2015 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)

Distribution Company and Microgrids Behaviour in Energy and Reserve Equilibirum

M. Parsa Moghaddam, S. Bahramara, M.Y. Damavandi, M.R. Haghifam
Faculty of Electrical and Computer Engineering
Tarbiat Modares University (TMU)
Tehran, Iran
parsa@modares.ac.ir

***Abstract*—In this paper, the cooperation of distribution company (Disco) and microgrids (MGs) in a local energy and reserve markets is addressed. To investigate the behavior of these decision makers in local energy and reserve equilibrium, a bi-level optimization model is presented. In the proposed bi-level model, Disco and MGs are considered as the leader and the followers, respectively. Disco decides about energy and reserve price in local markets. In addition, MGs decides about optimal scheduling of their resources and energy and reserve interactions with Disco in local markets. In energy and reserve equilibrium point, the local energy and reserve prices and the amount of energy and reserve interactions between Disco and MGs are determined. Duality theory is employed to solve the proposed bi-level model. The proposed model has been applied on a distribution grid with four MGs and the numerical results demonstrate the effectiveness of the proposed modeling framework.**

***Index Terms*—Active distribution grid, bi-level optimization problem, dual theory, local energy and reserve markets.**

I. Nomenclature

Indices

j	Number of microgrid
EM	Energy market
RM	Reserve market
LEM	Local energy market
LRM	Local reserve market
D	Distribution company (Disco)
MG	Microgrid
DG	Diesel generator
IL	Interruptible load
$Demand$	Energy demand
in	Input energy to disco or microgrid
out	Output energy from disco or microgrid

Parameters and Variables

p, P	The amount of power
r	The amount of reserve
κ	Probability
FOR	Forced outage rate
π, Π	Price
$\overline{\Pi}$	Price cap
η	Efficiency

Remark I: An overlined variable is used to represent the maximum value of that variable.

Remark II: Capital letters denote parameters and small ones denote variables.

II. Introduction

A. Motivation and Aim

Reducing fossil fuel consumption, mitigating greenhouse gas emissions, and enhancing efficiency of power delivery cause more attention for meeting the load locally. To achieve this goal, distributed energy resources (DERs) emerged in distribution grid level [1]. In such environment, microgrids (MGs) are introduced as a framework to integrate DERs to satisfy local loads in both grid connected and isolated modes. Therefore, there are two levels of decision makers in active distribution grids (ADGs) including distribution company (Disco) and MGs. The cooperation of these two levels of energy players is a key factor to fill the gap between wholesale energy markets and small scale demand side players. Moreover, this cooperation framework enhances flexibility of Disco to participate in wholesale energy and reserve markets by releasing inherent flexibility of MGs.

Modeling the cooperation environment between these energy players in demand side introduces new challenges for researchers in energy studies. In this environment, each decision maker optimizes its objective function with respect to its internal energy resource scheduling and cooperates with other decision makers to enhance its functionality. Therefore, the aim of this paper is modeling the cooperation environment of Disco and MGs in distribution grid level.

B. Literature review and Contributions

The presence of MGs on the ADGs is evaluated from different viewpoints in [2-5]. In these papers, the impact of MGs on the economical, technical, and environmental issues of ADGs is investigated comprehensively, but the cooperation frameworks between Disco and MGs are not discussed. The cooperation between MGs is modeled in [6-8]. Cooperation of several MGs is modeled as cooperative power dispatching algorithm in [6] to power sharing with the main grid. Energy resource scheduling of several MGs is modeled using multi-

978-1-4673-8132-1/15/$31.00 ©2015 IEEE

agent systems in [7]. A decentralized optimal control algorithm is presented in [8] to energy management in distribution grid with multi-microgrids. Moreover, the cooperation between Disco and MGs is evaluated using system of systems (SOS) framework in [9, 10]. In the proposed framework in these papers, Disco and MGs are considered as the independent entities and cooperation between them is modeled in a hierarchical framework. At first, all MGs receive required parameters from Disco and solve their objective function individually. Then, Disco receives required parameters to solve its objective function from MGs. This process is continued until the convergence condition which is defined for this problem is satisfied.

