Strategic Behavior of a Distribution Company in the Wholesale Energy Market: A Risk-Based Stochastic Bi-Level Model

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***Abstract*—In active distribution grids (ADNs), a distribution corporation (Disco) can trade electricity with micro-grids (MGs) besides trading electricity with wholesale markets. Therefore, the operational flexibility of the Disco is increased so that it can play as a price-maker agent in electricity markets. To model the actions of Disco, a bi-level optimization method is developed where Disco problem is modeled at the upper-level problem, whereas the MGs problem together with the day-ahead market clearing procedure are modeled as the lower-level problems. To take the stochastic performance of green energy integration and loads into account, the Disco analysis is shown as two-stage stochastic problem, in which the Disco risk aversion is programmed considering the conditional value-at-risk tool. The subsequent non-linear bi-level approach is converted into a linear single-level approach through Karush-Kuhn-Tucker (KKT) conditions and dual theory. To validate the success of the proposed method, a 24-bus power system is used. Conclusions are duly drawn.**

***Keywords*—Active distribution grid, Bi-level method, Micro-grids, Risk management, Stochastic approach**

I. NOMENCLATURE

A. Indexes and Sets

b, B	Electricity offers/bids block of *Genco/TNL*.
d, D	Index/set for *TNL*.
g, G	Index/set for *Genco*.
j, J	Index/set *MG*.
M_n^G / M_n^D	*Genco/TNL* placed on bus *n*.
$n, N / r, R$	Index/set for *TN* buses.
t, T	Index/set for time slot.
ω, W	Index/set for scenarios.
Λ_n^{TN}	Buses straight connected to *TN* bus *n*.

B. Parameters

B_{n-r}	Susceptance of branches
$C_{b,g,t}^{TN}/C_{b,g,t}^{TN}$	Offers/bids block of *Genco/TNL* ($/MWh)
$C_{j,t}^{IL-DN}/C_{j,t}^{IL-MG}$	Cost of interruptible loads ($/MWh)
$C_{j,t}^{DG}/C_{j,t}^{ES}$	Cost of *DG/ES* ($/MWh).
d_t	Period of time *t* (hour).
$\overline{E}_j^{ES}$ / $\underline{E}_j^{ES}$	Max/Min energy stored in *ES* (MWh).
$\overline{f}_{n-r}^{TN}$	Capacity limit of branches (MW).
$\overline{L}_{d,t}^{TN}/\overline{l}_{b,d,t}^{TN}$	Max load/magnitude of *TNL* energy (MW).
$\bar{P}_g / \overline{\rho}_{b,g}^{TN}$	Max production/magnitude of *Genco* block (MW).
$\overline{P}^{Dis-TN}/\underline{P}^{Dis-TN}$	Disco power trading limits with market (MW).
$\bar{P}_j^{Dis-MG}$ / $\underline{P}_j^{Dis-MG}$	Disco power trading limits with *MG*s (MW).
$P_t^{DNL-Det}$ / $P_{t,\omega}^{DNL}$	Deterministic/Probabilistic *DNL* (MW).
$P_{j,t}^{MGL}$	Deterministic *MGL* (MW).
$\bar{P}_j^{DG}/\underline{P}_j^{DG}$	Capacity limits of *DG* (MW).
$\bar{P}_j^{ESch}$ / $\bar{P}_j^{ESdch}$	Max. charging/discharging power of *ES* (MW).
$\gamma^{Dis}/\gamma_j^{MG}$	Max. load break factors of *DN/MG*s (MW).
$\bar{P}_{t,\omega}^{RER}/C_t^{RER}$	Maximum output power of *RER* (MW)/their operation cost ($/MWh).
RU_g/ RD_g	Ramp-up and down bounds of *Genco* (MW/h).
RU_j^{DG}/RD_j^{DG}	Ramp-up and down bounds of *DG* (MW/h).
α/β	Confidence level/Risk-aversion parameters.
$\lambda_{j,t}^{MGL}$	Retailing electricity value to *MGL*s by the *MG*s ($/MWh).
λ_t^{DNL}	Retailing electricity value to *DNL* ($/MWh).
λ_ω	Scenario probabilities.

