Designing a Distribution Level Flexibility Market using Mechanism Design and Optimal Power Flow

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***Abstract*—Modern Smart Grids with high RES penetration at the distribution level, face great challenges related to congestion avoidance and voltage control. The development of a flexibility market that guarantees the constraint satisfaction of the distribution network and truthful (as opposed to strategic) player participation is necessary. This paper proposes an efficient flexibility market architecture that facilitates flexibility service provision in a distribution network. It leverages an optimal and incentive compatible mechanism in order to achieve efficiency (energy services with lower cost) and truthful participation.**

***Index Terms*—Distribution network, energy market architecture, flexibility market, truthful market participation, market power mitigation.**

NOMENCLATURE

Sets and Indices

H	Set of timeslots in the time horizon, indexed by t.
N	Set of Distribution Network's nodes, indexed by n.
F	Set of Flexibility Service Providers (FSPs), indexed by i.
G	Set of scheduled generation, indexed by i.
D	Set of scheduled demand, indexed by i.
$\Omega_{d/p}(n)$	Set of descendant/predecessor nodes connected to node n, indexed by k/j.
B	Set of Distribution Network's branches, indexed by nk.
X	Set of optimization variables.

Variables

$x_{i,t}^{p/q,up/dn}$	Upward/Downward P/Q-flexibility dispatch at node i, at timeslot t.
$p/d_{i,t}^{cut}$	Generation/Load shedding, at timeslot t.
$f_{nk,t}^{p/q}$	Active/Reactive power flow in branch nk, at timeslot t.
$U_{n,t}$	Square voltage magnitude at node n, at timeslot t.

Parameters

P_t^{sub}/Q_t^{sub}	Active/Reactive power exchanged with the main grid (TSO), at timeslot t.
$c_{i,t}^{p/q,up/dn}$	Price bid of FSP i for upward/downward P/Q-flexibility, at timeslot t.
$c_{i,t}^{p/d,cut}$	Cost of generation/load shedding, at timeslot t.
$\overline{x}_{i,t}^{p/q,up/dn}$	Quantity bid of FSP i for upward/downward P/Q-flexibility, at timeslot t.
$p/d_{n,t}$	Scheduled generation/demand at node n, at timeslot t.
$\delta_{n,t}^{p/d}$	Parameters converting active power into reactive power: $tan(cos^{-1}(powerfactor))$.
r_{jn}, x_{jn}	Resistance, reactance of branch jn.
$\underline{U}_n, \overline{U}_n$	Lower, upper limits of the square voltage magnitude at node n.
$\underline{f}_{nk}^{p/q}, \overline{f}_{nk}^{p/q}$	Lower, upper limits on active/reactive power capacities of branch nk.

I. INTRODUCTION

A. Motivation and Background

Smart grids have been trying to integrate a high level of RES penetration at the distribution network level [1], in a distributed and bottom up fashion. Distribution System Operators (DSOs) may face voltage and congestion issues that can be handled by either investing in network expansion/upgrade, or by requesting services (flexibility) from Flexibility Service Providers (FSPs) through an innovative market architecture. Aggregators of flexible loads, storage facilities and microgenerators are examples of entities that can act as FSPs and constitute the players of the proposed market.

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An important issue concerns the market architecture through which the DSO acquires services from FSPs. The network topology introduces constraints towards the activation of the flexibility assets of FSPs, located at various network sites. In the usual operation of these markets only a few flexibility assets are eligible to contribute at a specific time instant and network location. In these cases, better modeled as oligopolistic markets, fair (truthful) market participation highly enhances market efficiency (economic welfare). Thus, the challenge is how to compensate the FSPs for their services, so as to ensure fair market participation and mitigate the exercise of market power that could be employed through strategic FSP bidding.

Today's distribution grids cope with congestion avoidance and voltage control by constraining future RES investments, curtailing peak RES generation, or establishing static and long-term direct activation contracts between the DSO and the FSP. However, our work in FLEXGRID project [2] focuses on the evolvement of the current energy markets' operation towards new energy market architectures that better accommodate distributed and high RES penetration, the efficient aggregation of end-user flexibility assets by FSPs and their optimal and parallel use in multiple energy markets, and the optimal use of FSPs' assets and their operation according to market signals.