On the other hand, the participation of Disco in wholesale energy and reserve markets are investigated in many literatures [11-16]. In [11] a two-stage framework is presented to model the behavior of Disco in day-ahead and real time markets. At the first stage, Disco decides about participation in day-ahead market and its resource scheduling. These decisions are used in the second stage of the Disco problem in which Disco participate in real market with optimal scheduling of resources. The proposed framework for operation of Disco in [11] is extended with notice to uncertainties of real-time market prices and load in [12]. Participation of Disco in both energy and reserve markets is investigated in [14-16]. In these papers, Disco includes DGs and interruptible loads (IL). Therefore, the optimal decision of Disco for participating in competitive markets is determined with respect to the optimal scheduling of these resources. In ADGs, with presence of MGs, Disco can participate in wholesale energy and reserve markets considering its cooperation with MGs in a local energy and reserve markets. In fact, in distribution grid level, there is energy and reserve equilibrium between Disco and MGs.

The main contributions of this paper are as follows:

- Proposing a bi-level optimization problem for modeling local energy and reserve equilibrium in distribution grid levels.
- Transforming this bi-level problem to a single level mixed-integer linear problem by applying duality theory.

C. paper organization

The rest of the paper is organized as follows. In section III, the problem description is presented. The problem is formulated in Section IV. Numerical results are presented in section V and the paper is concluded in section VI.

III. Problem Description

In this paper, the cooperation of Disco and MGs in energy and reserve local markets is addressed. Fig. 1 demonstrates the energy and reserve interactions between these decision makers. Regarding the signal prices of energy and reserve (Π^{EM} and Π^{RM}) which Disco receives from the wholesale markets, it decides about the energy and reserve interactions with markets. On the other hand, Disco offers the signal prices of energy and reserve (π^{LEM} and π^{LRM}) to the MGs. MGs receives these prices and schedule their resource and deciding to interact the energy and reserve with Disco. The behavior of Disco and MGs in this environment is modeled as a bi-level optimization problem, which consists of two levels of decision makers namely as leader and followers, respectively. Therefore, in the proposed model, Disco is leader and MGs are considered as the followers. To solve this problem, the Karush-Kuhn-Tucker (KKT) optimality conditions and duality theory are used. Using these methods, the bi-level optimization problem is transformed to a mathematical programing with equilibrium constraints (MPEC).

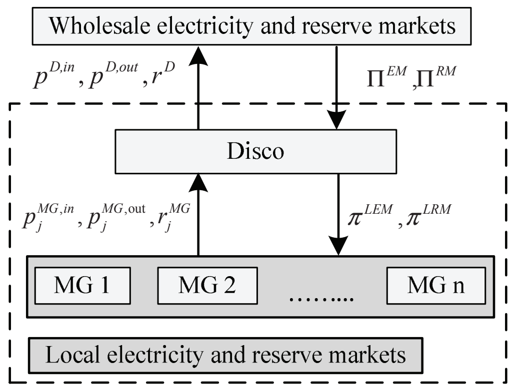

Fig. 1. A schematic of the interactions between Disco and MGs.

IV. Mathematical Modeling

A. Bi-Level Formulation

Disco and MGs decision making in local energy and reserve markets are modeled as a bi-level optimization problem as follow:

$$Maximize\left\{Profit^{D,EM}+Profit^{D,RM}+Profit^{D,LRM}+Profit^{D,LEM}\right\} \quad (1)$$

$$Profit^{D,EM}=-\left(p^{D,in}-p^{D,out}\right)\Pi^{EM} \quad (2)$$

$$Profit^{D,RM}=r^{D}\Pi^{RM}+\kappa^{RM}r^{D}\Pi^{EM}-\kappa^{RM}r^{D}FOR^{D}\Pi^{EM} \quad (3)$$

$$Profit^{D,LRM}=\sum_{j}\left(-r_j^{MG}\pi^{LRM}-\kappa^{RM}r_j^{MG}\pi^{LEM}+\kappa^{RM}r_j^{MG}FOR_j^{MG}\pi^{LEM}\right) \quad (4)$$

$$Profit^{D,LEM}=\sum_{j}\left(p_j^{MG,in}-p_j^{MG,out}\right)\pi^{LEM} \quad (5)$$