C. Variables

C_t^{Dis-TN}	Offers/bids of *Disco* to wholesale market ($/MWh).
C_t^{Dis-MG}	Offers/bids of *Disco* to *MG*s ($/MWh).
$E_{j,t}^{ES}$	The quantity of energy stored in *ES* (MWh).
$L_{d,t}^{TN}, l_{b,d,t}^{TN}$	The quantity of *TNL* and its block (MW).

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$P_{g,t}^{TN}, p_{b,g,t}^{TN}$	Production of *Genco* and its block (MW).
P_{t}^{Dis-TN}	*Disco* power trading with wholesale market (MW).
$P_{j,t}^{Dis-MG}$	*Disco* power trading with *MG*s (MW).
$P_{t,\omega}^{IL-Dis}$	Bulk of load interruption of the *Disco* (MW).
$P_{t,\omega}^{RER}$	Production of the *RER*s (MW).
$P_{j,t}^{IL-MG}$	Bulk of load interruption in each *MG* (MW).
$P_{j,t}^{DG}$	Production of the *DG*s (MW).
$P_{j,t}^{ES}$	Power charging/discharging of the *ES* (MW).
γ_t	Bulk of demand shifting factor.
$\theta_{n,t}$	Angle of *TN* buses (rad).
$\lambda_{n,t}^{Dis-TN}$	*MCP*/*LMP* at *TN* bus *n* .
$\lambda_{j,t}^{Dis-MG}$	Local market price.
ξ , η_ω	Auxiliary variables used in *CVaR* calculation.

II. INTRODUCTION

A. Motivation and Aim

Environmental concerns, depletion of fossil resources, and power losses in transmission and distribution networks (DNs) are major problems of power system to meet the increasing electricity consumption. To face aforementioned concerns, distributed energy resources (DERs) are emerged into the power system especially in DNs. To better management of these resources, they are integrated as micro-grids (MGs) to meet the demand locally [1]. Distribution Corporation (Disco) has two roles in DNs which consist of network planning, operation, and maintenance and selling electricity to the consumers as a retailer.

In active distribution networks (ADNs), in the existence of MGs, the decision making background of Disco is changed therefore it may exchange electricity with MGs in its network besides trading electricity with the wholesale markets as described in details in [2]. However, the stochastic behaviors of renewable energy resources (RERs) and the customers offer new concerns for Discos. This paper aims at modeling a Disco in the day-ahead (DA) electricity market while it cooperates with MGs in a local electricity market in its network.

B. Background and Contributions

The strategic behavior of Discos is modeled from various point-of-view, when Disco participates in the wholesale markets as a price-taking agent [3]. In [4], the strategic behaviors of price-taking Disco in DA and real-time (RT) electricity markets are shown as two-stage hierarchical outline. In [5], the strategy shown in [4] is explored as a stochastic two-stage problem for controlling uncertainty of RT electricity load and price.

In [6], a complete operational model of a Disco, with regard to DA and reserve markets, was addressed. The performance of a Disco in cooperation with MGs is demonstrated in some studies from different perspective [7]. In [8], an optimal control procedure for MGs and Disco cooperating with each other was presented. In [9], a mathematical model for optimal scheduling of some MGs in an islanded DN was presented considering multi-agent systems.

In [10], electricity consumption scheduling in a distribution grid consist of several MGs considering the stochastic loads was analyzed. In [11, 12], strategic behavior of a Disco and DERs aggregator was investigated in RT markets considering bi-level optimization approach. The incomes of the Disco and DERs aggregator were optimized at the upper-level (UL) and the lower-level (LL) perspectives.

In [13], a bi-level optimization model was presented to analyses the decision-making of a Disco which cooperates with MGs in its network. In the presence of DERs, the Disco is able to contribute to wholesale markets as a price-making agent since it can meet some of its required demand from these resources.

The operation problem of a Disco with regard to DERs in wholesale market was investigated in some work. In [14], a model to analyses the operation of a Disco in electricity market was proposed. To this end, Disco, DA and RT markets were correspondingly treated as leader and followers.

In [15], the performance of a Disco in RT electricity market was studied. The Disco could play in RT market as a price-making participant using demand response aggregator in DN. The proposed framework was analysed considering a bi-level optimization methodology in which Disco and RT market agents were correspondingly treated as leader and follower.