B. *Relevant Literature*

The optimal operation (and constraint satisfaction) of the distribution network has been extensively studied in the literature, albeit mostly within a direct control architecture. Truthful bidding in electricity markets has been addressed in studies where techniques from game theoretic mechanism design are employed in wholesale [3] or local [4]- [7] electricity markets. However, to the best of our knowledge, game-theoretic studies for local electricity markets have not accounted for the operational constraints of the distribution network, while studies that address operational issues of the distribution network did not aim to obtain an efficient market procedure [8].

There are two major algorithms that are involved in the operation of the flexibility market. The first one relates to the allocation rule (dispatch algorithm) and the second relates to a pricing rule for the market participants (payment algorithm).

Concerning the dispatch algorithm, an optimization problem is solved, known as Optimal Power Flow. Assuming that the market participants (FSPs) truthfully and honestly declare their costs, Distribution Locational Marginal Prices (DLMPs) for each node of the distribution network can be calculated [9] in three ways. The first concerns duality analysis of the problem formulated with a global power balance constraint, the second a duality analysis of a second-order cone program relaxation, and the third an analysis of marginal losses' impact on price.

Regarding the declaration of the participants' local parameters and costs, [10] assumes that market participants accurately provide the operator with their preferences, and the latter optimizes the social welfare. Additionally, [11] assumes that market players (e.g., consumers) forecast their energy requirements and truthfully report their forecast to an aggregator. Furthermore, [12] deals with a set of truthful consumers that participate in a centrally coordinated load controller whose objective is to meet demand side management requirements. In these studies, market players honestly declare their bids.

The work in [13] develops two simple billing rules and proves that best-response dynamics converges to Nash Equilibrium, while [14] proposes a game-theoretic mechanism that also accommodates coupling constraints. Recent studies, [15] and [16], present payment algorithms that consider an additional requirement, namely the pricing fairness of the consumption allocation. Furthermore, [17] studies the effect of the FSP's profit policy. However, these studies also assume that market players truthfully interact with the payment algorithm, and thus they don't compromise the algorithm's properties.

It is, however, well reported (e.g. using bi-level programming [8]) that a participant can benefit through strategic bidding, while compromising social welfare. Therefore a different clearing process is needed to guarantee that non-truthful bidding will not be beneficial to the bidder.

Luckily, game theory offers theoretical tools that allow the relaxation of the truthful bidding assumption. More specifically, this paper is interested in a setting where a given set of resources needs to be allocated to a number of players (FSPs) based on their bids. Assuming rational, selfish and strategic players, typical criteria for such a mechanism include efficiency of the allocation in terms of Social Welfare, tractability of the outcome and incentive compatibility. In particular, the VCG mechanism is provably [18] the unique dominant-strategy-incentive-compatible welfare maximizing mechanism.

C. *Contributions and Organization*

In this paper, we propose a flexibility market where the network topology is accounted for, and is compatible with the existing smart grid market architecture. Furthermore, in our proposal, FSPs interact with the DSO through a market procedure that guarantees truthful participation. In more detail, this paper offers the following contributions:

- A novel market architecture model for the provision of flexibility services in distribution networks, which is compatible with the existing market architecture.
- An optimization and data exchange framework able to provide a dispatch schedule that respects distribution network constraints with the minimum flexibility cost.
- A Vickrey-Clarke-Groves (VCG) mechanism for the market's reward structure, so that FSPs cannot cheat the system for their own benefit.
- A set of simulations that compare the outcome of the proposed system with solutions provided in the literature.

The rest of this paper is organized as follows. Section II describes the architecture and the algorithms of the proposed flexibility market. Section III evaluates the efficiency of the flexibility. Finally, Section IV concludes and presents hints for future work.

II. PROPOSED SYSTEM MODEL

Regarding the design of the proposed distribution level flexibility market architecture, FLEXGRID [2] examines various

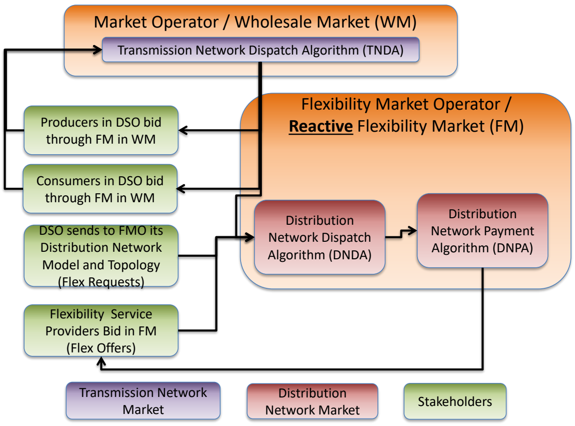

Fig. 1. Reactive Flexibility Market Architecture.

trade-offs between two approaches [19]. The first one, proposes an iterative interaction between TSO and DSO, offering the maximum efficiency. The second approach acts reactively to the existing energy markets and sacrifices efficiency.