Subject to:

$$0\le\pi^{LEM}\le\overline{\Pi}^{LEM},\ 0\le\pi^{LRM}\le\overline{\Pi}^{LRM} \quad (6)$$

$$0\le p^{D,in}\le\overline{P}^{D} \quad (7)$$

$$p^{D,out}\ge 0 \quad (8)$$

$$p^{D,out}+r^{D}\le\overline{P}^{D} \quad (9)$$

$$r^{D}\ge 0 \quad (10)$$

$$\sum_{j}\left(p_j^{MG,in}-p_j^{MG,out}\right)=p^{D,in}\eta^{D}-p^{D,out}/\eta^{D} \quad (11)$$

$$\sum_{j}r_j^{MG}=r^{D}/\eta^{D} \quad (12)$$

$$Where\ \mathbf{\Gamma}_j \in arg\Big\{Minimize\Big(p_j^{MG,in} - p_j^{MG,out}\Big)\pi^{LEM} + c_j^{DG}p_j^{DG} + c_j^{IL}p_j^{IL} - r_j^{MG}\pi^{LRM} - \kappa^{RM}r_j^{MG}\pi^{LEM} + \kappa^{RM}r_j^{MG}FOR_j^{MG}\pi^{LEM} + c_j^{DG}\kappa^{RM}r_j^{DG} \quad (13)$$

$$p_j^{MG,out} \geq 0 \quad :\mu_j^1\ ,\ p_j^{MG,out} + r_j^{MG} \leq \overline{P}_j^{MG} \quad :\mu_j^2 \quad (14)$$

$$0 \leq p_j^{MG,in} \leq \overline{P}_j^{MG} \quad :\mu_j^3,\mu_j^4 \quad (15)$$

$$p_j^{DG} \geq 0 \quad :\mu_j^5\ ,\ p_j^{DG} + r_j^{DG} \leq \overline{P}_j^{DG} \quad :\mu_j^6 \quad (16)$$

$$0 \leq p_j^{IL} \leq \overline{P}_j^{IL} \quad :\mu_j^7,\mu_j^8 \quad (17)$$

$$r_j^{DG} \geq 0 \quad :\mu_j^9 \quad (18)$$

$$r_j^{DG} = r_j^{MG}/\eta_j^{MG} \quad :\lambda_j^1 \quad (19)$$

$$p_j^{MG,in}\eta_j^{MG} + p_j^{DG} + p_j^{IL} = p_j^{MG,out}/\eta_j^{MG} + P_j^{Demand} \quad :\lambda_j^2\Big\},\forall j \quad (20)$$

Equations (1)-(12) represent the decision making problem of Disco and the decision making problem of each MG is described in (13)-(20). Objective function of Disco is modeled in (1) that consists of four main terms. Equation (2) describes the first term which models the energy interaction of Disco with wholesale energy market. The reserve provision for wholesale reserve market and buying reserve from local reserve market are modeled by (3) and (4), respectively. The reserve interaction includes income from reserve provision and delivering energy after reserve call and penalty for not being ready to deliver required reserve amount. Disco buys the reserve service from MGs in equilibrium reserve price (π^{LRM}) and provides reserve service in wholesale reserve market (Π^{RM}) for upstream network. Moreover, energy interaction with local energy market is described by (5). Cooperation between Disco and MGs determines equilibrium energy price (π^{LEM}) in local energy market. The local energy and reserve prices are limited by (6) to avoid price spike in local energy markets. Equations (7)-(10) determine the restriction of Disco to exchange energy and reserve with upstream network. Moreover, the energy and reserve balance of Disco is modeled in (11) and (12), respectively.

The objective function of each MG is modeled in (13) that consists of energy exchange with Disco, DG generation cost, cost of the load curtailment, and reserve financial interaction with Disco. Γ_j is the vector of lower level problem decision variables including $\Gamma_j = [p_j^{MG,in}, p_j^{MG,out}, r_j^{MG}, p_j^{DG}, p_j^{IL}]$. The capability of MGs to exchange energy and reserve with Disco is bounded by (14) and (15). Furthermore, (16)-(18) represent the operational limits for DGs and ILs to provide energy and reserve in MGs. The reserve and energy balance are illustrated in (19) and (20), respectively. λ and μ are the dual variables for equality and non-equality constraints of lower level problem, respectively that are shown in the right hand of each equation.

