A Review on Coordination Schemes Between Local and Central Electricity Markets

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***Abstract*—A Local electricity market (LEM) is a market place for trading the electricity produced and consumed locally while ensuring the security constraints of the distribution grid. Moreover, LEM acts as a mediator for participation of distributed local resources into the central electricity market (CEM) by facilitating the communication to CEM. However, effective utilization of local resources in the system necessitates effective coordination between the LEM operator (e.g., DSO) and the CEM operator (e.g., TSO) because these resources can potentially be used both locally and system-wide. In this paper, we review different coordination schemes in this regard. Coordination schemes are categorized as DSO leader, DSO follower and TSO-DSO iteration. Independent local market design with no coordination is also reviewed.**

***Index Terms*—Local Electricity Market, Distributed Energy Resources, TSO-DSO Coordination.**

I. Introduction

Electricity power systems are expected to be highly penetrated by distributed energy resources (DERs) from renewable generation and flexible loads, which are located mainly in distribution grids. As these resources grow, the transmission system operator (TSO) will start procuring balancing services from distribution grids [1]–[4]. In this paper we focus mainly on balancing markets. The market traditionally operated by the TSO, is called in this context central electricity market (CEM), in order to distinguish it from the emerging, locally-oriented electricity markets. Participation of DERs as numerous new players in the CEM while maintaning secure operation of the power system are facing two challenges: 1- a central communication hub needs to be installed for providing market participants a platform for receiving/sending information from/to the central electricity market, 2- a global system operator needs to be implemented that monitors both the transmission and distribution systems. However, neither existing nor emerging centralized market clearing approaches can be feasibly extended to manage the communication and security requirements of DERs and flexible loads in distribution systems [5], [6]. Nevertheless, more transparent real time-prices down to the final nodes where DERs, flexible consumers and prosumers are located is a key factor to stimulate participation of local resources, either individually or through aggregation, and make the electricity system more able to integrate electricity from renewable energy sources. Studies on proposing trading strategies for DERs under current market mechanisms can be categorized in two groups, according to whether an energy aggregator (EA) exists [7]–[10] or not. Some of the EAs may own distributed generation (DG) or electrical storage systems (ESS) to hedge against risks [11]. However, this attribute results in problems regarding allocation of profits/costs among players, as well as computational difficulties introduced by the increasing number of players.

In addition to this, distribution networks are designed to transport electricity from transmission grid to end customers with minimal levels of control. The Energy Transition involving the introduction of DERs, DGs, prosumers in the distribution grid, i.e., distributed players, which is increasing and is expected to further increase [12], requires distribution system operators (DSOs) to actively manage congestion in their grids. Otherwise, the conventional "fit and forget" approach requires huge investments in expansion of distribution grids [13]–[16]. Allowing DSOs to manage some of the challenges associated with variable generation more locally (e.g. by managing local flexibility resources) could significantly reduce network costs. Performing this by DSOs requires DSOs' neutrality in their new functions, e.g. in terms of data management and using flexibility to manage local congestions [17].

In order to facilitate the direct (not through EA) participation of local resources in the electricity market while ensuring the security of the distribution grid, local electricity market (LEM) is considered as a solution [18]–[24]. In this new framework, LEM is seen as a mediator between CEM and DERs and producers/consumers in the distribution system. An overview is provided in Fig. 1.

However, as these resources can potentially be used both locally and system wide, effective coordination between the central and local system operators and markets is crucial [16], [16], [25]–[28]. ENTSO-e emphasizes the need for system operators interaction with respect to the exchange of data, operational procedures, and market design [25]. The need for coordination is more emphasized considering the liberalization regime enacted in the EU's Third Energy Package (2011) that imposes the separation between trading functions and transmission and distribution operator entities [29].

