A Bilevel Scheduling Approach for Modeling Energy Transaction of Virtual Power Plants in Distribution Networks

Farshid Nazari*, Ali Zangeneh(C.A.) and Ali Shayegan-Rad*

Abstract: By increasing the use of distributed generation (DG) in the distribution network operation, an entity called virtual power plant (VPP) has been introduced to control, dispatch and aggregate the generation of DGs, enabling them to participate either in the electricity market or the distribution network operation. The participation of VPPs in the electricity market has made challenges to fairly allocate payments and benefits between VPPs and distribution network operator (DNO). This paper presents a bilevel scheduling approach to model the energy transaction between VPPs and DNO. The upper level corresponds to the decision making of VPPs which bid their long- term contract prices so that their own profits are maximized and the lower level represents the DNO decision making to supply electricity demand of the network by minimizing its overall cost. The proposed bilevel scheduling approach is transformed to a single level optimizing problem using its Karush-Kuhn-Tucker (KKT) optimality conditions. Several scenarios are applied to scrutinize the effectiveness and usefulness of the proposed model.

Keywords: Bilevel scheduling approach; distributed generation; distribution network operator; Karush-Kuhn-Tucker; virtual power plant.

Nomenclature

Acronyms

DNO	Distribution network operator
DG	Distributed generation
DISCO	Distribution company
KKT	Karush-Kuhn-Tucker
VPP	Virtual power plant

Indices

i	Index of VPPs
j	Index of DGs
n, m	Index of network busses
nm	Index of network lines
t	Index of time intervals

Parameters

c_j	Production cost of DG j
$\overline{P}_{sb}$, $\underline{P}_{sb}$	Maximum and minimum substation limits for active power (MW)
$\overline{P}_{dg_j}$, $\underline{P}_{dg_j}$	Maximum and minimum DG capacity limits for active power (MW)
$P_n^{dn}(t)$	Active power demand in bus n at period t (MW)
$\overline{P}_{nm}$	Maximum active power flow limit in line (n-m) (MW)
$\overline{V}_n$, $\underline{V}_n$	Maximum and minimum limits on bus voltage n (KV)
Z_{nm}	Line impedance between busses n, m (Ω)
$\rho(t)$	Price of electricity market at period t (€ /MW t)
Δt	Time interval duration t (h)

Variables

$Cvpp_i$	Contract price of VPP i ($/MW h)
$P_{dg_j}(t)$	generation of DG j at period t (MW)
$P_n^{gn}(t)$	Active power injection at bus n at period t (MW)
$P_{nm}(t)$	Active power flow in line (n-m) at period t (MW)
$P_{sb}(t)$	Active power purchased from electricity market at period t (MW)
$V_n(t)$	Voltage of bus n at period t (kV)

$\overline{\delta}_k(t)$, $\underline{\delta}_k(t)$	Dual variable associated with the constraint of maximum and minimum substation limits for purchasing power from the electricity market at period t
$\overline{\omega}_n(t)$, $\underline{\omega}_n(t)$	Dual variable associated with the constraint of maximum and minimum voltage limits on bus n at period t
$\overline{\beta}_j(t)$, $\underline{\beta}_j(t)$	Dual variable associated with the constraint of maximum and minimum active power generated by DG j at period t
$\overline{\varphi}_{n,m}(t)$,	Dual variable associated with the constraint of maximum and minimum active
$\underline{\varphi}_{n,m}(t)$	Power flow limits from bus n to bus m at period t
$\pi_n(t)$	Dual variable associated with the constraint of active power balance in bus n at period t

1. Introduction

According to the IEA report [1], the liberalization of the electricity market and regulatory environment change has been one of the five reasons resulting in an increase in the penetration rate of distributed generations (DGs) which, however, this potential benefit had previously not been properly used due to both non-dispatchable characteristic and regulation barriers limiting the participation of small DGs in the electricity market [2]. To help solve this problem, a new entity, called virtual power plant (VPP), has been defined to aggregate and schedule DGs and enable them to either participate in the electricity market or provide system support [3, 4]. In other words, by using the concept of VPP, individual DGs can earn visibility and accessibility in addition to the fact that they benefit from market intelligence to maximize their revenues [5].