B. MPEC

In this paper, the proposed bi-level problem is transformed to a MPEC through KKT optimality conditions [17-20]. The main assumption to apply this method is that the lower level problems (i.e. MGs problems) should be a convex and linear problem. Due to the upper level price signals are introduced as input parameters for lower level problem, the lower level problem is considered as a convex and linear optimization problem. Moreover, the nonlinear terms of Disco's objective function is replaced with linear ones using dual theory. The MPEC formulation of the bi-level problem is as follow:

$$Maximize\ \Big\{-\Big(p^{D,in} - p^{D,out}\Big)\Pi^{EM} + r^D\Pi^{RM} + \kappa^{RM}r^D\Pi^{EM} - \kappa^{RM}r^D FOR^D\Pi^{EM} + \sum_j\Big(-c_j^{DG}p_j^{DG} - c_j^{IL}p_j^{IL} - c_j^{DG}\kappa^{RM}r_j^{DG} - \overline{P}_j^{MG}\mu_j^2 - \overline{P}_j^{MG}\mu_j^4 - \overline{P}_j^{DG}\mu_j^6 - \overline{P}_j^{IL}\mu_j^8 + P_j^{Demand}\lambda_j^2\Big)\Big\} \quad (21)$$

Subject to:

Equations (6)-(12).

Equations (19) and (20).

$$\pi^{LEM} - \mu_j^3 + \mu_j^4 - \lambda_j^2\eta_j^{MG} = 0 \quad (22)$$

$$-\pi^{LEM} - \mu_j^1 + \mu_j^2 + \lambda_j^2/\eta_j^{MG} = 0 \quad (23)$$

$$c_j^{DG} - \mu_j^5 + \mu_j^6 - \lambda_j^2 = 0 \quad (24)$$

$$c_j^{IL} - \mu_j^7 + \mu_j^8 - \lambda_j^2 = 0 \quad (25)$$

$$-\pi^{LRM} - \kappa^{RM}\pi^{LEM} + \kappa^{RM}FOR_j^{MG}\pi^{LEM} + \lambda_j^1/\eta_j^{MG} - \mu_j^1 + \mu_j^2 = 0 \quad (26)$$

$$c_j^{DG}\kappa^{RM} - \mu_j^5 + \mu_j^6 - \mu_j^9 - \lambda_j^1 = 0 \quad (27)$$

$$0 \leq p_j^{MG,out} \perp \mu_j^1 \geq 0 \quad (28)$$

$$0 \leq \Big(\overline{P}_j^{MG} - p_j^{MG,out} - r_j^{MG}\Big) \perp \mu_j^2 \geq 0 \quad (29)$$

$$0 \leq p_j^{MG,in} \perp \mu_j^3 \geq 0 \quad (30)$$

$$0 \leq \Big(\overline{P}_j^{MG} - p_j^{MG,in}\Big) \perp \mu_j^4 \geq 0 \quad (31)$$

$$0 \leq p_j^{DG} \perp \mu_j^5 \geq 0 \quad (32)$$

$$0 \leq \Big(\overline{P}_j^{DG} - p_j^{DG} - r_j^{DG}\Big) \perp \mu_j^6 \geq 0 \quad (33)$$

$$0 \leq p_j^{IL} \perp \mu_j^7 \geq 0 \quad (34)$$

$$0 \leq \overline{P}_j^{IL} - p_j^{IL} \perp \mu_j^8 \geq 0 \quad (35)$$

$$0 \leq r_j^{DG} \perp \mu_j^9 \geq 0 \quad (36)$$

$$0 \leq r_j^{MG} \perp \mu_j^{10} \geq 0 \quad (37)$$

Equation (21) is the linear form of (1) that the non-linear terms ($p_j^{MG,in}\pi^{LEM}$, $p_j^{MG,out}\pi^{LEM}$, $r_j^{MG}\pi^{LRM}$, $\kappa^{RM}r_j^{MG}\pi^{LEM}$, and $\kappa^{RM}r_j^{MG}FOR_j^{MG}\pi^{LEM}$) are replaced through strong duality condition. Equations (22)-(27) are the stationarity conditions of lower level problem which are the first order derivations of lagrangian functions with respect to primal variables. In addition, (28)-(37) demonstrate the complementary slackness for non-equality equations of lower level problem. These nonlinear equations are transformed to linear ones as proposed in [17-20]. In addition, λ_j^1 and λ_j^2 are free variables because they are dual variables of equality constraints.

