

## AN ALTERNATIVE APPROACH FOR MARKET INTEGRATION OF DISTRIBUTED ENERGY RESOURCES

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### ABSTRACT

*Distributed energy resources present important economic and technical advantages for operation and development of power grid. However, the level of their deployment in power systems is still rather low. It is considered that one of the main reasons behind this is their poor integration in electricity market. This paper firstly analyses the main approaches currently being used to address the given problem, namely employment of virtual power plants and application of retail real-time pricing. As an alternative solution the paper then proposes a new framework for electricity retail, which among other benefits encourages new installations and effectively manages high grid penetration of distributed energy resources.*

### INTRODUCTION

Electricity is generated in large power plants and transmitted via high-voltage power lines over long distances. This power infrastructure requires significant capital investments for its renewal and expansion with aging equipment and growing electrical demand. As substitute means of power delivery are scarce and electricity consumption is inherently inelastic, the new investments have to be made in advance in order to secure power supply. The natural result is an economically inefficient utilization of the infrastructure. This explains importance of the research in the area of distributed energy resources (DER) aimed at creating the local alternative for electricity supply and increasing demand elasticity, which allow postponing the capital investments into the bulk power infrastructure. DER, in addition to their potential for improving economic efficiency of power system operation, also present significant technical advantages. In fact, DER proximity to the point of energy use allows avoiding transmission losses and increasing consumer flexibility. The energy efficiency benefits become indisputable when employing renewables and cogeneration. Despite the positive aspects, DER penetration into the power grid is still low. This is generally attributed to poor integration of DER into electricity market.

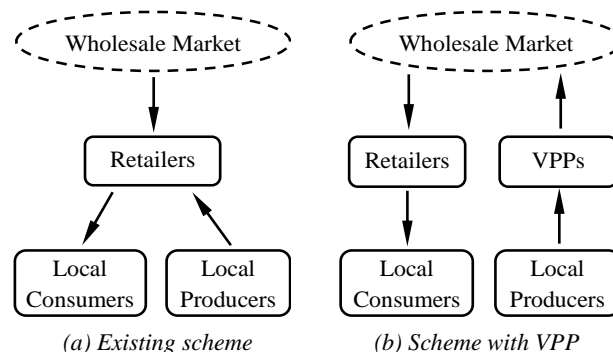
### CURRENT DEVELOPMENTS

The literature review on the issue of DER market integration shows that in most of the works the implied goal is to link DER with wholesale electricity market (WEM). And the two main approaches currently being promoted are based on virtual power plant (VPP) and real-time pricing (RTP). These techniques are briefly analysed below.

### Virtual power plants

VPP basically represents a group of the individual local producers with the total generation capacity sufficiently large in order to participate in the wholesale market as shown in Fig. 1. The given approach is advocated in numerous recent scientific publications, among which are, for example, the research papers [1]-[3] and technical reports from industrial projects [4]-[6]. Since at present small electricity consumers are aggregated and represented in the wholesale market by the retailers, it is logical to apply this aggregation principle also to the small producers by using VPPs. But, on the other hand such integration of DER into electricity market has a number of serious drawbacks:

- 1. Organizational inefficiency.** The equivalent trading procedure for electricity delivery between the local producer and consumer becomes more complicated. As shown in Fig. 1 in the existing retail market configuration (without VPP) the local electricity supply is accomplished only in two trading steps, whereas in the market framework with VPPs the number of these steps is doubled.
- 2. Potential misuse.** As the marginal costs of the small generators tend to be higher than that of the large power plants [7], DER cannot compete directly on a day-ahead wholesale market with generating companies. In most of the reviewed works this is acknowledged and the primary target area for DER integration is considered to be the balancing market instead [4], [6], which is more attractive due to its higher and volatile electricity prices. But the problem with DER participation in the balancing market is that it might encourage: financial speculations; use of inexpensive (inefficient) generators; and interest in having large imbalances between the supply and demand.