In this current work, the operation problem of a Disco in DA wholesale market is analyzed, whereas it collaborates with MGs in a native market in Disco's network. For this end, a risk-based bi-level optimization method would be developed where Disco problem is analyzed as UL problem, and the clearing of DA market together with the problem of MGs are considered as the LL problem. The goals of this work are:

- Modelling the operation of a Disco in wholesale and local markets with regard to a stochastic risk-based bi-level approach in order to include the RERs and load behavior.
- Considering the CVaR tool to control the impact of uncertainty on the decision making process of the Disco and to manage Disco's risk-level.

The remaining work is prepared as follows. The strategy model explanation is provided in Section 3. Section 4 shows the necessary mathematical formulation. Section 5 shows the case study and main results. Section 6 provides the main findings of this work.

III. STRATEGIC MODEL DESCRIPTION

In this work, the operation problem of a Disco in DA market is analyzed while it cooperates with MGs in its network as exposed in Fig. 1. To investigate the decision making framework, a bi-level model is proposed. The Disco's strategic behavior is modeled as the UL problem while the operation problem of MGs and the wholesale market, which is controlled by the independent system operator (ISO), are considered as LL problems as shown in Fig. 2.

In fact, the problem is modeled as a one-leader multi-followers one. The Disco strategic behavior is a stochastic risk-based two-stage problem where bids/offers of the Disco to the wholesale market, the price of electricity exchange with MGs, and the electricity exchange with MGs are decisions that are not dependent on the comprehension of stochastic process, and are considered as the first-stage decisions.

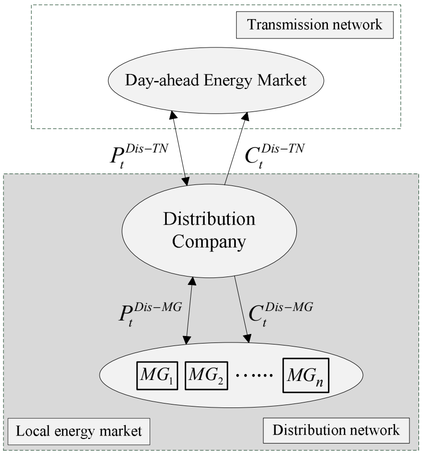

Fig. 1. Proposed decision-making environment of Disco in wholesale and local electricity market.

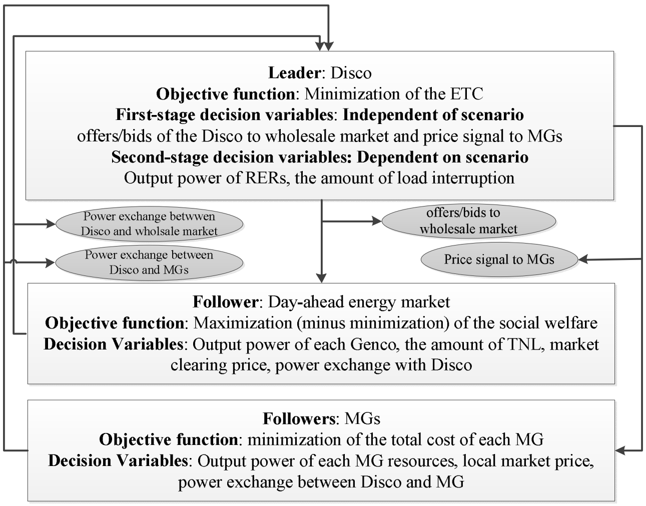

Fig. 2. Bi-level decision-making strategy.

The strategy of Gencos and demands players in DA market is not planned, their bids/offers would be only measured in this model. The bids/offers of Disco to acquisition/trade electricity from/to market and the trading electricity with the market and its prices are decision variables that couple the Disco and market to each other. The operation cost of MGs is minimized in the LL problems while they cooperate with the Disco. The price of electricity exchange and trading electricity are two decision variables that couple the Disco and MGs.