V. Numerical Results

To demonstrate the effectiveness of the proposed model, an ADG including four MGs are considered as the case study. All MGs are equipped with DG units and IL. The price cap for local energy and reserve markets are assumed as 80 and 50 (\$/MWh), respectively. Table I shows input data for MGs. Maximum interaction of MGs with Disco is considered with notice to some characteristics of MGs including maximum DG production, transformer efficiency, and demand. The maximum amount of interruptible loads is 10 percent of demand and the cost of it is \$41/MW. The Disco FOR is 0.04. The maximum interaction of Disco with wholesale market and its transformer efficiency are 40 MW and 0.95, respectively. The probability of reserve calling is 8 percent. The range of wholesale energy and reserve prices are collected from Spain electricity market [21]. To show the effectiveness of the proposed model, the behavior of Disco and MGs in different ranges of wholesale energy and reserve markets prices is investigated in this section.

TABLE I
Data of MGs' Elements

Elements	MG 1	MG 2	MG 3	MG 4
Cost of DG (\$/MW)	37	40	35	45
Maximum DG production (MW)	5	4	5.5	7
Maximum interaction with Disco (MW)	5	5.3	5.5	7.5
Transformer efficiency	0.95	0.95	0.95	0.95
FOR	0.02	0.02	0.02	0.02
Demand (MW)	4	5	4	7

Figures 2 and 3 depict the profit of Disco and the cost of MGs for various amount of wholesale energy and reserve prices. As it is shown in fig. 2, as the wholesale energy price increases, Disco purchases the required energy of MGs in higher price and consequently the profit of Disco decreases. On the other hand, the Disco as a provider of reserve service obtains higher profit while the wholesale reserve price increases. It should be noted that Disco as leader of this bi-level problem determines the main strategies to maximize its profit and MGs follow the leader strategies to minimize their cost as shown in fig. 3. Therefore, the cost of MGs operation is decreased while the profit of Disco is increased.

However, in some cases, the behavior of MGs does not follow the mentioned pattern. For instance while the reserve price is \$19/MWh, by increasing the energy price, the MGs operation cost is not increased, continuously in $\Pi^{EM} = \$36/MWh$ and $\Pi^{EM} = \$40/MWh$. Figure 4 depicts the behavior of MGs in this case. In case $\Pi^{EM} = \$34/MWh$, the Disco determines the local energy and reserve prices $\Pi^{LEM} = \$34/MWh$ and $\Pi^{EM} = \$1.12/MWh$ lower than the cost of DGs. Therefore, Disco maximizes its profit by delivering all demand and providing reserve to the wholesale market with purchasing reserve from MGs with lower local reserve price. In next case $\Pi^{EM} = \$36/MWh$, the Disco increases the local energy and reserve prices to $\Pi^{LEM} = \$38.95/MWh$ and $\Pi^{EM} = \$6.21/MWh$. As a matter of fact, with higher wholesale energy price, Disco delivers energy to MGs in higher price but to prevent the DGs' generation, it increases the reserve price to encourage the MGs to participate in local reserve market. In $\Pi^{EM} = \$38/MWh$, the Disco re-decreases the local energy and reserve prices to maintain its share from supplying MGs' demand. After case $\Pi^{EM} = \$40/MWh$, due to high wholesale energy price, Disco increases the local energy price continuously to maximize its profit.

Moreover, fig. 5 shows the variation of local energy and reserve prices while $\Pi^{EM} = \$40/MWh$. Disco due to increase of the wholesale reserve market, decreases the local energy price to increase its share from supplying the MGs' demand. Therefore, the Disco's purchased power from the wholesale energy market is increased. Two important behaviors of decision makers from figures 2-5 can be concluded. First, the leader-followers behavior of decision makers in which Disco as the leader determines strategies and MGs follow the leader strategies. Second, the cooperation environment between decision makers in which the profit of Disco and the cost of MGs are depended to each other.

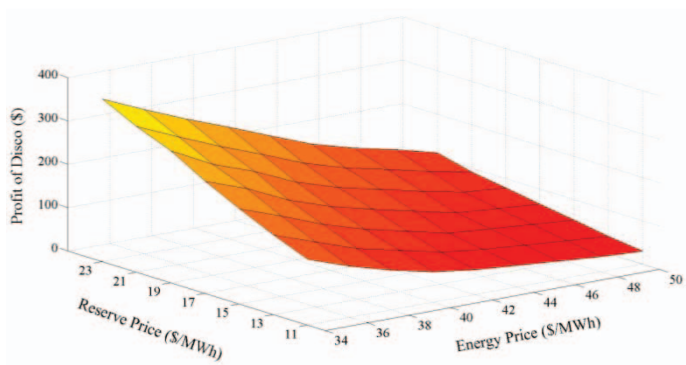

Fig. 2. Profit of Disco for different ranges of wholesale energy and reserve market prices.