In this paper, we focus on the second approach which follows a given Day-Ahead or Balancing Market Dispatch. The proposed architecture (Fig. 1) is capable to handle forecast inaccuracies in energy production/consumption in assets connected to the distribution and transmission networks.

In our perspective, the compatibility requirement leads to the only drawback of this approach, which is the possibility of an infeasible Day-Ahead and/or Balancing Market Dispatch due to the lack of flexibility assets. Furthermore, in cases where this dispatch is modified through corrective actions, spot market price in the transmission level has to be paid.

In this architecture, we consider a Flexibility Market Operator (FMO) which operates a Flexibility Market on behalf of the DSO in the distribution network level. The FMO's objective is to procure the necessary flexibility at the minimum cost to the DSO, in order for the latter to avoid congestion and voltage violation problems. The steps of the process that the proposed reactive flexibility market follows are:

Step 1: The FMO takes as input the wholesale market dispatch that is composed from the power flows in the coupling point with TSO and the dispatch that concerns prosumers and consumers in its distribution network.

Step 2: DSO sends information that suffice to model its distribution network to FMO.

Step 3: FSPs connected to the DSO send their bids to FMO.

Step 4: FMO generates Distribution Network Dispatch through the execution of an optimization algorithm, noted as Distribution Network Dispatch Algorithm, which respects distribution network constraints i.e. a) active/reactive power balance, b) mitigates network congestion, c) accommodates voltage control, and implements fundamental economic rules which means that: distribution network constraints will be satisfied by activating flexibility bids in the least costly manner. Distribution Network Dispatch Algorithm is analysed in detail in Section II-A.

Step 5: Flexibility assets (FSPs) are compensated for their operation according to a Distribution Network Payment Algorithm executed by the FMO, which is analyzed in Section II-B.

A. Distribution Network Dispatch Algorithm

We consider that the Flexibility Market's gate closure time is after a distribution network agnostic WM clearing process and also after the calculation of the Day-Ahead Dispatch. First, the FSPs declare their flexibility assets' capabilities and costs. Then, the FMO seeks to ensure the feasible and reliable operation of the distribution network by procuring the necessary flexibility at minimum cost. Thus, the FMO solves the following Optimal Power Flow problem in order to calculate the Distribution Network Dispatch:

$$\min_X C_f(x) = \sum_{t\in H}\Bigg(\sum_{i\in F}(c^{p,up}_{i,t}x^{p,up}_{i,t} + c^{p,dn}_{i,t}x^{p,dn}_{i,t} + c^{q,up}_{i,t}x^{q,up}_{i,t} + c^{q,dn}_{i,t}x^{q,dn}_{i,t}) + \sum_{i\in G}(c^{p,cut}_{i,t}p^{cut}_{i,t}) + \sum_{i\in D}(c^{d,cut}_{i,t}d^{cut}_{i,t})\Bigg) \quad (1)$$

Subject to:

$$0 \le x^{p,up}_{i,t} \le \overline{x}^{p,up}_{i,t}; \quad \forall i\in F, t\in H \quad (2)$$

$$0 \le x^{p,dn}_{i,t} \le \overline{x}^{p,dn}_{i,t}; \quad \forall i\in F, t\in H \quad (3)$$

$$0 \le x^{q,up}_{i,t} \le \overline{x}^{q,up}_{i,t}; \quad \forall i\in F, t\in H \quad (4)$$

$$0 \le x^{q,dn}_{i,t} \le \overline{x}^{q,dn}_{i,t}; \quad \forall i\in F, t\in H \quad (5)$$

