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Modeling Cooperation of Multi-Microgrids in Smart Distribution Netowroks

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Abstract— **In this paper, cooperation of several microgrids (MGs) in smart distribution networks is addressed. To investigate the behavior of MGs, a bi-level optimization model is presented. In the proposed bi-level model, MGs and distribution company (Disco) are considered as the leader and the followers, respectively. MGs decide about optimal scheduling of their resources and price offers to Disco for energy interactions with other MGs. In addition, Disco determines trading energy between MGs and energy transaction with wholesale electricity market as well. To obtain the equilibrium point, the Karush-Kahn-Tucker (KKT) conditions and dual theory are used to transform the proposed bi-level model to the equilibrium problem with equilibrium constraints (EPECs). In equilibrium point, the energy trading between MGs, energy trading with wholesale electricity market, and MGs' resources scheduling are determined. The proposed approach has been applied on a distribution grid with four MGs and the numerical results demonstrate the effectiveness of the proposed modeling framework.**

Keywords— ***Microgrids, smart distribution networks, bi-level optimization problem, dual theory, Karush-Kahn-Tucker conditions.***

I. NOMENCLATURE

Indices

j, j^*	Number of microgrid
EM	Energy market
MG	Microgrid
DG	Distributed generation
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
π	Price
$\overline{P}$	The maximum amount of power
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

Power system administrators are challenging with certain problems including restricted fossil fuel resources, greenhouse gas emissions, high investment cost in power generation and transmission, and low energy efficiency especially in distribution networks. Moreover, electrical energy consumption is increasing due to population growth and enhancement of life standards. To overcome these challenges, distributed generations (DGs) are emerged in distribution grids to serve the load locally [1]. Microgrids (MGs) are introduced as a framework to integrate DGs with local loads [2]. Therefore, there are several MGs in distribution networks. Each MG can operate in both grid connected and standalone modes. MGs minimize their objective function in the time period of operation with optimal scheduling of their resources and optimal energy trading with distribution company (Disco). Moreover, to operate the distribution networks in an optimal manner, MGs can cooperate with each other. In fact, energy trading with other MGs is added to objective function of each MG. This cooperation increases the usage of the MGs' resources and decreases the cost of the whole network. Modeling the cooperation between MGs introduces new challenges for the researchers.

In the literature, optimal operation of MGs is investigated in both grid connected and standalone modes from different viewpoints [3-6]. For instance, the operation problem of MGs considering uncertainty is modeled as a linear two-stage stochastic model in [4]. In some other studies the cooperation between MGs is modeled using different approaches [7-11]. In [7] the energy consumption scheduling of a distribution network including several MGs is modeled as a multi-objective optimization problem. In the above study, an adaptive scheduling approach is presented with online stochastic iteration to obtain optimal solution. Cooperation of several MGs is modeled as cooperative power dispatching algorithm in [8] to power sharing with the main grid. Energy resource scheduling of several MGs is modeled using multi-agent systems in three stages in [9]. In the first stage, each MG optimizes its objective function individually. In the next one, the best possible bids for energy trading with the wholesale energy market are determined. In the final stage, each MG reschedules its decision variables with notice to the previous stages. A decentralized optimal control algorithm is presented in [10] to manage energy in distribution grid with multi-microgrids. To solve the problem a coordinated dynamic programming algorithm is used. A comprehensive economic power transaction of several MGs using multi-agent system is proposed in [11].

In this paper, a bi-level optimization approach is used to model the operation problem of each MG considering the behavior of other MGs. Then, to model the cooperation of several MGs in distribution networks, the proposed bi-level model is transformed to a multi-objective equilibrium problem with equilibrium constraints (MOEPECs) using the Karush-Kahn-Tucker (KKT) conditions and dual theory. In such framework, MGs are coupled with each other through price signal. Based on this price signal which couples the MGs, optimal scheduling of MGs' resources and optimal power purchased from the market are determined. Therefore, the main contributions of this paper are as follows:

- Modeling the cooperation between several MGs as a bi-level optimization problem.
- Transforming this non-linear bi-level problem to a single level mixed-integer linear problem (MILP) by applying KKT conditions and dual theory.