Researchers have introduced various kinds of VPPs with different functions in the previous literatures. Bignucolo et al. [6] define the VPP as an aggregator of the various DG technologies which are sited in different points of the medium voltage distribution network. In [7, 8] the application of VPP to facilitate trading of DGs in the electricity market and also the provision of ancillary services have been studied and Pudjianto et al. [9] present a VPP including several DGs with different operating patterns in detail and technologies connected to the distribution network. Authors of [10] propose a VPP aggregating power generation of both dispatchable and stochastic DGs in the distribution network to provide energy and required reserves to maximize the overall profit. Jadid and Bahreyni [11] presented a stochastic unit commitment model to schedule dispatchable and non-dispatchable units. They also render a novel three-program model which enable ag-

gregator to make contacts with loads and DGs and help to participate in the wholesale market through these contacts.

These papers only take into account one perspective and neglect the behavior of the other beneficiaries of the system. Hence, cost and benefit would be allocated among all market agents in an unreasonable manner. A bilevel scheduling approach which is usually composed of two agents can be used to overcome this drawback [12]. The first agent, the leader, is implemented in the upper-level of the bilevel model while the second, the follower, is considered in the lower-level. This approach provides a framework to model both the leader and the follower's interests [13]. Yu et al. [14] presented a novel bilevel programming model consisting of the VPP in the upper level and distributed energy resources in the lower level to determine the optimal economic dispatch. A bilevel scheduling model including robust coefficients regarding the uncertainties of wind power plant and photovoltaic is presented in [15]. This model maximizes the VPP revenue in the upper level based on the output prediction of wind power plant and photovoltaics in the day-ahead operation while in the lower level the day-ahead scheduling is revised with the actual output of the wind power plant and photovoltaic. Authors of [16] propose a novel control and bidding strategy to minimize the cost of the VPP in both day-ahead and balancing markets. The problem is modeled as a bilevel stochastic optimization and solved using a local search algorithm.

The reviewed articles have not considered the participation of several VPPs and the location of their own DGs in the distribution network. This paper proposes a bilevel scheduling model to investigate the interaction among VPPs and DNO in a day-ahead market. VPPs bid their long-term contract prices to maximize their own profits in the upper level. Having been given the prices at which the VPPs are interested to sell their energy, DNO, considered in the lower level, then decides on the share of energy to be supplied from either the electricity market or VPP, rest assured that its total cost is minimized. The KKT optimality conditions are implemented to transform the bilevel scheduling model into a single-level mathematical formulation with equilibrium constraints. The decision making process simultaneously determines the long-term contract price of each VPP and power purchased from both/either the electricity market and/or VPPs. The proposed bilevel scheduling model is basically adopted from the idea presented in [17].

The main contributions of this paper are highlighted as follows:

1. Simulating several VPPs and their competition to provide energy in the distribution network.
2. Proposing a bilevel scheduling model to investigate the interaction between VPPs and DNO to partici-

pate in energy supply.

3. Considering technical characteristics and constraints of the distribution network along with the different location of DG units throughout distribution network.

The rest of the paper is organized as follows: Section 2 describes the proposed bilevel scheduling framework and Section 3 provides the required mathematical formulation of the bilevel scheduling approach. The numerical results are presented in section 4 to illustrate the efficient performance of the proposed bilevel scheduling approach. Finally, the conclusions are discussed in section 5.

2. Bilevel scheduling framework of VPPs and DNO

In this paper, the virtual power plants (VPPs) and distribution network operator (DNO) are introduced as different agents with various benefits and objectives individually looking for their optimal decision making in a bilevel scheduling approach shown in Fig. 1. The VPPs schedule and aggregate the power generation of their own DGs and deliver their generation to the DSO based on an optimal and agreed long-term contract prices. Therefore, the objective of VPPs is to optimally determine and bid their long-term contract prices by predicting the DNO's reaction to whether or not to accept them. On the other hand, the DNO determines the supply share of each VPP and electricity market to provide the customers' energy demand so that its total cost is minimized regarding the received contract prices. The objectives of the agents in the proposed bilevel scheduling approach are: maximizing the profits of the each VPP and also minimizing the total cost of the DNO.