The literature on coordination between local and central markets is limited [30]. The existing research so far has focused more on the impact and possibilities of distributed players to provide services from the distribution grid to sys-

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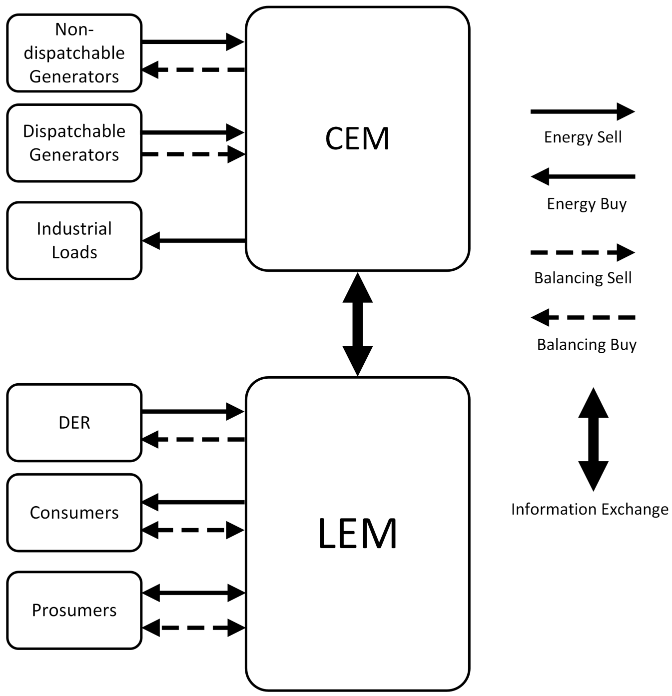

Figure 1: Market framework with local and central electricity and ancillary service markets.

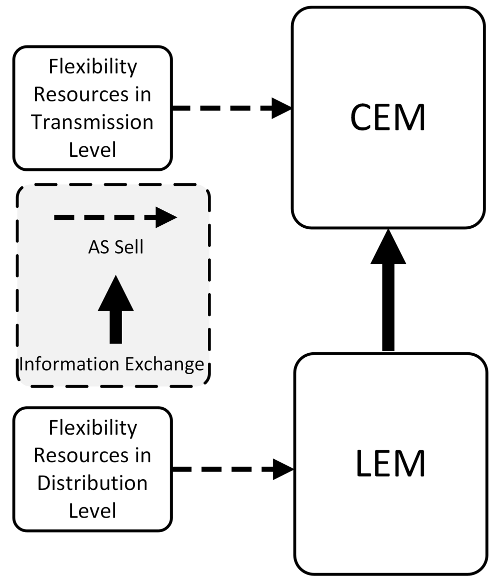

Figure 2: Local AS market model [34].

tem operators, e.g., pricing mechanisms and the relationship between the aggregator and the DSO [31]. To encourage the research in local and central markets coordination, in this paper, we review related publications and proposed coordination schemes both in academic and real-world systems. Each coordination scheme will determine the operational processes and information exchanges between system operators with respect to market design and security of the system. Moreover, we investigate the advantages and disadvantages of each coordination scheme. Note that, for simplicity, in the rest of this paper, grid operators are also considered as market operators

II. Local Electricity Market

In this section, different coordination schemes between local and central electricity markets and their related operators, i.e., DSO and TSO, is discussed.

A. DSO Leader

1) Non-strategic DSO: In the approach proposed in [32], [33], DSO moves first and clears the local market, then, if the demand cannot be fulfilled or there is supply that cannot be consumed, i.e., if the order book is not completely cleared, the DSO imports or exports electricity from higher voltage grid levels.

Similarly, in the local ancillaty service (AS) market model proposed in [34], DSO has the priority over the TSO for the allocation of flexibility resources from the distribution grid. After solving local grid constraints, DSO aggregates and offers the remaining bids to the TSO. This corresponds to Fig. 2.

In this scheme, a trading platform operated directly by the DSO or in collaboration with the DSO needs to be implemented. As an example, in the Netherlands, a platform to trade customers self-generated power has been implemented, in which the trade happens between peers under certain contracts [35]. The concept of Distributed System Platform Provider (DSPP) [1] for utilization of distributed energy resources (DERs) is introduced in the US, as addressed in the New York Reforming Energy Vision (NY REV) [37]. The concern about a non-strategic DSO leader is that there is no guarantee that the resources are used optimally throughout the whole system.