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 framework of MGs in distribution networks is modeled as shown in Figure.1. For this purpose, at first, the operation problem of each MG considering the behavior of other MGs and Disco is modeled as the bi-level optimization problem in which the operation problem of each MG and Disco are considered as upper and lower levels problem. Each MG optimizes its objective function and proposes its price offer to disco for energy trading with other MGs. Disco receives the offers from MGs and solve its objective function to determine the energy trading with the wholesale electricity market and energy trading with MGs.

Since the prices offered by MGs are considered as parameters in the lower level problem, it is linear and convex. Therefore, each lower level problem can be replaced with its KKT optimality conditions and the resulting model is a mathematical programing with equilibrium constraints (MPEC). To determine the equilibrium point between MGs, MPEC of each MG which are obtained from previous step is replaced with its KKT conditions. The resulting model is named as EPEC. For solving this model, the sum of objective functions of MGs is considered as an appropriate objective function. The nonlinear terms in the model are transformed to linear expressions using the dual theory. The resulting model is MILP. In equilibrium point of the model, MGs' resources are dispatched, the power transactions between MGs are determined, and also the power purchased from the market is obtained. This cooperation between MGs can increase the utilization of MGs' resources and decreases the power purchased from the wholesale market in comparison with non-cooperative case. To implement of the proposed framework in real life, an advanced metering infrastructure (AMI) is required for exchange data between decision makers.

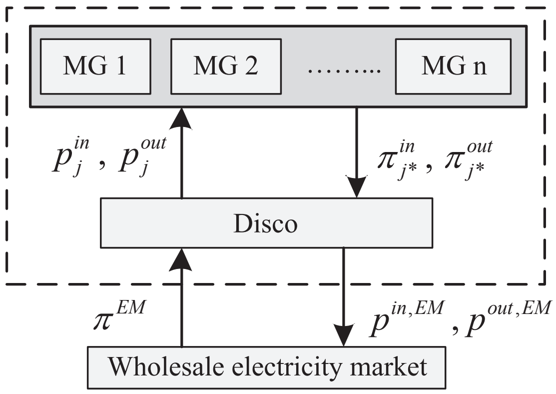

Fig. 1. The cooperation framework in distribution networks between Disco and MGs.

IV. Mathematical Modeling

The operation problem from the viewpoint of each microgrid is described as follows:

$$\text{Minimize}\left\{\left(p_{j^*}^{in}\lambda - p_{j^*}^{out}\lambda\right) + C_{j^*}^{DG} p_{j^*}^{DG} + C_{j^*}^{IL} p_{j^*}^{IL}\right\} \quad (1)$$

Subject to:

$$p_{j^*}^{in}\eta_{j^*}^{MG} - p_{j^*}^{out}/\eta_{j^*}^{MG} + p_{j^*}^{DG} + p_{j^*}^{IL} - p_{j^*}^{Demand} = 0 \quad : \gamma_{j^*}^1 \quad (2)$$

$$0 \le p_{j^*}^{DG} \le \bar{P}_{j^*}^{DG} \quad : \xi_{j^*}^1, \xi_{j^*}^2 \quad (3)$$

$$0 \le p_{j^*}^{IL} \le \bar{P}_{j^*}^{IL} \quad : \xi_{j^*}^3, \xi_{j^*}^4 \quad (4)$$

$$\pi_{j^*}^{in} \ge 0 \quad : \xi_{j^*}^5 \quad , \quad \pi_{j^*}^{out} \ge 0 \quad : \xi_{j^*}^6 \quad (5)$$

$$where\ \mathbf{\Gamma_j} \in arg\left\{\text{Minimize}\sum_j\left(-p_j^{in}\pi_j^{in} + p_j^{out}\pi_j^{out}\right) + p^{in,EM}\pi^{EM} - p^{out,EM}\pi^{EM}\right. \quad (6)$$

$$\sum_j\left(p_j^{in} - p_j^{out}\right) = p^{in,EM}\eta^{EM} - p^{out,EM}/\eta^{EM} \quad : \lambda \quad (7)$$

$$0 \le p_j^{in} \le \bar{P}_j \quad : \mu_j^1, \mu_j^2 \quad (8)$$

$$0 \le p_j^{out} \le \bar{P}_j \quad : \mu_j^3, \mu_j^4 \quad (9)$$

$$0 \le p^{in,EM} \le \bar{P}^{EM} \quad : \mu^5, \mu^6 \quad (10)$$

$$\left. 0 \le p^{out,EM} \le \bar{P}^{EM} \quad : \mu^7, \mu^8 \right\} \quad \forall j \quad (11)$$

