Electricity markets overview – market participation possibilities for renewable and distributed energy resources

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***Abstract*—The main idea of the paper is to provide a detailed analysis of market set-ups in Europe, North America and Australia as well as to define obstacles and potentials for full market integration for renewable and distributed energy resources. Comparing rules and market operational principles from different continents, elaborated through examples of most evolved markets, indicates how different technologies could benefit from offering market products on multiple time frame basis. In this line, recent European documents set a framework for non-discriminatory access to market for all entities. Since benefits for new entrants are maximized in case of co-optimized participation in multiple markets, the paper discusses how implementing segments and concepts from USA and Australian markets could help in achieving this in Europe.**

***Index Terms*—distributed energy resources, electricity markets, renewable energy, market products.**

I. Introduction

A history of power systems stretches from the late 19th century. They expanded from small systems powering strings of lamps to large systems supplying vast areas such as European ENTSO-E power system that covers 35 countries and serves 500 million customers. Since the early stage of power system development, they have been managed by the vertically organized and highly monopolized public utilities. Generally, power generation was composed of large centralized thermal and hydro power plants connected to high voltage lines. Energy crises in the second half of the 20th century rose a question of energy resources scarcity and ever increasing prices. In order to give an answer to long-term challenge, the governments worldwide started integrating renewable energy sources (RESs) along with the power sector liberalization and restructuring. RESs integration opposes conventional thermal energy resources by introduction of sustainable energy generation while a creation of electricity markets brings private capital to, so far, mainly government-funded industry.

At the early stage investments in RESs technology were financially too intensive and unsecure. Therefore, additional remuneration to encourage investors was required. It was achieved by fixed feed-in tariffs payed to the RESs owners. Today, feed-in tariffs are no longer feasible and new policies to achieve the planned RESs share arise. The first steps are partially subsidizing RESs policies such as market premium payments or contracts for difference, where RESs sells their power as any other market participant but still receive additional remuneration up to some amount above the market price. However, non-dispatchable RESs generation causes two undesirable effects to power systems - additional variability and unpredictability. Increase in variability entails increased high-ramp flexibility requirements, while increase in unpredictability entails increased flexibility reserve.

In this paper, distributed energy resources (DERs) are perceived as grid users connected to distribution network capable to change their working point in response to market or network signals. DERs include demand response, electric vehicles, microgrids, energy storage, small-scale RESs etc. and they could complement large scale RESs in terms of power system flexibility. Both RESs and DERs should be able to participate in electricity markets on equal terms as conventional power plants. Due to DERs' specific features, several aspects of electricity markets should be observed in order to be able to facilitate DERs' participation:

- New products at power exchanges;
- Trading intervals time span;
- Gate closure times;
- Day-ahead and intraday market coordination;
- Electricity market and balancing market coordination.

This paper firstly analyses new market design proposed by the European Commission, then assesses the current market possibilities for RESs and DERs in organized markets around the world.

II. Clean Energy for All Europeans

The European Commission proposed a package of measures at the end of 2016 to maintain clean energy transition to low-carbon power system. The package is named "Clean

Energy for All Europeans" [1]. One of the guiding principles is that consumers and DERs will have the central role in the European energy market of the future. As a counterbalance to uncontrollable and weather conditioned generation from RESs, new players should be enabled to participate in the market individually or through aggregation and to provide ever more necessary flexibility to the power system.

In such DERs orientated day-ahead and intraday market, market gate closure time and bid sizes become extremely important. A higher amount of energy traded at anonymous-bidding organized electricity markets means less discrimination toward small capacity participants and an increase in their trading opportunities. A shorter gate closure time means a closer to real time trading which entails better balancing of RESs and higher flexibility value of DERs. A smaller bid size enables smaller RESs and DERs to participate in markets and to utilize their flexibility at a higher value. Therefore, the proposal of Regulation on the internal market for electricity [2] imposes minimum boundaries for both features. For example, for the gate closure time, Article 7 of [2] defines:"…as close to real time as possible…":

- "…at least as the intraday cross-zonal gate closure time determined in Regulation (EU) 2015/1222" [3]– where it says: "at most one hour before…"
- "…at least as short as the imbalance settlement period in both day-ahead and intraday markets."

In this document, strict rules are imposed for specific electricity market features mostly because the European Commission goal is harmonization of the national markets. In order to create a common electricity market stretching over European Union, minimum requirements should be met. The algorithm used for a single price coupling among national electricity markets is known as EUPHEMIA (stands for EU + Pan-European Hybrid Electricity Market Integration Algorithm). EUPHEMIA is used to calculate energy allocation and electricity prices across Europe, maximizing the overall welfare and increasing the transparency of the computation of prices and flows. In the coupled EU-wide electricity market, each member state will act as a bidding zone where cross-border interconnections act as borders (if there are structural congestions within member states they can be divided into more bidding zones, e.g. Germany).