2) Strategic DSO: Reference [36] proposes a methodology to optimize the trading strategies of a profit maximizing proactive distribution company (PDISCO) in the real-time market by mobilizing the demand response. While this is not in line with EU regulation, a separate entity from the DSO could take on the role of PDISCO to manage the distributed resources, and coordinate with the DSO to respect network constraints and provide congestion management services. The PDISCO renders continuous offers and bids strategically to a transmission-level real-time market, e.g., the CEM in this survey paper. Modelling of PDISCO together with profit maximizing distributed generation is presented in [38]. PDISCO in this framework is basically an aggregator that acts in the wholesale market by finding the best aggregated offer based on the individual offers received from the DGs while respecting the network constraints. Thus, the upper level problem is DGs profit maximization and the lower level problem the PDISCO's offers to day-ahead and real-time markets. However, it is modelled the other way around in [38]. Also, the fair allocation of profits/costs among resources available to PDISCO is another concern about this approach. In general, this concern arises about all approaches that consider a type of aggregator acting

[1] The distribution company (DISCO) can bee seen as a DSPP [36].

on behalf of resources in the distribution grid.
A similar approach to a European local market is seen in [39]. This paper proposes a new market player role titled smart energy service provider (SESP), a communication platform that would facilitate trading and scheduling of energy, flexibility and other services to all members of a local community. The SESP supervises the local market operations with the aim to maximize social welfare for its members, while also acting as an aggregator able to participate in wholesale markets for supplementing its local market operations. The SESP essentially represents a peer-to-platform (where direct negotiations between traders are not allowed) approach which alleviates the transaction-related burden on each trader. The local market supports trade of end-user flexibility for the benefit of the DSO and its operations for managing grid bottlenecks and providing power curtailments under request. The local market also supports power system balancing in the TSO's central market.

The concern about strategic DSO leader is difficulty in reallocation of the benefits among local resources. In addition to this, DSO acting as the only strategic aggregator in the distribution grid might create large market power for the DSO and this can hamper the competitiveness of the electricity market.

B. DSO Follower

In this scheme, CEM is the first mover and fixes the price or quantity of the power in the connection point between the transmission and distribution grids. Then, LEM dispatches the local resources.
As an example of fixed price in the connection point, in reference [40], the LEM operator maximizes the social welfare in the local area based on the offering/bidding parameters (prices and amounts) from different players and CEM day-ahead prices in the connection point of the distribution and transmission systems.
As an example of fixed quantity in the connection point, reference [41] proposes to let the TSO coordinate the generation in the temporal dimension while the DSO optimizes the spatial distribution of EVs through controlling the charging and discharging schedules of the EVs. Also, in the local AS market model proposed in [42], first, the transmission level imbalances are supplied using the ancillary services capacity of the balancing resources in the distribution grid and then, fixing the amount of real power injection from/to the transmission to the distribution grid, the imbalance of the distribution grid is supplied using the remaining capacity of the local resources. By contrast, the shared balancing responsibility in [34] requires that the TSO clears transmission-level imbalances by using transmission level resources only, and the DSO clears distribution-level imbalances by using distribution-level resources only. The injection to the distribution network is fixed to the result of the TSO imbalance clearing.

The disadvantage in DSO follower scheme, as was the case in the non-strategic DSO leader scheme, is non-optimal utilization of local resources throughout the whole system.

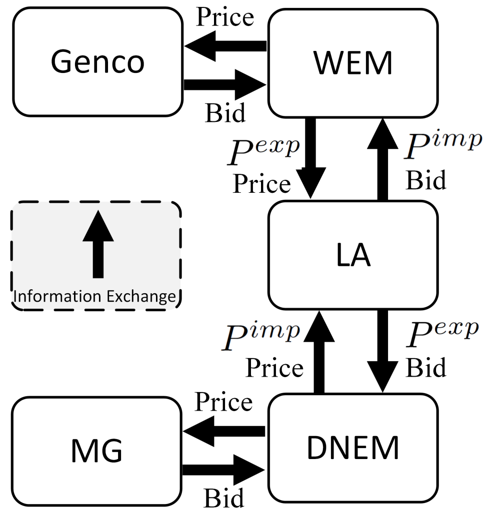

Figure 3: The hierarchical electricity market structure with LA [43]. LA: load aggregator, DNEM: distribution network electricity market, WEM: wholesale electricity market, MG: micro grid.

C. TSO-DSO Iteration

Reference [30] proposes a hierarchical coordination mechanism for coordinating the economic dispatch of TSO and DSO. The proposed hierarchical coordination mechanism works by iteratively communicating the generalized bid function (GBF) from DSO to TSO. GBF is the Benders cut in Benders decomposition formed from the AC OPF of the distribution network by the objective function of minimizing the dispatch cost of the local DERs. In other words, GBF builds a linear relation between the dispatch cost in the distribution network and power transferred from the distribution network to the transmission network.