Equations (1)-(5) represent the decision making problem of each MG and the decision making problem of Disco is described in (6)-(11). Each MG models the lower level problem from its viewpoint which in this case the indices j is equal to j* and also from the viewpoint of other MGs which for which the indices j is considered for MGs except j*. Therefore, Each MG models its optimal behavior considering optimal behavior of other decision makers.

The objective function of each MG modeled in (1) consists of three terms including the cost of energy trading with Disco, DG generation cost, and the cost of load curtailment. Equation

(2) describes the power balance constraint for each MG. The DG and IL operational limits are described by (3) and (4). Equation (5) limits the amount of the bid and offer of each MG to the positive ones.

The objective function of Disco is modeled by (6) including energy trading with MGs and with the wholesale electricity market. Equation (7) describes the power balance constraint of Disco in which the power trading with MGs is equal to the power exchange with the wholesale electricity market. The power exchange between MGs and Disco are limited by (8)-(9). In addition, the power trading of Disco with the wholesale electricity market is limited by (10)-(11). Γ_j is the vector of lower level problem decision variables including $\Gamma_j = \left[p_j^{in}, p_j^{out}, p_j^{in,EM}, p_j^{out,EM}, \lambda \right]$. γ and ξ are the dual variables for equality and non-equality constraints of upper level problem. Moreover, λ and μ are the dual variables for equality and non-equality constraints of lower level problem, respectively. Dual variables are shown in the right hand of each equation. The power losses of the distribution network is neglected and distribution network is considered as single bus network. However, the proposed model can be extended to consider the optimal power flow in distribution network.

A. MPEC Problem

In this paper, the proposed bi-level problem is transformed to a MPEC through KKT optimality conditions [12-15]. The main assumption to apply this method is that the lower level problems (i.e. Disco problem) should be a convex and linear problem. Since the upper level price offers are considered as input parameters for the lower level problem, this problem (the lower level problem) is taken as a convex and linear problem. The MPEC formulation of the bi-level problem is as follows:

Equations (1)-(5).

$$-\pi_j^{in} + \lambda - \mu_j^1 + \mu_j^2 = 0 \qquad : \gamma_{j*,j}^2 \tag{12}$$

$$\pi_j^{out} - \lambda - \mu_j^3 + \mu_j^4 = 0 \qquad : \gamma_{j*,j}^3 \tag{13}$$

$$\pi^{EM} - \lambda \eta^{EM} - \mu^5 + \mu^6 = 0 \qquad : \gamma_{j*,j}^4 \tag{14}$$

$$-\pi^{EM} + \lambda / \eta^{EM} - \mu^7 + \mu^8 = 0 \qquad : \gamma_{j*,j}^5 \tag{15}$$

$$\begin{aligned} &\sum_j \left(-p_j^{in} \rho_j^{in} + p_j^{out} \rho_j^{out} \right) + p^{in,EM} \rho^{EM} - p^{out,EM} \rho^{EM} \\ &+ \mu_j^2 \bar{P}_j + \mu_j^4 \bar{P}_j + \mu^6 \bar{P}^{EM} + \mu^8 \bar{P}^{EM} = 0 \qquad : \gamma_{j*,j}^6 \end{aligned} \tag{16}$$

$$\sum_j \left(p_j^{in} - p_j^{out} \right) - p^{in,EM} \eta^{EM} + p^{out,EM} / \eta^{EM} = 0 \qquad : \gamma_{j*}^7 \tag{17}$$

$$0 \le p_j^{in} \le \bar{P}_j \qquad : \xi_{j*,j}^7, \xi_{j*,j}^8 \tag{18}$$

$$0 \le p_j^{out} \le \bar{P}_j \qquad : \xi_{j*,j}^9, \xi_{j*,j}^{10} \tag{19}$$

