed capacity of 100kW. Since French households typically have between 6 and 15kW capacities, acceptable community sizes would be between 6 and 16 typical French households. Beyond these regulatory aspects, barriers may be of societal nature, as the nature and amplitude of the change may be too much for most small consumers. Similarly to the fact that most consumers stick to their historical power providers when electricity markets are deregulated, one would imagine that most consumers would have the tendency to prevent from transitioning towards this very novel system even if presented with all its benefits.

III. Organization and Functioning

In Europe, electricity markets take the form of pools, where producers and consumers meet through this central mechanism that yields an equilibrium price and a dispatch. More consideration is given to the technical characteristics of the assets (generation and transmission) in the US, though still within a centralized optimization framework. An overly simplified representation of a pool mechanism is given in Figure 2 (left). Markets participants do not interact with each other directly, since always going through this central market operator. In contrast, in a peer-to-peer setup, all market participants interact directly with each other, without the need for a central market operator, as depicted in Figure 2 (right). In that simplified representation, market participants are referred to as prosumers, i.e., entities that can both produce and consume electric energy. They do not have to be: such structures are generic enough to allow for all to interact similarly. In addition, arrows serve as a representation of the flows of energy from their source to their destination. For instance there, prosumer 1 is a producer only and providing energy to prosumers j and n, who are consumers only. In principle, one could imagine that any prosumer could exchange with any other prosumer, but in practice, exchanges will be limited based on technical constraints, preferences of the market participants, etc.

Besides the different way the market participant interact within these two market models, also implying different form of offering and clearing algorithms, there are other implications from going from pool-based and centralized market structures to peer-to-peer setups. Fundamentally, the most important of those is that in a pool-based setup, there will be a single price for electricity, to be paid by consumers and received by the producers. Electricity is there a non-differentiable product. However, in a peer-to-peer setup, there may be different prices for each and every trade since those comprise one-on-one transactions, as described in [15]. The fact that all market participants simultaneously negotiate with all others help prices to converge to the similar values, though these will reflect participants' preferences. For example, consider that one of these participants prefer to buy wind energy; another one favors local generation while a third one requires energy to originate from a given solar PV plant. A peer-to-peer setup then allows for product differentiation, which is at the root of many of the novel business models that may emerge in a near future.

Pool-based and peer-to-peer approaches can be seen as two extremes of a broad range of structures for electricity markets. Recently, Ref. [3] listed and discussed alternative organizations for consumer-centric electricity markets. These are mainly motivated by different grid and communication layouts for market participants. A first example is that for which only actors on the same microgrid engage in peer-to-peer trading, in line with the French setup mentioned before where actors of an energy community are restricted to be under the same electric bus. Alternatively, however, prosumers may organize in so-called energy collectives (illustrated in Figure 3) where these participants that engage in peer-to-peer trading are not doing so because of grid-related considerations, but owing to shared interests [16].

Whatever the type of consumer-centric electricity market, the fact that these rely on direct exchanges between each and every actor of the power system eventually allows mapping those exchanges on the grid and to possibly allocate grid costs in a dynamic fashion [17]. A consequence will consist in rethinking grid tariffs, with potential substantial impact on

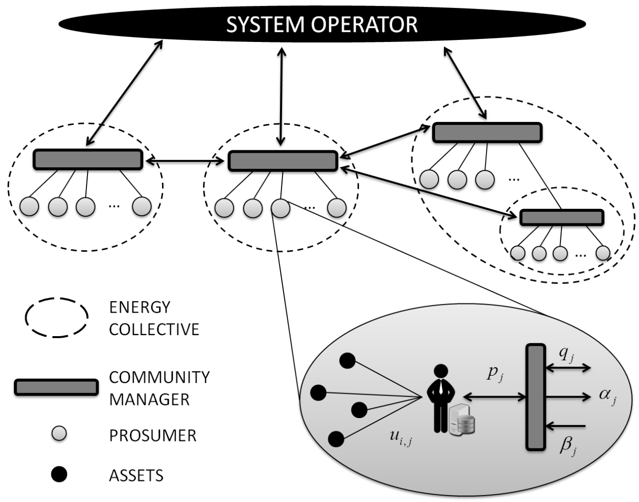

Fig. 3. Organizing prosumers in energy collectives.

the need for future electric power grid infrastructure.

IV. Wealth of Novel Business Models

Besides the promises of digitization in the electric energy sector, consumer-centric electricity markets have the potential to enable a large number of novel, and potentially disruptive, business models. These business models may have varied motivations and objectives, from increased resilience to increased usage of locally produced electric energy, and to improving customers' choice thanks to product differentiation.

Certainly the most iconic real-world deployment of a consumer-centric electricity market is that in Brooklyn in New York, aiming to manage the local power system as a microgrid and where all actors transact directly with each other [18]. There, even if resilience is the original driver after the damages suffered with the passage of hurricane Sandy, an additional affect is that of increasing awareness of local actors in terms of existing resources in the neighborhood, limitations from the grid and its management, as well as incentives for investment in distributed generation capacities and solutions. Similar motivations related to grid resilience exist in many other areas of the world and they will drive similar developments in, e.g., Australia, India, Brazil, etc. In the same vein, these deployment may transfer and increase responsibility in local grid developments in fast-developing countries like China.

In areas of the world where electricity markets have been liberalized for a while already, these developments make us rethink the hows and the whys of electricity markets. An example lies in the fact that the idea of pools and centralized electricity markets managed by market operators were acted a the way to manage and design markets at the wholesale level, even if some forms of bilateral contracts remained. However, a recent experiment called Enerchain looks at the possibility to operate within a blockchain-based peer-to-peer market at the wholesale level, hence removing the need for a market operator and allowing for more flexibility in the handling of large trades.

Going further than the wholesale level only, those concepts can extend seamlessly to all actors of the electric power system from large producers to small consumers and prosumers. There, consumers may directly choose the type and origin of their electricity, in a dynamic manner and based on their preferences. A result is that certain consumers have the possibility to only charge their electric car with solar power, certain households can source their electric energy from certain offshore wind farms (or their uncle's house), and groups of consumers may jointly invest in a community battery to serve as a buffer for their local production and consumption. It is actually difficult today to foresee the whole breadth of business models that could emerge thanks to such consumer-centric structures, both in terms of investment and in the day-to-day operation of the electric power system.

V. Conclusions and Perspectives

The electric energy landscape has been evolving fast owing to the deployment of distributed renewable energy capacities. The pace of this transition may even get faster thanks to the promises of consumer-centric electricity markets. A large number of challenges remain, however, related to the necessary adaptation of the regulatory framework, but also to a number of technical parameters like the necessary IT and communication infrastructure required for their functioning. Assuming that these challenges can be met, the deployment of these markets will have to be thought in a way that will prevent conflicts with existing wholesale-retail market structures and their historical actors, since these are key to a smooth and manageable energy transition.

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