$$0 \le p^{cut}_{i,t} \le p_{i,t}; \quad \forall i\in G, t\in H \quad (6)$$

$$0 \le d^{cut}_{i,t} \le d_{i,t}; \quad \forall i\in D, t\in H \quad (7)$$

$$\sum_{j\in\Omega_p(n)} f^p_{jn,t} - \sum_{k\in\Omega_d(n)} f^p_{nk,t} + x^{p,up}_{n,t} - x^{p,dn}_{n,t} = (d_{n,t} - d^{cut}_{n,t}) - (p_{n,t} - p^{cut}_{n,t}); \quad \forall n\in N, t\in H \quad (8)$$

$$\sum_{j\in\Omega_p(n)} f^q_{jn,t} - \sum_{k\in\Omega_d(n)} f^q_{nk,t} + x^{q,up}_{n,t} - x^{q,dn}_{n,t} = \delta^d_{n,t}(d_{n,t} - d^{cut}_{n,t}) - \delta^p_{n,t}(p_{n,t} - p^{cut}_{n,t}); \quad \forall n\in N, t\in H \quad (9)$$

$$U_{n,t} = U_{j,t} - 2(r_{jn}f^p_{jn,t} + x_{jn}f^q_{jn,t}); \quad \forall n\in N, t\in H \quad (10)$$

$$\underline{U}_n \le U_{n,t} \le \overline{U}_n; \quad \forall n\in N, t\in H \quad (11)$$

$$\underline{f}^p_{nk,t} \le f^p_{nk,t} \le \overline{f}^p_{nk,t}; \quad \forall nk\in B, t\in H \quad (12)$$

$$\underline{f}^q_{nk,t} \le f^q_{nk,t} \le \overline{f}^q_{nk,t}; \quad \forall nk\in B, t\in H \quad (13)$$

$$\sum_k f^p_{0k,t} = P^{sub}_t; \quad k\in\Omega_d(0), \forall t\in H \quad (14)$$

$$\sum_k f^q_{0k,t} = Q^{sub}_t; \quad k\in\Omega_d(0), \forall t\in H \quad (15)$$

The FMO's objective is to minimize the flexibility cost (1) through the optimal (active/reactive power) dispatch ($x^{p/q,up/dn}_{i,t}$) of the FSPs. In the objective function (1), set F contains the FSPs (players/participants). Each FSP $i\in F$ bids its active/reactive power capacity and its marginal cost $\{c^{p,up/dn}_{i,t}, c^{q,up/dn}_{i,t}\}$. Furthermore, each MW of reduction in the load/generation calculated in Day-Ahead Dispatch will incur societal and monetary costs for the load representatives and distributed generators (i.e. Lost Load, RES spillage, penalties for the deviation from the WM scheduled operating points, etc.). These costs are represented in the objective function by the terms $c^{d,cut}_{i,t} d^{cut}_{i,t}$ and $c^{p,cut}_{i,t} p^{cut}_{i,t}$, respectively. Equations (2)-(5) represent the operating constraints of flexibility devices $\left(\overline{x}^{p,up}_{i,t}, \overline{x}^{p,dn}_{i,t}, \overline{x}^{q,up}_{i,t}, \overline{x}^{q,dn}_{i,t}\right)$, while (6)–(7) limit the shedding in the generation $\left(p^{cut}_{i,t}, \forall i \in G, t \in H\right)$ and consumption $\left(d^{cut}_{i,t}, \forall i \in D, t \in H\right)$ of the distribution network.

Moreover, constraints (8)-(15) are the network constraints, which are a function of active/reactive power flow and the nodal voltage magnitude among others. To model the radial distribution network, with N nodes and B branches, and the constraints that it imposes, we use the linearized DistFlow equations presented in [20]. The use of linearized equations is acceptable as the quadratic terms represent the power losses, which are far smaller than the active and reactive power flows on each branch. Equations (8)-(10) are called *branch flow equations*. Specifically, $f^{p}_{nk,t}$ and $f^{q}_{nk,t}$ are the active and reactive power flowing in the branch nk connecting nodes $n \in N$ and $k \in N$ of the distribution network. Thus, equations (8) and (9) represent the active and reactive power balances at each distribution node. The day-ahead dispatch in terms of demand and production of active power at node n at timeslot t is indicated with $d_{n,t}$ and $p_{n,t}$, respectively, while $\delta^{d}_{n,t}$ and $\delta^{p}_{n,t}$ are parameters relating active and reactive power. In addition, $x^{p/q,up/dn}_{n,t}$ denote the active/reactive upward/downward flexibility of FSP $\in F$ that is connected at node $n \in N$, whereas if there is no such connection these terms are equal to zero. The square of the voltage of each node is $U_{n,t}$ and is calculated in (10), while r_{jn} and x_{jn} are the resistance and the reactance, respectively, of branch jn of the distribution network. In (11) the upper $(\overline{U}_n)$ and lower $(\underline{U}_n)$ limits of the voltage magnitude are set. Equations (12) and (13) impose the upper $(\overline{f}^{p,q}_{nk,t})$ and lower $(\underline{f}^{p,q}_{nk,t})$ bounds of active and reactive power flows of branch nk. Finally, to observe the interaction between TSO and DSO at the substation ($n = 0$), we use the Eqs. (14) – (15). In (14), P^{sub}_{t} expresses the active power that the distribution network exchanges with the transmission system at timeslot t. A positive value of P^{sub}_{t} means that the distribution network imports power from the transmission system. Similarly, Eq. (15) presents the reactive power exchange.