3. Mathematical formulation

3. 1. Upper level- Profit function of the VPPs

The upper level of the problem represents the profit maximization of the VPPs by (1). The total profit value is determined using the expected revenues from selling energy to the DNO minus the production costs of DGs over a time period.

$$\underset{Cvpp_i}{Max} \quad \sum_{i \in I} \sum_{j \in VPP_i} \sum_{t \in T} \Delta t.(Cvpp_i - c_j).P_{dg_j}(t) \tag{1}$$

3. 2. Lower level - Cost function of the DNO

The lower level of the model presents the total cost of DNO to be minimized subject to constraints (3-8). The first and second terms of (2) are the purchasing cost of electric energy from the electricity market and VPPs respectively.

$$\underset{P_{sb},P_{dg_i},V_n}{Min} \quad \sum_{t \in T} \Delta t.\rho(t).P_{sb}(t) + \\ \sum_{i \in I} \sum_{j \in VPP_i} \sum_{t \in T} \Delta t.Cvpp_i.P_{dg_j}(t) \tag{2}$$

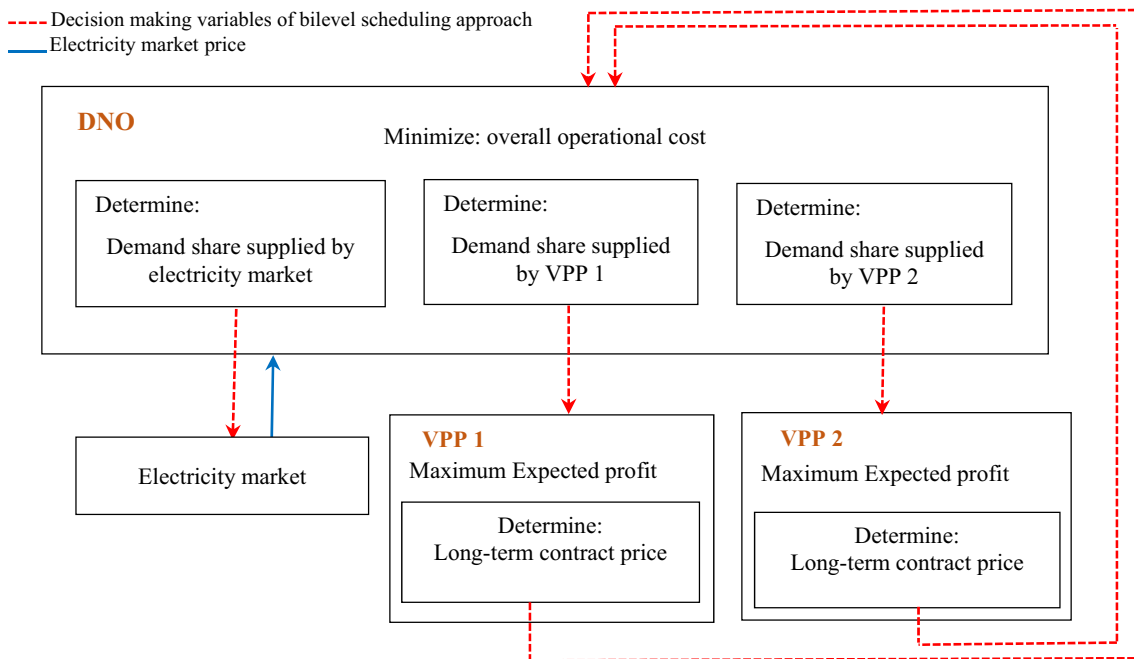The Distribution network is modeled by applying ap-

Fig. 1. Bilevel scheduling model modelframework

proximate power flow equations [17]. The active power flow from node n to m is approximately determined by (3) and the maximum allowable power flowing through branches are assessed using (4). Eq. 5 presents the energy balance constraint for each bus of the distribution network and the acceptable voltage limits should be satisfied using (6) throughout distribution network. Maximum capacity of the main substation and allowable range of DG units are presented in (7) and (8) respectively.