$$0 \le p^{in,EM} \le \bar{P}^{EM} \qquad : \xi_{j*}^{11}, \xi_{j*}^{12} \tag{20}$$

$$0 \le p^{out,EM} \le \bar{P}^{EM} \qquad : \xi_{j*}^{13}, \xi_{j*}^{14} \tag{21}$$

$$\mu_j^1 \ge 0 \quad : \xi_{j*,j}^{15} \quad , \quad \mu_j^2 \ge 0 \quad : \xi_{j*,j}^{16} \tag{22}$$

$$\mu_j^3 \ge 0 \quad : \xi_{j*,j}^{17} \quad , \quad \mu_j^4 \ge 0 \quad : \xi_{j*,j}^{18} \tag{23}$$

$$\mu^5 \ge 0 \quad : \xi_{j*}^{19} \quad , \quad \mu^6 \ge 0 \quad : \xi_{j*}^{20} \tag{24}$$

$$\mu^7 \ge 0 \quad : \xi_{j*}^{21} \quad , \quad \mu^8 \ge 0 \quad : \xi_{j*}^{22} \tag{25}$$

Equations (12)-(15) describe the stationarity constraints of lower level problem which are the first order derivations of lagrangian functions with respect to primal variables. The complementary slackness constraints are replaced with strong duality constraint which is described with (16). Primal and dual constraints are described by (17)-(25). Therefore, equations (1)-(5) and (12)-(25) shows the MPEC of each MG. γ_{j*}^7 is the dual variable of power balance constraint of Disco which is the price signal that couples MGs to each other and MGs trade energy with each other based on it.

B. EPEC Problem

To access the equilibrium point between MGs, MPEC of each MG should be replaced with its KKT conditions as follows:

Equations (2), (12)-(17).

$$\left\{ \lambda - \gamma_{j*}^1 \eta_{j*}^{MG} \right\}_{j=j*} - \gamma_{j*,j}^6 \pi_j^{in} + \left\{ \gamma_{j*}^7 \right\}_{j=j*} - \xi_{j*,j}^7 + \xi_{j*,j}^8 = 0 \tag{26}$$

$$\left\{ -\lambda + \gamma_{j*}^1 / \eta_{j*}^{MG} \right\}_{j=j*} + \gamma_{j*,j}^6 \pi_j^{out} + \left\{ -\gamma_{j*}^7 \right\}_{j=j*} - \xi_{j*,j}^9 + \xi_{j*,j}^{10} = 0 \tag{27}$$

$$\left\{ \gamma_{j*,j}^6 \pi^{EM} \right\}_{j=j*} - \left\{ \gamma_{j*}^7 \eta^{EM} \right\}_{j=j*} - \xi_{j*}^{11} + \xi_{j*}^{12} = 0 \tag{28}$$

$$\left\{ -\gamma_{j*,j}^6 \pi^{EM} \right\}_{j=j*} + \left\{ \gamma_{j*}^7 / \eta^{EM} \right\}_{j=j*} - \xi_{j*}^{13} + \xi_{j*}^{14} = 0 \tag{29}$$

$$\left\{ -\xi_{j*}^5 \right\}_{j=j*} - \gamma_{j*,j}^2 - \gamma_{j*,j}^6 p_j^{in} = 0 \tag{30}$$

$$\left\{ -\xi_{j*}^6 \right\}_{j=j*} + \gamma_{j*,j}^3 + \gamma_{j*,j}^6 p_j^{out} = 0 \tag{31}$$

$$C_{j*}^{DG} - \gamma_{j*}^1 - \xi_{j*}^1 + \xi_{j*}^2 = 0 \tag{32}$$

$$C_{j*}^{IL} - \gamma_{j*}^1 - \xi_{j*}^3 + \xi_{j*}^4 = 0 \tag{33}$$

$$\left\{ p_{j*}^{in} - p_{j*}^{out} \right\}_{j=j*} + \gamma_{j*,j}^2 - \gamma_{j*,j}^3 - \gamma_{j*,j}^4 \eta^{EM} + \gamma_{j*,j}^5 / \eta^{EM} = 0 \tag{34}$$