By solving the above optimization problem, the FMO calculates the optimal Distribution Network Dispatch over a given time horizon H $\{x^{p,up}_{i,t}, x^{p,dn}_{i,t}, x^{q,up}_{i,t}, x^{q,dn}_{i,t} \forall i \in F, \forall t \in H | p^{cut}_{i,t}, \forall i \in G, \forall t \in H | d^{cut}_{i,t}, \forall i \in D, \forall t \in H\}$ and the optimal cost of flexibility $(C_f(x))$ which is necessary for the Distribution Network to operate within its physical and technical limits.

B. Distribution Network Payment Algorithm

In contrast with the recent literature, which typically uses the Lagrangian multipliers to produce nodal DLMPs, this paper leverages the Vickrey-Clarke-Groves (VCG) mechanism in order to develop the Distribution Network Payment Algorithm. In more detail, a game is typically defined by a set F of f players, a set S_i, $i \in F$, of strategies available to each player (e.g. bids), and a set of payoffs that maps each joint strategy combination $\times\{S_i, i \in F\}$ to a set of player rewards (payoffs) $\times\{r_i, i \in F\}$. The VCG mechanism is the predominant mechanism of mechanism design theory. It guarantees truthful player participation by solving the welfare maximization problem f times, where each time one player is absent from the market, plus one more time with all participants present in the market, in order to find the optimal allocation. More specifically, after calculating the Distribution Network Dispatch, the FMO calculates the rewards to each FSP using the Clarke pivot rule:

$$r_i = \boldsymbol{C_f}(\boldsymbol{x}_{-i}) - \boldsymbol{C_f^{-i}}(\boldsymbol{x}_{-i}) \tag{16}$$

where r_i is the payment to FSP i, $\boldsymbol{C_f}(\boldsymbol{x}_{-i})$ denotes the flexibility cost of FSPs that belong to set $F \backslash i$ in case that i participates in the market, and $\boldsymbol{C_f^{-i}}(\boldsymbol{x}_{-i})$ denotes the flexibility cost of FSPs' that belong to set $F \backslash i$ in case that FSP i is excluded from the market. The second term in the above payment rule (16) represents the contribution of FSP i in the total flexibility cost. In order for the first term of (16) to be calculated, the optimization problem (1) is solved without considering the bids and capacity of FSP i. In this way, the FMO offers an efficient clearing process of a topology aware market in the distribution network level.

III. PERFORMANCE EVALUATION

In this section, we compare our proposed VCG-based Flexibility Market to a DLMP Market under various market setups and levels of Distributed Generation (DG) penetration. We consider an imperfect flexibility market, in which there is one strategic FSP that chooses its optimal bidding strategy in order to maximize its profits, while the other FSPs truthfully bid in the market. In order for the strategic FSP to achieve higher market profits, it can either declare a higher cost of its services than the true one (economic withholding) or offer a lower flexibility capacity (physical withholding). We will show that in a DLMP Flexibility Market, an FSP acting strategically can manipulate the market in order to achieve higher profits, thus resulting in a higher Flexibility cost, in contrast to our proposed VCG-based Flexibility Market, in which every FSP is incentivized to declare its true cost and capacity.