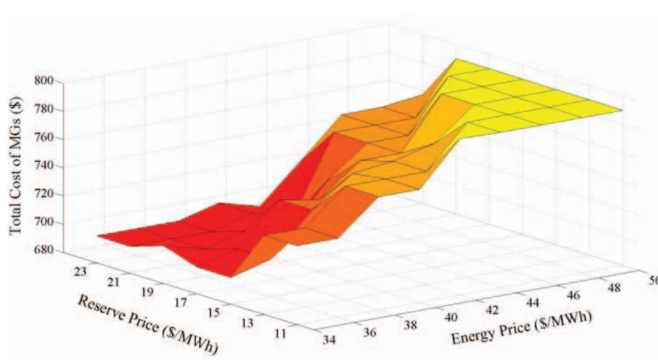

Fig. 3. Total cost of MGs for different ranges of wholesale energy and reserve market prices.

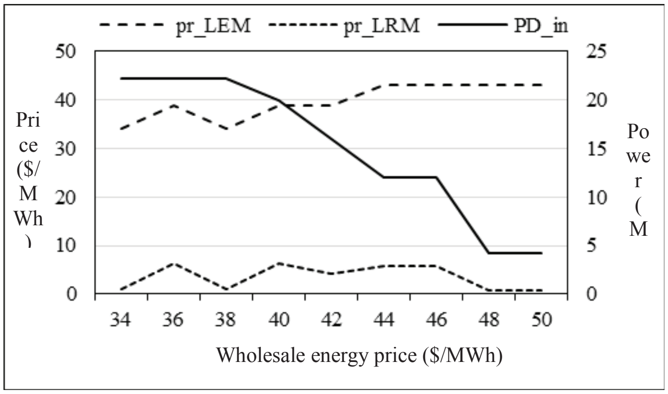

Fig. 4. Variation of locale energy and reserve prices and Disco's power exchange based on wholesale energy price while $\Pi^{RM} = \$19/MWh$.

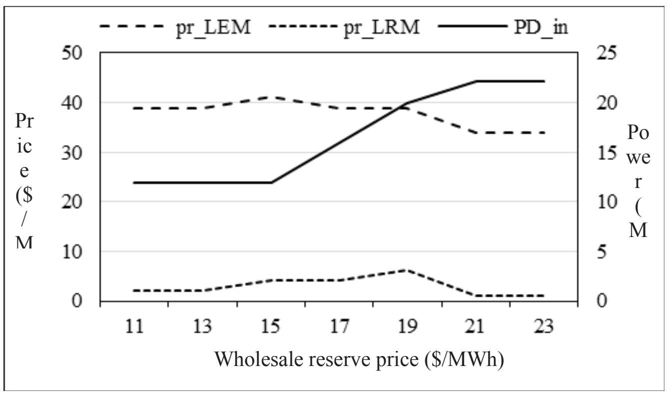

Fig. 5. Variation of locale energy and reserve prices and Disco's power exchange based on wholesale reserve price while $\Pi^{EM} = \$40/MWh$.

VI. Conclusion

In this paper, cooperation of Disco and MGs in local energy and reserve equilibrium has been investigated. This cooperation environment has been modeled as the bi-level optimization problem. To transform the proposed non-linear bi-level problem to a linear MPEC, KKT conditions and dual theory are employed. The numerical results have demonstrated the behavior of these decision makers in the local energy and reserve markets. The results show that the Disco as the leader of the problem determines its strategies about changing the local energy and reserve prices to maximize its profit. With variation of the local energy prices, MGs decides to supplying their demand with scheduling of resources or purchasing energy from the Disco. Moreover, due to variation of local reserve prices, MGs decide about participating in local reserve market by scheduling their DGs with providing the required reserve of Disco.

References

[1] S. Chowdhury and P. Crossley, *Micrograms and active distribution networks*: The Institution of Engineering and Technology, 2009.