$$-\gamma_{j*,j}^2 - \xi_{j*,j}^{15} = 0 \tag{35}$$

$$\gamma_{j*,j}^2 + \gamma_{j*,j}^6 \bar{P}_j - \xi_{j*,j}^{16} = 0 \tag{36}$$

$$-\gamma_{j*,j}^3 - \xi_{j*,j}^{17} = 0 \tag{37}$$

$$\gamma_{j*,j}^3 + \gamma_{j*,j}^6 \bar{P}_j - \xi_{j*,j}^{18} = 0 \tag{38}$$

$$-\gamma_{j*}^4 - \xi_{j*}^{19} = 0 \tag{39}$$

$$\gamma_{j*}^4 + \gamma_{j*,j}^6 \bar{P}^{EM} - \xi_{j*}^{20} = 0 \tag{40}$$

$$-\gamma_{j*}^5 - \xi_{j*}^{21} = 0 \tag{41}$$

$$\gamma_{j*}^5 + \gamma_{j*,j}^6 \bar{P}^{EM} - \xi_{j*}^{22} = 0 \tag{42}$$

$$0 \le p_{j*}^{DG} \perp \xi_{j*}^1 \ge 0 \quad , \quad 0 \le (\bar{P}_{j*}^{DG} - p_{j*}^{DG}) \perp \xi_{j*}^2 \ge 0 \tag{43}$$

$$0 \le p_{j*}^{IL} \perp \xi_{j*}^3 \ge 0 \quad , \quad 0 \le (\bar{P}_{j*}^{IL} - p_{j*}^{IL}) \perp \xi_{j*}^4 \ge 0 \tag{44}$$

$$0 \le \pi_{j*}^{in} \perp \xi_{j*}^5 \ge 0 \quad , \quad 0 \le \pi_{j*}^{out} \perp \xi_{j*}^6 \ge 0 \tag{45}$$

$$0 \le p_j^{in} \perp \xi_{j*,j}^7 \ge 0 \quad , \quad 0 \le (\bar{P}_j - p_j^{in}) \perp \xi_{j*,j}^8 \ge 0 \tag{46}$$

$$0 \le p_j^{out} \perp \xi_{j*,j}^9 \ge 0 \quad , \quad 0 \le (\bar{P}_j - p_j^{out}) \perp \xi_{j*,j}^{10} \ge 0 \tag{47}$$

$$0 \le p^{in,EM} \perp \xi_{j*}^{11} \ge 0 \quad , \quad 0 \le (\bar{P}^{EM} - p^{in,EM}) \perp \xi_{j*}^{12} \ge 0 \tag{48}$$

$$0 \le p^{out,EM} \perp \xi_{j*}^{13} \ge 0 \quad , \quad 0 \le (\bar{P}^{EM} - p^{out,EM}) \perp \xi_{j*}^{14} \ge 0 \tag{49}$$

$$0 \le \mu_j^1 \perp \xi_{j*,j}^{15} \ge 0 \quad , \; 0 \le \mu_j^2 \perp \xi_{j*,j}^{16} \ge 0 \tag{50}$$

$$0 \le \mu_j^3 \perp \xi_{j*,j}^{17} \ge 0 \quad , \; 0 \le \mu_j^4 \perp \xi_{j*,j}^{18} \ge 0 \tag{51}$$

$$0 \le \mu^5 \perp \xi_{j*}^{19} \ge 0 \quad , \; 0 \le \mu^6 \perp \xi_{j*}^{20} \ge 0 \tag{52}$$

$$0 \le \mu^7 \perp \xi_{j*}^{21} \ge 0 \quad , \; 0 \le \mu^8 \perp \xi_{j*}^{22} \ge 0 \tag{53}$$

Equations (2) and (12)-(17) show the equal constraints of MGs' MPEC. As equation (16) is nonlinear, it is replaced with complementary slackness constraints which are obtained from KKT conditions of (6)-(11). Equations (26)-(34) describe the stationarity constraints for MPEC of MGs. Moreover, the primal, dual, and complementary slackness constraints are described by (43)-(53). The complementary slackness constraints of the problem which are nonlinear are replaced with two sets of linear constraints as proposed in [2, 12].