**Fig. 1.** Main trading steps for accomplishing local electricity supply.

**3. Implementation complexity.** VPP participation as one entity in the wholesale market requires a strong and fast communication infrastructure allowing automatic control of all its individual generation units across a wide area [8]. Considering large-scale and high dynamism of this system the other technical challenge is to develop effective and reliable control algorithms [9]. Also, VPP implementation is impeded by a number of still unresolved organizational issues, particularly concerning bidding procedures, remuneration mechanisms and interaction with distribution network company in view of shared resources [2], [9].

**Real-time retail pricing**

RTP represents one of the time-varying pricing schemes and involves applying to the retail customers the pricing linked to the current or anticipated wholesale market prices. Numerous studies give preference to RTP as it provides symmetric treatment of load and generation in electricity market and increased elasticity of consumption [10], [11]. In this paper, we agree that the retail prices should be dynamic and should reflect the variations in electrical demand and supply. But, we believe that the current approach to implementing this by simple relaying the wholesale electricity prices to the retail customers is not adequate. The first reason is that RTP leads to distortion of natural load diversity and might provoke unexpected peaks in daily electricity consumption which in turn creates the risk of market price instabilities [12]-[14].

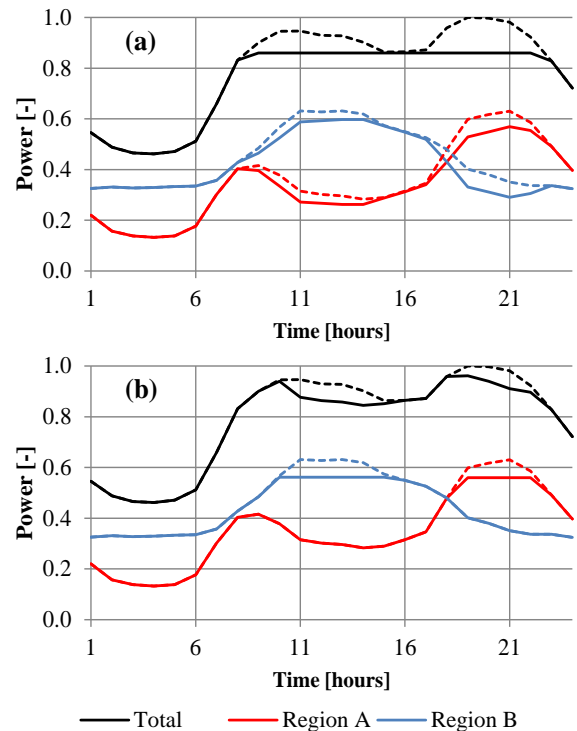
The second reason is that the given approach does not allow capturing the regional differences in daily demand profiles, which are important for providing adequate investment signals [14], [15]. A simplified demonstration of this point is given in Fig. 2. The example shows that when DER is employed only based on the global power supply conditions (as in case of retail RTP), the capacity utilization on the local level might reduce. And however, if DER development is driven entirely by the regional grid limitations, the global use of the power infrastructure might become less efficient. Therefore a certain compromise between these two extreme cases is required in order to assure adequate expansion of DER.