IV. MATHEMATICAL FORMULATION

A. Disco's Strategic Behavior

UL problem is formulated as follows:

$$\text{Minimize } ETC=\sum_{\omega=1}^{W}\lambda_{\omega}TC_{\omega} \tag{1}$$

$$TC_{\omega}=\sum_{t=1}^{T}\begin{bmatrix}\lambda_{m,t}^{Dis-TN}P_{t}^{Dis-TN}+\sum_{j=1}^{J}\lambda_{j,t}^{Dis-MG}P_{j,t}^{Dis-MG}+C_{t}^{RER}P_{t,\omega}^{RER}+\\(C_{t}^{IL-DN}+\lambda_{t}^{DNL})P_{t,\omega}^{IL-Dis}-\lambda_{t}^{DNL}P_{t,\omega}^{DNL}\end{bmatrix} \tag{2}$$

$$P_{t,\omega}^{RER}+P_{t,\omega}^{IL-Dis}+P_{t}^{Dis-TN}+\sum_{j=1}^{J}P_{j,t}^{Dis-MG}=P_{t,\omega}^{DNL} \quad :\forall t,\omega \tag{3}$$

$$0\le P_{t,\omega}^{IL-Dis}\le\gamma^{Dis}P_{t}^{DNL-Det} \quad :\forall t,\omega \tag{4}$$

$$0\le P_{t,\omega}^{RER}\le\overline{P}_{t,\omega}^{RER} \quad :\forall t,\omega \tag{5}$$

The Disco operation cost is modeled (1) and (2), which contains the cost of electricity exchange with the wholesale and MGs, the operation cost of RERs, the amount of load interruption, and energy sold to its customers; (3) imposes the power balance equation; (4) is considered to model the upper limit of the load interrupted by the Disco; (5) defines limitations of the RERs output power.

1) Risk Management Tool

The Disco's cost in the presented method would be a random variable. Based on the risk-neutral design, the expected cost should be minimized whereas the remained parameters exemplifying the cost would be disregarded.

A risk management tool is proposed in order to analyses the stochastic behavior [5]. The Disco's risk aversion can be computed considering CVaR tool due to its benefit over other risk tools as described in [16]. $(1-\alpha)$-quantile is determined in VaR technique as the minimum amount guaranteeing that the possibility of obtaining a cost higher than such amount is less than $(1-\alpha)$:

$$\text{Minimize}_{\xi,\eta_{\omega}}\ CVaR=\xi+\frac{1}{1-\alpha}\sum_{\omega=1}^{W}\lambda_{\omega}\eta_{\omega} \tag{6}$$

$$TC_{\omega}-\xi-\eta_{\omega}\le 0 \tag{7}$$

$$\eta_{\omega}\ge 0 \tag{8}$$

2) Final Objective Function of the UL Strategy

$$\text{Minimize } \ ETC+\beta\left(CVaR\right) \tag{9}$$

B. Wholesale DA Electricity Market Problem: LL Problem

The DA electricity market problem formulation is presented as follows:

$$\text{Minimize }\sum_{t=1}^{T}d_{t}\begin{bmatrix}\sum_{g=1}^{G}\sum_{b=1}^{B}(C_{b,g,t}^{TN}\ \rho_{b,g,t}^{TN})-\sum_{d=1}^{D}\sum_{b=1}^{B}(C_{b,d,t}^{TN}\ l_{b,d,t}^{TN})\\-C_{t}^{Dis-TN}P_{t}^{Dis-TN}\end{bmatrix} \tag{10}$$

subject to:

For Disco location at bus *m*:

$$\sum_{g\in M_{n}^{G}}P_{g,t}^{TN}-P_{t}^{Dis-TN}=\sum_{r\in\Lambda_{n}^{TN}}B_{m-r}\left(\theta_{m,t}-\theta_{r,t}\right)\ :\lambda_{n,t}^{Dis-TN}\ \forall n=m,t \tag{11}$$

For other buses:

$$\sum_{g\in M_{n}^{G}}P_{g,t}^{TN}-\sum_{d\in M_{n}^{D}}L_{d,t}^{TN}=\sum_{r\in\Lambda_{n}^{TN}}B_{n-r}\left(\theta_{n,t}-\theta_{r,t}\right)\ :\lambda_{n,t}^{Dis-TN}\ :\forall n,n\neq m,t \tag{12}$$

$$\underline{P}^{Dis-TN}\le P_{t}^{Dis-TN}\le\overline{P}^{Dis-TN}\ :\underline{\mu}_{t}^{1-TN},\overline{\mu}_{t}^{1-TN}\ \forall t \tag{13}$$

$$0\le L_{d,t}^{TN}\le\overline{L}_{d,t}^{TN}\ :\underline{\mu}_{d,t}^{2-TN},\overline{\mu}_{d,t}^{2-TN}\ \ \forall d,t \tag{14}$$