To solve this problem, an appropriate objective function should be determined [16, 17]. In this paper, the total cost minimization of MGs is considered as the objective function which is described by (54). Therefore, the mentioned problem is described as MOEPEC. As the equation (54) has nonlinear terms, they are replaced with linear ones through dual theory. For this purpose, the dual problem of equations (6)-(11) is obtained. The resulted linear objective function is described by (55) with equations (2), (12)-(17), (26)-(53) as constraints which is a MILP model.

$$\text{Minimize} \sum_{j*} \left\{ \left(p_{j*}^{in} \lambda - p_{j*}^{out} \lambda \right) + C_{j*}^{DG} p_{j*}^{DG} + C_{j*}^{IL} p_{j*}^{IL} \right\} \tag{54}$$

$$\begin{aligned} &\text{Minimize} \sum_{j*} \left\{ C_{j*}^{DG} p_{j*}^{DG} + C_{j*}^{IL} p_{j*}^{IL} \right\} \\ &+ p^{in,EM} \pi^{EM} - p^{out,EM} \pi^{EM} + \mu^6 \bar{P}^{EM} + \mu^8 \bar{P}^{EM} \end{aligned} \tag{55}$$

V. NUMERICAL RESULTS

To demonstrate the effectiveness of the proposed model, a distribution network including four MGs are considered as the case study. All MGs are equipped with DG units and IL. Table I shows input data for MGs. The maximum amount of interruptible loads is 10 percent of the demand with the cost of \$41/MW. The maximum interaction of Disco with the wholesale electricity market and its transformer efficiency are 40 MW and 0.98, respectively. The range of the wholesale energy prices are collected from Spain electricity market [18].

TABLE I
DATA OF MGS' ELEMENTS

Elements	MG1	MG2	MG3	MG4
Cost of DG (\$/MW)	37	40	35	45
Maximum DG production (MW)	4	5	5.5	7
Maximum interaction with Disco (MW)	10	10	10	10
Transformer efficiency	0.98	0.98	0.98	0.98
Demand (MW)	2	4	3	5

In this paper, the Disco is considered as price taker in the wholesale electricity market which only purchases energy from market. To show the effectiveness of the proposed model, the behavior of MGs in different ranges of the wholesale energy prices is investigated in two cases. In the first one, the operation problem of each MG is solved individually which this case is named as "without coordination". In the second case, the operation results of MGs in cooperation framework are obtained which is named as "with coordination".

Figure 2 shows the operation results of MGs in cooperation framework. In case $\pi^{EM} = \$34/MWh$ and $\pi^{EM} = \$35/MWh$, the demand of the system is met by dispatching the MG3' DG and purchasing energy from the wholesale electricity market. When the price of wholesale electricity market is between $\$36/MWh$ and $\$38/MWh$, MG1' DG is also dispatched due to lower generation cost of this DG in comparison with other DGs. Then, for wholesale electricity market prices greater than and equal to $\$39/MWh$, the demand of the system is met by optimal scheduling of DGs and curtailing the MG4' demand. In this manner, the power purchased from the market is decreased and reach to zero. Due to higher generation cost of MG4' DG, it is not dispatched in any time. As it is shown in the results, the demand of MGs in cooperation framework is met by optimal dispatching of DGs and ILs and optimal purchasing energy from the wholesale electricity market.

Operation results of the system in case one (without coordination) and case two (with coordination) are compared in Figures 3 and 4. When the wholesale electricity market price is $\$34/MWh$ and $\$35/MWh$, the total cost of MGs is equal in two cases. Also, the total power generation of DGs and power purchased from the market is equal in these prices in two cases as shown in Figure 4. When the wholesale electricity prices are increased, the total cost of MGs in coordination case is decreased in comparison with the other case (without coordination). As a matter of fact, in "without cooperation" case with higher wholesale electricity price, each MG dispatches its DG to meet the demand partly and purchases the remaining demand from the wholesale market. On the other hand, in "cooperation case" with higher wholesale electricity price, MGs purchase less power from wholesale market and meet their demand with optimal scheduling of DGs as shown in Figure. 4 which lead to decrease the total operation cost of the system. Therefore, in cooperation framework utilization of DGs is increased and power purchased from the market is decreased.