**PROPOSED GENERAL FRAMEWORK FOR ELECTRICITY RETAIL**

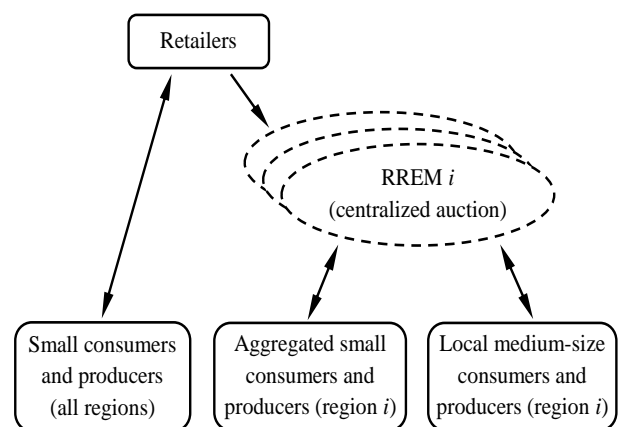
**Description of the framework**

In comparison with the existing works where the implied goal is to link DER to the wholesale market, in this paper the problem is defined as how to organize the electricity retail market so that it responds better to the conditions in WEM and encourages DER penetration. Also, in order to avoid the shortcomings of the current developments, the two conditions are adopted for DER market integration: 1) local trade and consumption of the locally generated electricity; and 2) indirect coupling of the retail and wholesale market pricing.

The new framework for electricity retail is based on splitting the national distribution grid into several geographic regions considering techno-economic aspects and creating in each of them the regional retail electricity market (RREM) coordinated by the local distribution system operator (DSO), an independent entity with the functions similar to that of transmission system operator (TSO) in WEM (Fig. 3).



**Fig. 2.** Effect of centralized (a) and regional (b) dispatch of distributed generation on the local and total demand profiles. In the example the distributed generation capacity in each region is 7% and it is used for peak load shaving only. The corresponding initial load profiles are shown in dashed line.



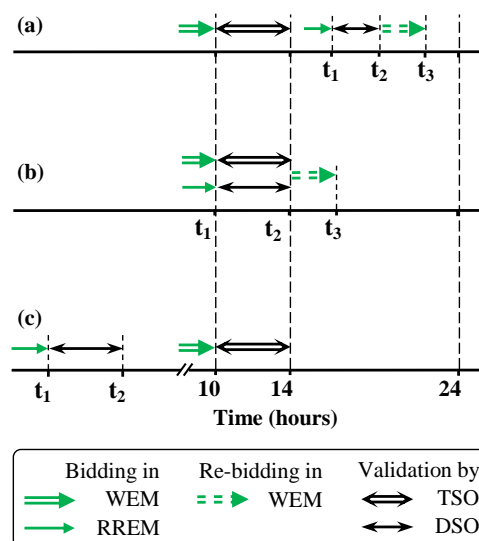
**Fig. 3.** Proposed new framework for electricity retail.

Electricity on retail level now is traded not only through bilateral contracts, but also through the regional day-ahead market. The retail market price for the given trade interval in RREM is determined based on the selling and purchase bids from retailers, local medium-size producers and consumers, at intersection of supply and demand curves, in similar way as in WEM. As participation of the local medium-size producers and consumers in RREM is essential for proper operation of RREM we assume that they are obligated to participate or have high incentives to do so. In case of the small consumers (producers), it is assumed that they are free to choose between setting up bilateral contracts with the retailers or to buy (sell) their electricity in RREM through local aggregators (Fig. 3).

The wholesale of electricity in general remains the same except that the participants of WEM, especially the retailers, will now have to and be able to take into account also the current situation in RREMs when preparing their bids. The main question here is how to schedule different stages of electricity trade in RREM with respect to the market operations in WEM. On the one hand, since the retailers need to know their supply volumes in RREM before preparing the wholesale bids, it seems logical to have the retail markets cleared first. The setback in this case is that the bidding in RREM is done almost two days ahead of the electricity delivery (Fig. 4c). On the other hand, when the wholesale precedes the retail trading we can have more rapid demand response, but in a view of the shortage of time available for all involved operations in RREM it might be difficult to implement (Fig. 4a).

The other option is, of course, to implement the electricity wholesale and retail simultaneously (Fig. 4b). The advantage in this case is that it guarantees more or less equal opportunities for both RREM and WEM participants in doing their price forecasts and also gives possibility for the retailers to update/correct their wholesale bids in the intraday market once both WEM and RREMs are cleared. In the present paper the preference is given to this approach considering the relative simplicity of its implementation.