$$\underline{P}_{g}\le P_{g,t}^{TN}\le\overline{P_{g}}\ :\underline{\mu}_{g,t}^{3-TN},\overline{\mu}_{g,t}^{3-TN}\ \ \forall g,t \tag{15}$$

$$P_{g,t-1}^{TN} - P_{g,t}^{TN} \le RD_g \quad :\mu_{g,t}^{4-TN} \quad \forall g,t>1 \tag{16}$$

$$P_{g,ini}^{TN} - P_{g,t}^{TN} \le RD_g \quad :\mu_{g,t}^{5-TN} \quad \forall g,t=1 \tag{17}$$

$$P_{g,t}^{TN} - P_{g,t-1}^{TN} \le RU_g \quad :\mu_{g,t}^{6-TN} \quad \forall g,t>1 \tag{18}$$

$$P_{g,t}^{TN} - P_{g,ini}^{TN} \le RU_g \quad :\mu_{g,t}^{7-TN} \quad \forall g,t=1 \tag{19}$$

$$0 \le \rho_{bgt}^{TN} \le \overline{\rho}_{bgt}^{TN} \quad :\underline{\mu}_{b,g,t}^{8-TN}, \overline{\mu}_{b,g,t}^{8-TN} \quad \forall b,g,t \tag{20}$$

$$0 \le l_{b,d,t}^{TN} \le \overline{l}_{b,d,t}^{TN} \quad :\underline{\mu}_{b,d,t}^{9-TN}, \overline{\mu}_{b,d,t}^{9-TN} \quad \forall b,d,t \tag{21}$$

$$P_{g,t}^{TN} = \sum_{b=1}^{B} \rho_{b,g,t}^{TN} \quad :\lambda_{g,t}^{1-TN} \quad \forall g,t \tag{22}$$

$$L_{d,t}^{TN} = \sum_{b=1}^{B} l_{b,d,t}^{TN} \quad :\lambda_{d,t}^{2-TN} \quad \forall d,t \tag{23}$$

$$-\overline{f}_{n-r}^{TN} \le B_{n-r}\left(\theta_{n,t} - \theta_{r,t}\right) \le \overline{f}_{n-r}^{TN} \quad :\underline{\mu}_{n,r,t}^{10-TN}, \overline{\mu}_{n,r,t}^{10-TN} \quad \forall n,r \in \Lambda_n^{TN}, t \tag{24}$$

$$-\frac{\pi}{2} \le \theta_{n,t} \le \frac{\pi}{2} \quad :\underline{\mu}_{n,t}^{11-TN}, \overline{\mu}_{n,t}^{11-TN} \quad \forall n,t \tag{25}$$

$$\theta_{n,t}\Big|_{n=slack} = 0 \quad :\lambda_{n,t}^{3-TN}\Big|_{n=slack} \quad \forall t \tag{26}$$

The variable vector of the LL strategy is defined as: $X = \{P_{g,t}^{TN}, L_{d,t}^{TN}, \rho_{b,g,t}^{TN}, l_{b,d,t}^{TN}, P_t^{Dis}, \theta_{n,t}\}$. The objective function of LL strategy is to find the maximum social welfare of the DA market presented in (10), which consist of the cost of Gencos, the income of trading electricity to the transmission network load (TNL), and the income of exchanging electricity with the Disco. It should be noted that, in the LL strategy, entire Gencos would be dispatchable and transmission network (TN) has been modeled by DC load flow.

Eqs. (11) and (12) impose the power balance limit at DN and TN buses, respectively; (13) illustrates power trading bounds of Disco in the market; Eqs. (14), (15) limit the TNLs consumption and Gencos generation, respectively.

Eqs. (16)-(19) reflect ramp-up (*RU*) and ramp-down (*RD*) bounds; (20), (21) limit the electricity blocks associated with Gencos and TNL consumption, respectively; (22), (23) show that the sum of electricity blocks associated with TNL and Genco is equivalent to the total output power and TNL consumption quantity, respectively; (24) shows the capacity limit of TN line $n - r$; (25) describes the array of TN voltage angle; and (26) sets TN bus as the location bus. The Lagrangian multipliers for each constraint of the LL strategy are considered at the exact side of LL.