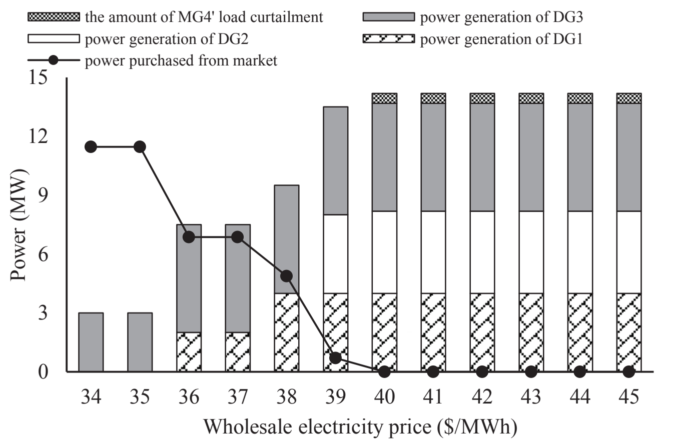

Fig. 2. Optimal scheduling of the distribution network in cooperation case

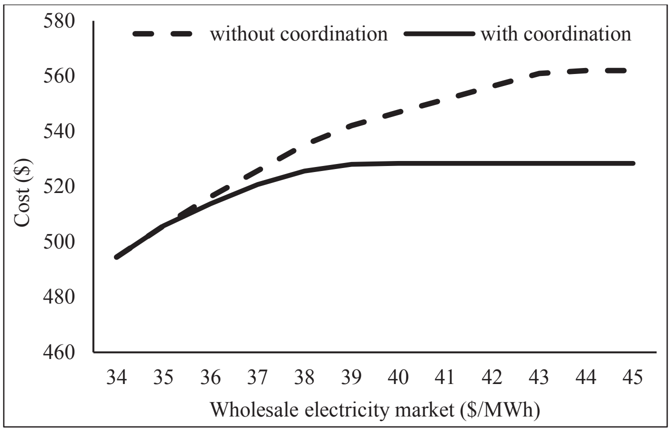

Fig. 3. Total cost of MGs in two cases for different ranges of wholesale energy market prices.

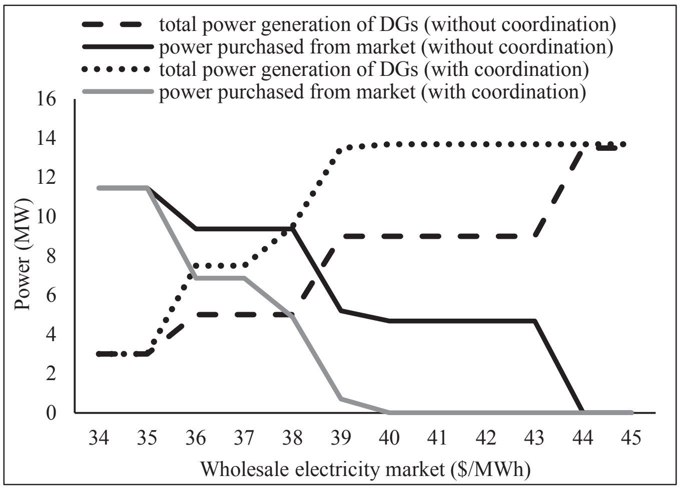

Fig. 4. Total power generation of DGs and power purchased from the market in two cases for different ranges of wholesale energy market prices.

VI. Conclusion

In this paper, cooperation of several MGs in distribution network has been investigated. This cooperation framework was modeled as a bi-level optimization problem. To transform the proposed non-linear bi-level problem to a linear MPEC, KKT conditions and dual theory was employed. Then, to determine the equilibrium point between MGs, the MPEC of each MG was replaced with its KKT conditions and MPEC has been transformed to EPEC. For solving this EPEC problem, an appropriate objective function is defined and with linearization of non-linear terms, the EPEC problem has been transformed to MILP. The numerical results were done in two cases named without coordination and with coordination. The operation results in coordination case show that MGs cooperate with each other to minimize the total operation cost. When the wholesale electricity price is increased, the power purchased from the market is decreased and the total power generation of DGs is increased. In addition, the results showed that, the total cost of MGs in cooperation case is decreased in compare with the other case due to optimal scheduling of DGs and lower energy purchased from the wholesale market.

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