III. ELECTRICITY MARKETS

Power sectors can be managed by the vertically integrated monopolies or they can operate as liberalized markets. Market-based power systems are organized as bilateral or pool-based with few consecutive markets: financial (long-term hedging) markets, day-ahead scheduling/markets and intraday markets (or real-time markets). Apart from energy markets, frequency control ancillary services, also called balancing services, can be acquired through a market mechanism. Balancing markets can be organized as separate markets or co-optimized with the energy market. Financial markets refer to hedging contracts not related to physical delivery of electricity and are out of scope of this paper.

Generally, day-ahead spot markets operate as follows: bids for power supply and demand are submitted and market clearing price is derived based on intersections of the supply and demand curves (demand curves are often forecasted). Balancing services can be marketed analogously. Bids for service provision are sorted in an increasing order constituting a supply curve. Demand curve represents service requirements. The crossing of the two determines the price of the service.

Intraday markets in Europe are usually continuous; the prices are set on a pay-as-bid basis for all transactions. Intraday market acts as balancing market to support day-ahead auctions. The prices for the same product may vary during the trading period. The following subsections describe several types of well-functioning markets throughout the world, more specifically in Europe, USA and Australia.

A. Europe

Each EU member state regulates its own power market, but the ultimate goal is coupling them into a single EU market. An important feature of national markets is possibility to trade both on bilateral basis and on the organized power market (power exchange, where transactions in a way create national electricity price) within the same geographical area. A metric called liquidity of organized power market can be used to determine a share of electricity traded in organized power markets in regards to the total system consumption. A higher market liquidity increases a market participation possibility for RESs and DERs. increase with. Table 1 shows liquidity of organized power markets in Europe.

Table 1 Liquidity of European Electricity Markets

Electricity market	**Countries**	**Liquidity**
Nord Pool	Nordic/Baltic	95 %
OMIE	Spain/Portugal	79 %
GME	Italy	68 %
EPEX UK & UK N2EX	United Kingdom	53 %
EPEX DE/AT	Germany/Austria	53 %
EPEX NL	Netherlands	39 %
EPEX CH	Switzerland	38 %
EPEX BL	Belgium	29 %
EPEX FR	France	23 %
CROPEX	Croatia	2%

Electricity markets and balancing markets in Europe are always organized as two separate markets. The main reason for such structure is existence of two separate entities for managing the electricity market operations – market operators, mostly in a form of power exchanges and transmission system operators (TSO) in charge of system balancing.

The so-called Nominated Electricity Market Operators (NEMOs) are in charge of organized electricity trading while TSOs are in charge of transmission grid and system balancing, i.e. organized balancing markets. Within a member state there could be more NEMOs (as competitors) and more TSOs (natural monopolies each operating a specific part of national transmission grid). More than one NEMO within a country brings competition between power exchanges and pushes them to increase efficiency of algorithms used and to design more flexible products. As examples of well-functioning electricity markets in Europe, Nord Pool and EPEX are analyzed in details.

B. Nord Pool

Nord Pool is a NEMO in 13 European countries, but it holds the strongest position in Nordic and Baltic countries – the joint Nordic/Baltic electricity market [4]. Because of network congestions, the market is divided into bidding areas (15 in total) where each of the areas can have different electricity price.

A day ahead market offers four different products:

- Single hourly order where market participant specifies the purchase and/or sales volume for each hour.
- Block order which consists of a specified volume and price for at least three (Nordic and Baltic region)/two (GB region) consecutive hours within the same day.
- Exclusive Group (Euphemia optimized) is a cluster of sell and/or buy blocks out of which only one block can be activated.
- Flexible order (Euphemia optimized) where a market participant can define the energy volume he is willing to sell or buy at a specified order price limit.

An intraday market offers four different type of products as well: 15-min, 30-min, hourly and block products.

Each TSO in Baltic/Nordic region oversees balancing of its area through proper allocation of balancing services. Even though they are currently developing a single Nordic Balancing Power Market [5], auctions are still organized separately in each country.

C. EPEX SPOT

EPEX SPOT is the most relevant NEMO in seven member states: Germany, Austria, France, Switzerland, UK, Belgium and the Netherlands [7].

A day-ahead market offers individual hours, block orders and smart blocks. Smart blocks can be linked block orders (a set of block orders with a linked execution constraint) and exclusive block orders (a set of block orders within which at the most one block order can be executed).