[2] N. Hatziargyriou, A. Anastasiadis, A. Tsikalakis, and J. Vasiljevska, "Quantification of economic, environmental and operational benefits due to significant penetration of Microgrids in a typical LV and MV Greek network," *European Transactions on Electrical Power,* vol. 21, pp. 1217-1237, 2011.

[3] J. Vasiljevska, J. Lopes, and M. A. Matos, "Multi-microgrid impact assessment using multi criteria decision aid methods," in *PowerTech, 2009 IEEE Bucharest*, 2009, pp. 1-8.

[4] J. Vasiljevska, J. Peças Lopes, and M. Matos, "Evaluating the impacts of the multi-microgrid concept using multicriteria decision aid," *Electric Power Systems Research,* vol. 91, pp. 44-51, 2012.

[5] J. Vasiljevska, J. Peças Lopes, and M. Matos, "Integrated micro-generation, load and energy storage control functionality under the multi micro-grid concept," *Electric Power Systems Research,* vol. 95, pp. 292-301, 2013.

[6] M. Fathi and H. Bevrani, "Statistical Cooperative Power Dispatching in Interconnected Microgrids," *Sustainable Energy, IEEE Transactions on,* vol. 4, pp. 586-593, 2013.

[7] T. Logenthiran, D. Srinivasan, and A. M. Khambadkone, "Multi-agent system for energy resource scheduling of integrated microgrids in a distributed system," *Electric Power Systems Research,* vol. 81, pp. 138-148, 2011.

[8] W. Jiang and G. Xiaohong, "Coordinated Multi-Microgrids Optimal Control Algorithm for Smart Distribution Management System," *Smart Grid, IEEE Transactions on,* vol. 4, pp. 2174-2181, 2013.

[9] A. Kargarian, B. Falahati, and F. Yong, "Optimal operation of distribution grids: A system of systems framework," in *Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES*, 2013, pp. 1-6.

[10] A. Kargarian Marvasti, Y. Fu, S. DorMohammadi, and M. Rais-Rohani, "Optimal Operation of Active Distribution Grids: A System of Systems Framework," *Smart Grid, IEEE Transactions on,* vol. 5, pp. 1228-1237, 2014.

[11] A. A. Algarni and K. Bhattacharya, "A generic operations framework for discos in retail electricity markets," *Power Systems, IEEE Transactions on,* vol. 24, pp. 356-367, 2009.

[12] A. Safdarian, M. Fotuhi-Firuzabad, and M. Lehtonen, "A Stochastic Framework for Short-Term Operation of a Distribution Company," *Power Systems, IEEE Transactions on,* vol. 28, pp. 4712-4721, 2013.

[13] A. Borghetti, M. Bosetti, S. Grillo, S. Massucco, C. A. Nucci, M. Paolone, *et al.*, "Short-Term Scheduling and Control of Active Distribution Systems With High Penetration of Renewable Resources," *Systems Journal, IEEE,* vol. 4, pp. 313-322, 2010.

[14] M. Doostizadeh and H. Ghasemi, "Day-ahead scheduling of an active distribution network considering energy and reserve markets," *International Transactions on Electrical Energy Systems,* vol. 23, pp. 930-945, 2013.

[15] M. Mashhour, M. A. Golkar, and S. M. Moghaddas-Tafreshi, "Extending market activities for a distribution company in hourly-ahead energy and reserve markets – Part I: Problem formulation," *Energy Conversion and Management,* vol. 52, pp. 477-486, 1// 2011.

[16] A. Zakariazadeh, S. Jadid, and P. Siano, "Economic-environmental energy and reserve scheduling of smart distribution systems: A multiobjective mathematical programming approach," *Energy Conversion and Management,* vol. 78, pp. 151-164, 2014.

[17] D. G. Luenberger and Y. Ye, *Linear and nonlinear programming* vol. 116: Springer, 2008.

[18] E.-G. Talbi, *Metaheuristics for bi-level optimization*: Springer, 2013.

[19] G. E. Asimakopoulou, A. L. Dimeas, and N. D. Hatziargyriou, "Leader-Follower Strategies for Energy Management of Multi-Microgrids," *Smart Grid, IEEE Transactions on,* vol. 4, pp. 1909-1916, 2013.

[20] S. Kazempour, A. J. Conejo, and C. Ruiz, "Strategic generation investment using a complementarity approach," *Power Systems, IEEE Transactions on,* vol. 26, pp. 940-948, 2011.

[21] "http://www.esios.ree.es/web-publica/."