It is useful to note that the VCG mechanism doesn't propose lower payments to flexibility resources relatively to DLMP. However, it forces market participants to disclose their true costs, and in this way high market efficiency is ensured. As it is analyzed in [18], it is proved theoretically that VCG achieves truthful bidding and under this perspective there is no need for simulations in order to testify incentive compatibility.

The computations were carried out on a personal computer, running CPLEX under MATLAB on an Intel Core i7 2.20 GHz processor with 12 GB of RAM.

A. Input Data

We consider a 15-node distribution test system (Fig. 2). The branches and load data can be found in [8]. We assume that

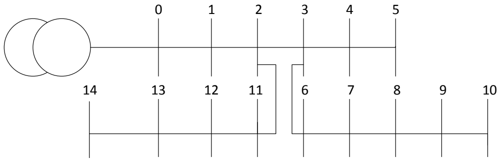

Fig. 2. A 15-node radial Distribution Network.

2 PVs are installed at nodes 2 and 13, while 4 Wind Turbines are located at nodes 5, 8, 10 and 11. Their production curves are derived from [21]. All distributed generators (DGs) are assumed to operate at a power factor of 0.95. The upper and lower limits of nodal voltage amplitude are set to 1.05 and 0.95 pu, respectively. Furthermore, we assume that the cost of shedding 1 MW of load is 450 €/MW, while the cost of shedding 1 MW of distributed generation is 50 €/MW. The base power and voltage are 1 MVA and 11kV, while a time horizon of T = 24h is considered.

B. DLMP Market

In order to evaluate our proposed Reactive Flexibility Market Architecture and demonstrate the advantages of the implementation of the VCG mechanism, we will compare it to the DLMP market. In the latter, the lagrangian multipliers of the Optimal Power Flow problem are utilized in order to extract the nodal prices at which the FSPs will be paid for their services. More specifically, the dual variables concerning the active/reactive power balance constraints (Eq. (8)/(9)) are used as the active/reactive power nodal prices. Each FSP is paid for its (active/reactive, upward/downward) flexibility services at the nodal price corresponding to the node(s) at which the assets of the FSP are connected.

In the strategic DLMP case, we assume that the FSP with the highest market power strategically chooses its bidding strategy (by declaring its costs without saying the truth) in order to earn the highest possible profits. Consequently, this leads to an increase of the flexibility cost. In order to calculate the Flexibility Cost in the Strategic DLPM case, we model a certain FSP calculating through an exhaustive search the optimal bidding strategy (quantity/price bids).

In what follows, our VCG-based market and the DLMP market are compared in two scenarios, a rather competitive reactive flexibility market (high market liquidity), and an oligopolistic reactive flexibility market (low market liquidity).

C. Competitive Reactive Flexibility Market

In this market setting, we consider 30 flexibility assets (physical assets or a virtual aggregation of small flexibility units) located in various nodes of the distribution network. The costs and capacities of these assets are described in [22]. In Fig. 3, we see the market equilibrium (Flexibility Cost) for both market architectures with one strategic FSP for various scenarios of DG penetration. The level of DG penetration is defined as the ratio of the Nominal Generation Capacity to the Peak Aggregate Load. In Fig 3, we can see that, in a competitive market environment, our proposed VCG-based Flexibility Market achieves up to 30.8% (in the 160% DG penetration scenario) less Flexibility Cost than the DLMP market when a certain FSP acts strategically. By implementing the VCG mechanism, the FMO incentivizes the FSPs to disclose their true capacities. This results in reaching the minimum flexibility cost in contrast to a DLMP market, in which a strategic FSP distorts the market. Moreover, we can see that as the distributed generation increases, the flexibility cost rises, because more flexibility services are needed in order for the network to operate safely.

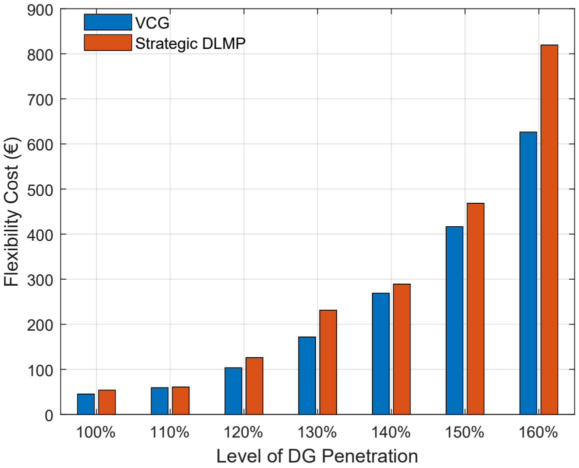

Fig. 3. Flexibility Cost comparison between high liquidity VCG-based Flexibility Market and DLMP Flexibility Market.