C. *MGs Problem Formulation: LL Problem*

The MGs problem formulation is presented as:

$$\text{Minimize} \quad TC^{MG}(j) = \sum_{t=1}^{T} \left[\begin{array}{l} -C_{j,t}^{Dis-MG} P_{j,t}^{Dis-MG} + C_j^{DG} P_{j,t}^{DG} + \\ C_{j,t}^{IL-MG} P_{j,t}^{IL-MG} \end{array} \right] \tag{27}$$

subject to:

$$P_{j,t}^{DG} + P_{j,t}^{IL-MG} + P_{j,t}^{ESdch} - P_{j,t}^{Dis-MG} = P_{j,t}^{ESch} + P_{j,t}^{MGL} \quad :\lambda_{j,t}^{Dis-MG} \quad \forall j,t \tag{28}$$

$$\underline{P}_j^{Dis-MG} \le P_{j,t}^{Dis-MG} \le \overline{P}_j^{Dis-MG} \quad :\underline{\mu}_{j,t}^{1-MG}, \ \overline{\mu}_{j,t}^{1-MG} \quad \forall j,t \tag{29}$$

$$0 \le P_{j,t}^{DG} \le \overline{P}_j^{DG} \quad :\underline{\mu}_{j,t}^{2-MG}, \overline{\mu}_{j,t}^{2-MG} \quad \forall j,t \tag{30}$$

$$P_{j,t}^{DG} - P_{j,t-1}^{DG} \le RU_j^{DG} \quad :\mu_{j,t}^{3-MG} \quad \forall j,t>1 \tag{31}$$

$$P_{j,t}^{DG} - P_{j,ini}^{DG} \le RU_j^{DG} \quad :\mu_{j,t}^{4-MG} \quad \forall j,t=1 \tag{32}$$

$$P_{j,t-1}^{DG} - P_{j,t}^{DG} \le RD_j^{DG} \quad :\mu_{j,t}^{5-MG} \quad \forall j,t>1 \tag{33}$$

$$P_{j,ini}^{DG} - P_{j,t}^{DG} \le RD_j^{DG} \quad :\mu_{j,t}^{6-MG} \quad \forall j,t=1 \tag{34}$$

$$0 \le P_{j,t}^{IL-MG} \le \gamma_j^{MG} P_{j,t}^{MGL} \quad :\underline{\mu}_{j,t}^{7-MG}, \overline{\mu}_{j,t}^{7-MG} \quad \forall j,t \tag{35}$$

$$0 \le P_{j,t}^{ESch} \le \overline{P}_j^{ESch} \quad :\underline{\mu}_{j,t}^{8-MG}, \overline{\mu}_{j,t}^{8-MG} \quad \forall j,t \tag{36}$$

$$0 \le P_{j,t}^{ESdch} \le \overline{P}_j^{ESdch} \quad :\underline{\mu}_{j,t}^{9-MG}, \overline{\mu}_{j,t}^{9-MG} \quad \forall j,t \tag{37}$$

$$\underline{E}_j^{ES} \le E_{j,t}^{ES} \le \overline{E}_j^{ES} \quad :\underline{\mu}_{j,t}^{10-MG}, \overline{\mu}_{j,t}^{10-MG} \quad \forall j,t \tag{38}$$

$$E_{j,t}^{ES} = E_{j,t-1}^{ES} + \eta_j^{ch} P_{j,t}^{ESch} - \frac{P_{j,t}^{ESdch}}{\eta_j^{dch}} \quad :\lambda_{j,t}^{1-MG} \quad \forall j,t>1 \tag{39}$$

$$E_{j,t}^{ES} = E_{j,ini}^{ES} + \eta_j^{ch} P_{j,t}^{ESch} - \frac{P_{j,t}^{ESdch}}{\eta_j^{dch}} \quad :\lambda_{j,t}^{2-MG} \quad \forall j,t=1 \tag{40}$$

The variable vector of the MGs strategy is defines as: $Y = \{P_{j,t}^{Dis-MG}, P_{j,t}^{DG}, P_{j,t}^{IL-MG}, P_{j,t}^{ESch}, P_{j,t}^{ESdch}, E_{j,t}^{ES}\}$. The objective function of MGs problem is modeled by (27) which consists of the income of the trading electricity with the Disco, the cost of DGs, and the cost of load interruption provided by responsive demand of each MG.