The intraday market products are in a form of single hour or block order in all countries except the UK. The UK intraday continuously offers half hour orders.

In addition to hourly day-ahead and intraday, Germany has also adopted a day-ahead 15-min auction after the hourly auction, while in UK half hour auctions are performed.

Generally, balancing markets are organized by each TSO separately. Germany was the first to introduce a joint tender for operating reserves. Each of the German TSOs, as well as Belgian, Dutch, French and Austrian TSOs' can take part in primary control reserve market. In addition, all German TSOs use a common tendering procedure for secondary and tertiary reserve. [8].

D. North America

The electricity markets in North America (USA and Canada) are organized either as traditional wholesale electricity markets or regional electricity markets [9]. Utilities in traditional markets are vertically integrated and customers are supplied based on regulated final prices and trading is achieved through bilateral transactions. Regional electricity markets are coordinated by regional transmission operators (RTO) whose tasks are both management of power grid and of power market. Even though bilateral transactions can exist in regional electricity markets, they are also managed by computer algorithms. Currently, there are seven RTOs in the USA (approximately 2/3 of the USA demand is supplied through RTOs) - CAISO, MISO, SPP, ERCOT, PJM, NYISO and ISO-NE and two in Canada - AESO and IESO. Each of these entities operates power system in their region, as natural monopolies.

Since USA RTOs are the entities in charge for market organization and transmission system operations, electricity and balancing services are often acquired through the same algorithm which co-optimizes electricity and balancing services procurement. This kind of procurement, due to its overall system requirements, increases total social welfare and utilization of system resources. Flexible resources are necessary to provide balancing services, hence mentioned co-optimization yields higher value to DERs. As an example of USA RTO, CAISO electricity market is elaborated in details.

E. CAISO

California Independent System Operator manages power system and organizes power market in the area of California and part of Nevada [10]. CAISO electricity market employs different rules and obligations for particular market participants.

Multi-stage conventional generators submit technical data such as maximum/minimum generation, ramp rates, minimum up/down time and economic data such startup and generation costs [11]. Day-ahead/real-time bids are submitted as a piece-wise linear curve with up to 10/5 different configurations. If a generator's minimum production is close to its maximum production it can bid as a constrained conventional generator [12].

Intermittent resources can participate in electricity market through *Participating Intermittent Resource Program* where

they submit their forecast in a real-time market without causing additional imbalance charges when they deliver the amount of energy different than forecasted [13].

Demand can also participate in a day-ahead, real-time and balancing market as a demand response or a participating load. Customers can bid their demand response services thorough a demand service provider and earn additional profit in a day-ahead and real time market. Participating loads can provide non-spinning reserve and demand reduction in the real time and balancing markets [14].

Storage units' flexibility provision can be obtained as a non-generator resource and a pump-storage resource. Non-generator resources can act as a generator or a load, depending on the system requirements and they can be dispatched over their entire capacity range. A pump-storage acts as a load when pumping water to the higher elevation reservoirs, and as a generator when generating electricity [14]. Pump storage participation data is similar as data for the multi-stage conventional generators.

Both day-ahead and real-time markets co-optimize electricity and balancing services: regulation up/down, spinning reserve and non-spinning reserve. Regulation is automatic secondary reserve, while spinning and non-spinning reserves refer to tertiary reserve.

F. Australia

Australian Energy Market Operator (AEMO) operates the National Electricity Market covering six states - Queensland, New South Wales, the Australian Capital Territory, Victoria, South Australia and Tasmania [15]. National electricity market is organized as a pool market. The rest of the country is supplied by vertically integrated companies or by trading through bilateral contracts (except WEM [16]). AEMO is both the power system operator and the market operator. Therefore, it organizes electricity and balancing markets.

AEMO calculates the electricity demand while generators are required to submit three types of bids: daily bids, default bids and re-bids. Daily bids can be regarded as a day- ahead market, while re-bids are in fact real-time market. Default bids, reflecting generators' marginal costs, are only active when no daily bids are submitted in order to maintain security of supply.

The biggest difference, as compared to the EU and USA markets, is that all bids re- submitted in 5-minute intervals, where spot price is calculated as a half-hour average of six dispatch prices during the previous intervals.

Balancing services, commonly known as Frequency Control Ancillary Services (FCAS), are organized separately from the electricity market as eight services: regulation FCAS raise/lower, contingency FCAS fast raise/lower (6 seconds), slow raise/lower (60 seconds) and delayed raise/lower (5 minutes) [17]. Offers and bids for FCAS services are defined by generators/loads capacity already allocated for energy generation or consumption. If system FCAS requirements are not met after all submitted bids, AEMO can make changes concerning accepted bids on electricity market in order to satisfy FCAS requirements. Therefore, this process can be seen as partial co-optimization between electricity and balancing (FCAS).