The main trading steps in the electricity market based on the new retail framework and parallel operation of WEM and RREMs can be described as follows. As shown in Fig. 4b, in the first step, the market participants submit to TSO and local DSOs (or other independent entities) their purchase and sale bids for each trade interval of the next day. The retailers are the only actors in this case who participate on both market levels. Starting from 10:00 when the bidding gate is closed, the system operators process the received bids and check that the volumes of electricity offered and requested for each trade interval at different parts of the power grid can be physically transferred without compromising the overall safety and stability of the grid. At this stage TSO have the possibility to exchange with local DSOs relevant information in order to improve the accuracy of the results. At 14:00 the wholesale and regional markets prices are cleared and the system operators announce to the



**Fig. 4.** Relative scheduling of trading steps in RREM and WEM: a) retail following wholesale; b) retail in parallel with wholesale; c) retail preceding wholesale. The start (10am) and end (2pm) of TSO validation process in WEM are according to [16]. The corresponding time-points for DSO validation step ( $t_1$ ,  $t_2$ ) and the end of re-bidding in WEM ( $t_3$ ) are shown approximately.

corresponding market participants the scheduled generation and consumption profiles for the next day. From this point starts the final re-bidding process in WEM, which allows the retailers to update the wholesale bids, since now they know the exact volumes of their electricity supplies to RREMs. As an alternative, the re-bidding on the wholesale level can be also accomplished in intraday market when available.

It is important to note that in the provided description of the new arrangement of electricity retail we assume that in RREM the purchase and sale bids are submitted one day ahead. In general, the retail bidding process can be performed, of course, less frequently than on a daily basis, while employing the same trade intervals (one or half-hour) in both RREM and WEM. This way one can simplify the billing procedure and reduce overall administration costs related to electricity retail.

### **Benefits and impact**

The implications of the new retail arrangement are profound for operation of the involved actors, particularly for the medium-size customers and retailers. As one can see, the former now have to buy or sell their electricity in the regional retail market which fundamentally changes their approach to planning and control of electricity consumption and generation. And the latter obtain possibility to compete on regular basis for supplying the electricity volumes, liberated from the bilateral contracts and thus would be required to modify their trading strategies.

The proposed retail framework clearly provides improved coupling between the wholesale and retail electricity markets and thus allows increasing long-term price elasticity of electrical consumption on a wholesale level. The particular benefits of the new retail structure in integrating DER into electricity market are as follows:

- Direct access to dynamic electricity trade for medium-size DER
- Organizational and technical efficiency of the local electricity supply. As electricity from DER is traded and consumed locally, naturally this allows simplifying the overall trading procedure and reducing the power losses in distribution lines. Besides, when bidding in RREM, medium-size (non-aggregated) consumers have to predict with certain accuracy their daily demand profiles and this requires them to have more extensive knowledge about their electricity consumption which obviously can assist in detecting possible energy inefficiencies.
- Provision of adequate investment signals. Different price levels in regional retail markets obviously encourage the capital investments where they are most needed. For instance, a region with low electricity prices would attract new loads, whereas in a region with high prices it would be appealing to invest in new DER and transmission capacity.
- Reduced requirements for communication infrastructure. Since RREM participants submit their sell and purchase bids to the local DSO only on daily or less frequent basis, information exchange in this case can be done using the existing communication facilities.
- Promotion of energy flexibility among the retail customers. In order to deal with demand uncertainties and decrease the consumption at the peak electricity prices the consumers are encouraged to install their own energy generation and storage capacity. Integrating DER by consumer to cover its own electricity demand is clearly advantageous because local electricity generation in this case does not require performing separate trading operations and from technical point of view also allows less "intelligence" in distribution networks.

## CONCLUSIONS

The main trends and leading developments in DER market integration were firstly addressed and analyzed. The authors proposed, as an alternative solution, a new general framework for electricity retail which assumes creation of regional retail markets operated on dynamic pricing schemes. These markets are similar to those of wholesale energy market and have the retailers and the local consumers (producers) among their main participants. Among other benefits it was demonstrated that the new retail arrangement encourages effective management and enables further penetration of DER.

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