$$P_{nm}(t) \cong \frac{|V_n(t)|.(|V_n(t)| - |V_m(t)|)}{|Z_{nm}|}$$

$$\forall n \in N; \quad \forall m \in M; \quad \forall t \in T; \tag{3}$$

$$\left| \frac{|V_n(t)|.(|V_n(t)| - |V_m(t)|)}{|Z_{nm}|} \right| \leq \overline{P}_{nm}$$

$$\forall n \in N; \quad \forall m \in M; \quad \forall t \in T; \tag{4}$$

$$P_n^{gn}(t) - P_n^{dm}(t) =$$

$$\sum_{m \in M} \frac{|V_n(t)|.(|V_n(t)| - |V_m(t)|)}{|Z_{nm}|} \quad \forall n \in N; \quad \forall t \in T; \tag{5}$$

$$\underline{V}_n \leq V_n(t) \leq \overline{V}_n \quad \forall n \in N; \quad \forall t \in T; \tag{6}$$

$$\underline{P}_{sb} \leq P_{sb}(t) \leq \overline{P}_{sb} \quad \forall t \in T; \tag{7}$$

$$\underline{P}_{dg_j} \leq P_{dg_j}(t) \leq \overline{P}_{dg_j} \quad \forall j \in J; \quad \forall t \in T; \tag{8}$$

3. 3. Equivalent single-level scheduling approach

The equivalent single level problem would be obtained using KKT optimality conditions associated with the lower level of the bilevel scheduling problem. The resulted objective function of the equivalent single level problem is provided in (9) that is maximized subject to the (10-20) and previous constraints (3-8).

$$\underset{Cvpp_i, P_{sb}, P_{dg_j}, V_n}{Max} \sum_{i \in I} \sum_{j \in VPP_i} \sum_{t \in T} \Delta t.(Cvpp_i - c_j)P_{dg_j}(t) \tag{9}$$

$$Cvpp_i - \pi_i(t) + \overline{\beta}_i(t) - \underline{\beta}_i(t) = 0; \quad \forall i \in I; \quad \forall t \in T; \tag{10}$$

$$\rho(t) - \pi(t) + \overline{\delta}(t) - \underline{\delta}(t) = 0; \quad \forall t \in T; \tag{11}$$

$$\pi_n(t) \times \sum_{m \in M} \frac{(2 \times |V_n(t)| - |V_m(t)|)}{|Z_{nm}|} - \sum_{m \in M} \pi_m(t) \times \frac{|V_m(t)|}{|Z_{nm}|}$$

$$+ \sum_{m \in M} (\underline{\varphi}_{m,n}(t) - \overline{\varphi}_{m,n}(t)) \times (\frac{|V_m(t)|}{|Z_{nm}|}) +$$

$$\sum_{m \in M} (\overline{\varphi}_{n,m}(t) - \underline{\varphi}_{n,m}(t)) \times (\frac{2 \times |V_n(t)| - |V_m(t)|}{|Z_{nm}|}) + \tag{12}$$

$$\overline{\omega}_n(t) - \underline{\omega}_n(t) = 0; \quad \forall n \in N; \quad \forall t \in T;$$

$$\overline{\varphi}_{n,m}(t) \times (\frac{|V_n(t)|.(|V_n(t)| - |V_m(t)|)}{|Z_{nm}|} - \overline{P}_{nm}) = 0;$$