D. Oligopolistic Reactive Flexibility Market

In this subsection, we consider 9 flexibility assets located in different nodes of the distribution network. The costs and capacities of these flex assets can be found in [22]. In this market setting, ‘nodal monopolies’ rise, as certain FSPs located in ‘critical’ nodes of the network monopolize the provision of flexibility services. As a result, the flexibility cost is rising. Particularly, in an imperfect DLMP market, the strategic FSPs can gain higher profits by performing physical withholding. Studying Fig. 4, we can confirm the previous statement. As expected, the overall flexibility cost is higher than in the competitive market scenario. On top of that, as in Section III-C, the flexibility costs are higher in a DLMP market with a strategic FSP by up to 71.5% (in 130% DG penetration scenario).

Another effect of an oligopolistic Reactive Flexibility Market under high DG penetration scenarios is the costly shedding of the distributed generation. The flexibility assets’ capacity is not enough to stabilize a network with high distributed generation. In addition to this, the behavior of the strategic FSP further reduces the flexibility capacity that is available to the FMO. This is illustrated in Fig. 5, where we can see that our proposed VCG-based Flexibility Market can achieve lower DG shedding than the DLMP market under various DG penetration scenarios (by 64% on average).

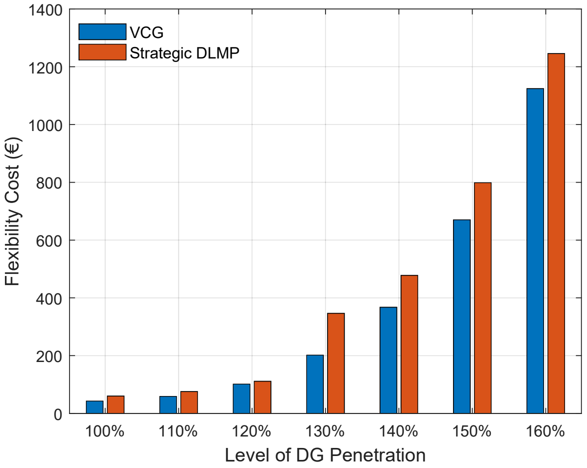

Fig. 4. Flexibility Cost comparison between oligopolistic VCG-based and DLMP Flexibility Markets.

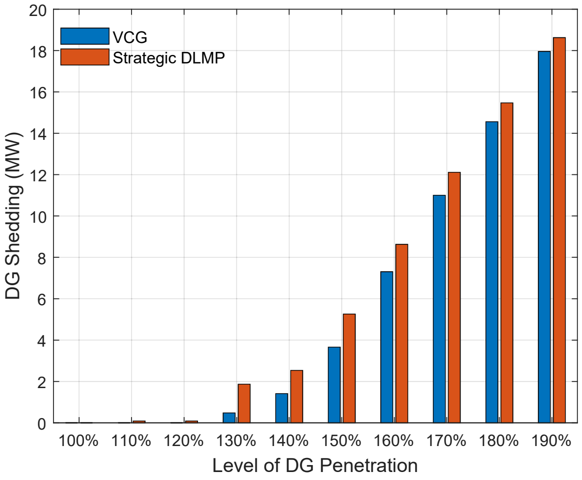

Fig. 5. Shedding comparison between oligopolistic VCG-based and DLMP Flexibility Markets.

IV. CONCLUSIONS AND FUTURE WORK

We proposed a novel market architecture for the provision of flexibility services, in order to deal with the management challenges of the distribution network, caused by high RES penetration. The three major requirements that we took into account are the compatibility with existing energy markets, the market efficiency and the avoidance of strategic behavior by market participants. We proposed a Distribution Network Dispatch Algorithm and a Distribution Network Payment Algorithm.

Our evaluation revealed that: i) the lack of a distribution management system discourages high RES penetration, ii) an advanced flexibility market in the distribution level is able to offer efficient energy services. Our future work will unfold around more requirements, such as fairness, budget balance, accurate distribution network modeling, scalability, etc. Finally, we will focus on the comparison between various architectures.

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