Eq. (28) guarantees the power balance limit; (29) limits the power exchanged between the Disco and each MG; (30) illustrates minimum and maximum output power of the DGs; (31)-(34) consider RU and RD limits of the DGs in each MG, respectively; (35) limits the upper bounds of the amount of load interruption; (36), (37) indicate the capacity limit of ES charging and discharging power, respectively; (38) represents the upper/lower limits of energy stored in the ES; finally (39), (40) show state of charge of ES.

D. *Mathematical Program with Equilibrium Constraints (MPEC)*

The presented strategy in the former sub-sections was a non-linear bi-level problem. Since the decision variables of UL problem would be treated as parameters in LL problems, such decision variables would be replaced considering KKT conditions [2], [13], [17].

Consequently, the bi-level model should be changed to a single-level model called MPEC. Furthermore, the non-linear formulations at UL problem would be substituted to linear terms by means of duality theory [2], [13]. The subsequent method would be an MILP formulation.

V. CASE STUDY AND RESULTS

To examine the efficiency of the proposed method, it has been tested on RTS 24-bus test case. The forecasted output of wind turbine (WT), the photovoltaic (PV) sets, the RERs and DNL data are given in [6], [18]. The maximum power capability of Disco exchange with the wholesale market has assumed to be 50 MW.

The modified details of each MG including ES, DG, and responsive load, the operation cost of RERs and the revenue/cost of load consumption/interruption which the Disco receives/pays it to the DNLs are extracted from [6], [13], [14]. Input data of this power system are presented in [16], [19].

The TNL number 17 placed at TN node 20, i.e., $m = 20$, is replaced with DN, and node 13 is assumed the reference node. The Disco's outcomes in the fourth scenario ($\omega = 4$) are presented as follows. It is noteworthy that the probability of the mentioned scenario is the highest among the considered scenarios in which the risk aversion parameter is zero.

- The wholesale market clearing price (MCP) and local market price (LMP) at each time step are shown in Fig. 3. The Disco's power balance is illustrated in Fig. 4. The results show that, the Disco's offers/bids to MGs are dependent on the cost of MGLs interruption, operation cost of MGs' DGs, and technical features of the resources such as ramp rates and so on. The LMPs are equivalent to the DGs' operation cost at hours 1-5 and 10-24. In hour 8, the LMP is equal to the cost of MGLs interruption.

  Moreover, at other time slots, the LMPs are obtained based on dynamic behavior of the ES of MG 1. The Disco buys energy from the wholesale market with low MCP to supply the DNL and selling power with higher prices to the MGs at hours 3-6. To decrease the ETC and bought energy from the wholesale market with high MCP, the Disco decides to present the bids which is less than MCP to the MGs and purchases power from them at hours 9-11, 14-17, and 20-21.

- The power balance between Gencos, TNL, and Disco in the wholesale market is illustrated in Fig. 5. Gencos/TNLs can be act as a price-maker at some hours.

  It should be noted that, Disco acts as a price-making participant in the wholesale market through interaction with MGs and its RERs. Therefore, its strategic offers/bids in the wholesale market can change the wholesale market outcomes including MCP, energy exchange amongst the Disco and the wholesale market, and power generation/consumption of Gencos/TNLs.

According to Figs. 3 and 5, the Disco can change MCP from 10.66, 18.20, 18.20, 11.96, and 10.66 $/MWh to 10.25, 15.97, 15.97, 11.72, and 10.25 $/MWh at hours 2, 15, 16, 22, and 24, respectively. The TNLs are price-making participants in the DA market during the period between 9-14 and 17-20, because MCP equals to 18.20 $/MWh. In addition, Gencos are also price-maker participants in periods 1, 3-8, 21, and 23.

To assess the impact of risk index, α is set to 0.8, which can mean the Disco would trust to 80% of scenarios and would manage 20% of them. Fig. 6 indicates the impacts of various values of risk aversion parameter on ETC and CVaR. As it can be seen, by considering higher values for the risk aversion parameter, the Disco's ETC increases and CVaR drops. When the mentioned parameter increases, the Disco changes its first decision variables including power exchange with market and MGs to decrease the $(1-\alpha)$ % worst scenarios.