A similar paradigm is described in the Decentralized Common TSO-DSO Market Model in [42], where a residual supply function is passed to the TSO for solving the balancing problem.

Defining a new entity for the coordination of local and wholesale electricity markets in [43], load aggregators (LAs) – similar to Energy Aggregators elsewhere in this paper – are considered as brokers who participate in the distribution network electricity market (DNEM) – similar to LEM in this paper – settled by the DSO, and wholesale electricity market (WEM) – similar to CEM – settled by the TSO. This is represented in Fig. 3.

The LA acts as a broker playing two different roles: 1) buy electricity from the WEM, P^{imp}, and sell the same volume to the DNEM, if the price on the LAs bus in the WEM is lower than that in the DNEM; and 2) purchase electricity from the DNEM, P^{exp}, and sell the same volume to the WEM, if the price in the DNEM is lower than the price on the LAs bus in the WEM. The bidding strategy of market participants and LAs is updated iteratively until the convergence criteria are satisfied. Reaching this point, the action of LAs, i.e., whether there is import or export from/to distribution system and the related bidding is found.

Although the approach proposed in [30], [42], [43] is mathematically valid and interesting, having an iterative platform between TSO and DSO for finding the optimum dispatch is difficult to implement, from a computational and administrative viewpoint.

Table I summarizes the roles of DSO and TSO in local and central electricity and AS markets, their different coordination schemes, and their respective advantages and disadvantages.

III. Independent Local Electricity Markets

In this section, independent LEM designs are reviewed. In this type of LEM, there is no coordination with CEM.

Distribution grid capacity market where capacity is allocated to aggregators and consumers with an optimized price is considered as a solution for congestion management in distribution grids [44]–[46]. In this way, DSO raises the network capacity tariff if network constraints are not respected. Asymmetry between the capacity market and the energy market due to the lack of information about the other commodity is a major problem in efficiency of introducing capacity markets [47].

Moreover, different forms of market solutions for distribution system AS have been suggested in literature, e.g., a spot market for voltage control [48], different types of auctions for long-term capacity contracts with DER to handle distribution grid overloads [49], a marketplace where DSO can procure various flexibility-based services for managing congestions caused by overload and voltage oscillations [50], [51]. For example in [51], DSO clears flexibility services through a flexibility clearing house named FLECH. The FLECH market and the existing markets coexist in time and space focusing on different issues of congestion and balancing, respectively. DERs, therefore, can play both in FLECH and in the wholesale market in parallel. This framework ignores the fact that the flexibility resources can be utilized both for the distribution level and the system level services. Moreover, the parallel framework results in price inconsistency between the resources offered in FLECH and the whole-sale market.

IV. Conclusion

Derived by the necessity of developing local electricity market (LEM) due to the integration of distributed energy resources (DERs), flexible consumers and prosumers in distribution grids, in this paper, we reviewed different types of LEMs with focus on coordination schemes between the LEM operator (e.g., DSO), and central electricity market (CEM) operator (e.g., TSO). The coordination schemes are categorized into: DSO leader, DSO follower and TSO-DSO iteration. Beside this, a few variants of the independent LEM scheme are also reviewed.

According to this review, the coordination scheme that utilized the resources both locally and system wide and therefore, results to a higher social welfare is TSO-DSO iteration scheme. However, having an iterative platform between TSO and DSO for finding the optimum dispatch is difficult to implement, from a computational and administrative viewpoint. On the other hand, DSO-leader and DSO follower schemes have easy operational process although the resources are not utilized optimally in the system in these schemes.

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Table I: A Summary of Different Coordination Schemes

Coordination Scheme		Role of DSO	Role of TSO	Advantage(s)	Disadvantage(s)
DSO leader	Non-strategic DSO	LM operator Mediator between DERs and TSO	CM operator	Easy operational process Transparent LM	DERs not optimally utilized in the system
	Strategic DSO	LM operator Acts as an aggregator in CM	CM operator considering the strategic bids from DSOs	Social welfare of distribution system is maximized More resources are utilized and allocated	Creates market power for DSO Difficulty in reallocating the benefits among local resources
DSO follower		LM operator	CM operator DSO import/export power to/from TSO	Easy operational process	DERs not optimally utilized in the system
TSO-DSO iteration		LM operator Communication with LM	CM operator Communication with LM	Social welfare of the whole system is maximized Optimal use of DERs	Heavy operational process Deadline for finishing the market clearing process might be endangered by this process

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