IV. COMPARISON

Bids in the EU and USA electricity markets are defined in a completely different manner. The European Commission, through the proposal of a new electricity package [1], promotes equality among all electricity market participants: conventional generators, RESs, DERs etc. A design of NEMO's is in accordance with Commission's new proposal, since the same products are available to different technologies. This means that NEMO's products are generally specified for all technologies and not technology-specific. Demand bids differentiate from supply bids in a negative sign in front of the bid. The RES also use the same products as the conventional generators despite the need to balance a difference between actually generated and forecasted generation.

The RTO design offers different programs/access for variable technologies. Conventional generators submit variable cost bids, whereas demand response bidders submit a range within which they can change their consumption. RESs do not offer bids in a conventional way, instead they offer their forecasted generation in real-time market where idea is to decrease their imbalance energy. The USA design does not promote inequality between different technologies, on the contrary, by developing more specific products it makes a market access easier for innovative market participants.

The day-ahead market in all three observed regions is similar in a way that bids (although differently observed) are submitted and market clearing price is set up for one day in advance (day-ahead market parameters can be seen in Table 2). The intraday and real-time markets are different in their approach. Some parameters are displayed in Table 3

Table 2 Market parameters comparison – day-ahead market

Electricity market	Gate Closure	Trading span	Bid size	Smallest bid span	Floor price	Price Cap
Nord Pool	12:00 D-1	24 h D	0,1 MW	1 hour	-500 EUR/MWh	3000 EUR/MWh
EPEX – Germany/Austria	12:00 D-1	24 h D	0,1 WW	1 hour	-500 EUR/MWh	3000 EUR/MWh
EPEX 30 min UK	15:30 D-1	48 half hour D	0,1 MW	30 min	-500 EUR/MWh	3000 EUR/MWh
EPEX 15 min Germany	15:00 D-1	96 quarter hour D	0,1 MW	15 min	-3000 EUR/MWh	3000 EUR/MWh
CAISO	10:00 D-1	24 h D	-	1 hour	/	$1000 /MWh
AEMO	12:30 D-1	24 h D	-	5 min	-$1000 /MWh	$12,500 /MWh

. Explored EU intraday markets use a continuous trading platform where bids for supply and demand are joint together and the price is determined on pay-as-bid basis.

On the other hand, USA (and re-bids in Australia) real-time market acts as a correction of the day ahead unit commitment decisions where only a redispatch of online participants is made in order to follow the actual power system conditions. A closer connection between day-ahead and intraday market in EU could bring more benefits to intermittent sources.

Co-optimization of electricity and balancing markets yields better utilization of the sources. However, precondition for such algorithms is a single entity in charge of both markets. In order to implement such algorithms in the EU, TSOs and NEMOs should work closely together. The first step could be, could be to integrate the Australian design, where adjustments in energy dispatch are made when insufficient reserve is allocated in balancing market.

A rationale behind German and UK second day-ahead auction is to introduce shorter term products in the market in order to allow better inter-hour balancing for intermittent RESs and DERs. The Australian case shows that 5-min based day-ahead bids and re-bids do not have negative impacts on the market operation.

Scarcity pricing is a very important feature for flexible DERs. In times of high flexibility requirements, the prices should represent real conditions not constrained by a market cap and a floor price. The price cap and floor price exist in all day-ahead markets, as seen in Table 2. The European Commission suggest their removal in [1].

Table 3 Market parameters comparison – intraday market

Electricity market	Gate Closure	Opening	Smallest bid span
Nord Pool – Nordic/Baltic	1 hour before delivery	After day ahead prices are set	15 min
Nord Pool – Germany	30 min before delivery	After day ahead prices are set	15 min
CAISO	75 min prior H-1	After day ahead prices are set	5 min
OMIE	5 min prior dispatch	After day ahead prices are set	5 min

V. CONCLUSION

European electricity markets are the most dynamic part of the modern power systems constant development, thus catching up with the state-of-the-art technologies and business concepts. Electricity markets worldwide have the same goal, to enable electricity dispatch under righteous prices both for producers and consumers, but the way they do that is often different. To find most suitable electricity market design for European markets in new RESs & DERs – orientated environment, knowledge and already tested concepts should be considered and applied. In general, market features which should be thoroughly analyzed in future works are 5–min bids, electricity and balancing services co-optimization, intraday market as redispatch of a day-ahead unit commitment, higher degree of deregulation, better adaptation of the bids to the different market participants etc.

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