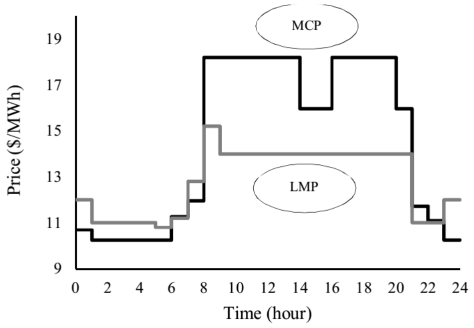

Fig. 3. MCP and LMP at each time interval.

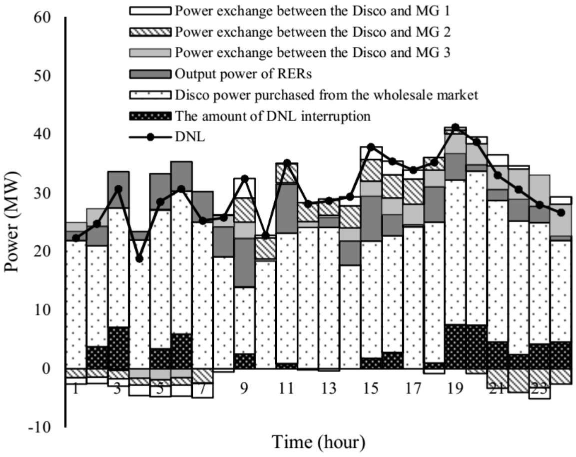

Fig. 4. Share of different power resources of the Disco to supply DNL.

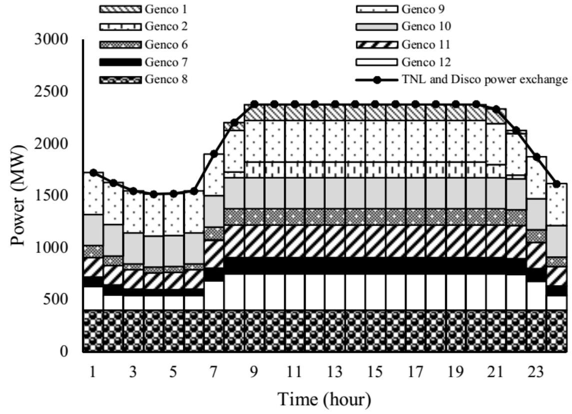

Fig. 5. Share of each Genco to supply TNL and power sold to the Disco.

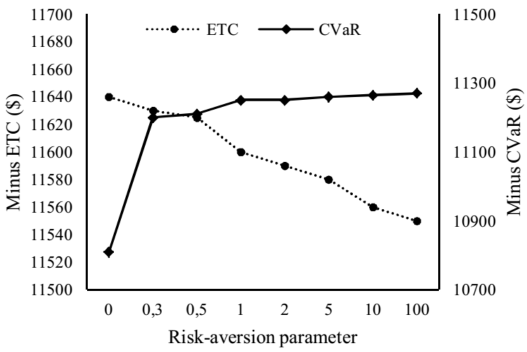

Fig. 6. Impact of risk-aversion parameter on ETC and CVaR.

The risk-averse Disco ($\beta = 100$, typically) decides to increase purchased power from the market from 17.332MW to 25.406MW and bought power from MGs by the Disco is decreased from 4.135MW to 0.885MW at hours 2 and 9, respectively. Therefore, the Disco's bids/offers in the wholesale and local markets change from 10.25$ and 15.20$ to 10.66$ and 14.00$, respectively. So, the risk parameter had critical impacts on the first-stage decision making of Disco that varies the markets outcomes and Disco's offers/bids to the markets.

VI. CONCLUSION

In this paper, a risk-based two-stage stochastic bi-level model was proposed to investigate the strategic behavior of a Disco in wholesale and local markets. In the proposed model, the UL decision maker is the Disco and the LL decision makers are ISO and MGs. The numerical studies showed that the performance of the Disco in the wholesale market using participation in the local market and interaction with the RERs and IL loads decreased the ETC. The Disco represented strategic offers/bids in the wholesale and local markets and acted as a price-making participant in these markets. Therefore, the Disco may affect the market's outcomes. Moreover, to decrease the CVaR, the risk-averse Disco changed first-stage decisions such as bids/offers in the markets and, consequently, the wholesale market clearing process and operation problem of each MG may change.

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