$$\overline{\varphi}_{n,m}(t) \geq 0; \quad \forall n \in N; \quad \forall m \in M; \quad \forall t \in T; \tag{13}$$
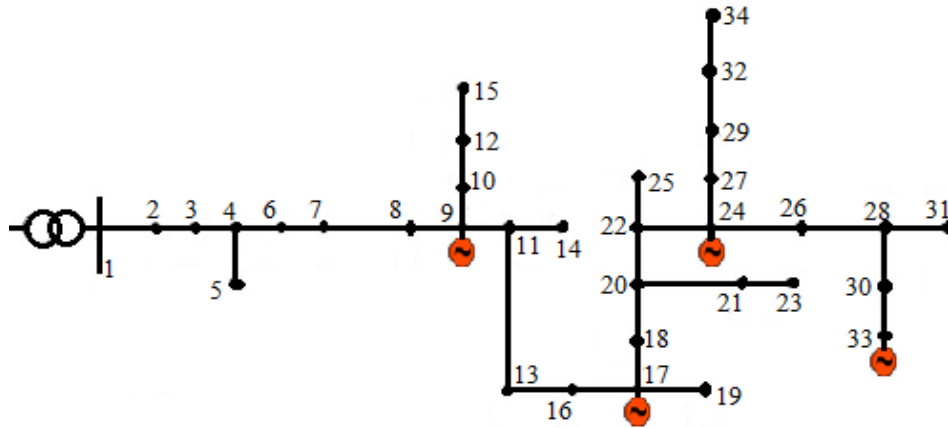

Fig. 2. Schematic diagram of the 34-bus distribution network

$$\underline{\varphi}_{n,m}(t) \times \left(-\frac{|V_n(t)| \cdot (|V_n(t)| - |V_m(t)|)}{|Z_{nm}|} - \overline{P}_{nm}\right) = 0;$$
$$\underline{\varphi}_{n,m}(t) \geq 0; \quad \forall n \in N; \quad \forall m \in M; \quad \forall t \in T; \qquad (14)$$

$$\overline{\omega}_n(t) \times (V_n(t) - \overline{V}_n) = 0;$$
$$\overline{\omega}_n(t) \geq 0; \quad \forall n \in N; \quad \forall t \in T; \qquad (15)$$

$$\underline{\omega}_n(t) \times (-V_n(t) + \underline{V}_n) = 0;$$
$$\underline{\omega}_n(t) \geq 0; \quad \forall n \in N; \quad \forall t \in T; \qquad (16)$$

$$\overline{\delta}(t) \times (P_{sb}(t) - \overline{P}_{sb}) = 0; \quad \overline{\delta}(h) \geq 0; \quad \forall t \in T; \qquad (17)$$

$$\underline{\delta}(t) \times (-P_{sb}(t) + \underline{P}_{sb}) = 0; \quad \underline{\delta}(t) \geq 0; \quad \forall t \in T; \qquad (18)$$

$$\overline{\beta_j}(t) \times (P_{dg_j}(t) - \overline{P}_{dg_j}) = 0;$$
$$\overline{\beta_j}(t) \geq 0; \quad \forall j \in J; \quad \forall t \in T \qquad (19)$$

$$\underline{\beta}_j(t) \times (-P_{dg_j}(t) + \underline{P}_{dg_j}) = 0;$$
$$\underline{\beta}_j(t) \geq 0; \quad \forall j \in J; \quad \forall t \in T \qquad (20)$$

4. Numerical results

The proposed bilevel scheduling model is applied to a modified IEEE 34-bus distribution system presented in Fig. 2 [17]. This distribution system, whose substation transformer at bus 1 connects the distribution network to the main grid, serves 34 load points. There are two VPPs in the distribution network: VPP1 owns DG1 and DG2 while VPP2 owns DG3 and DG4. The main parameters of the DGs are presented in Table 1. The time horizon is assumed one year (8760 hours) and it is equally divided into ten time periods (876 hours).

The effectiveness of the proposed bilevel scheduling model is scrutinized using three different demand levels namely high (scenario A), medium (scenario B) and low (scenario C). The annual demand profiles of the three different scenarios are shown in Fig. 3. Fig. 4 shows the electricity market prices of the annual time horizon [18].

As it can be seen the electricity market prices alter in proportion to the variations of the annual demand profiles. In other words, the higher electricity market prices are expected to take place during peak load hours of the distribution network and vice versa [17].

The proposed model has been implemented using SNOPT solver in GAMS [19] and the obtained results of the VPPs' long-term contract price are given in Table 2 for three different scenarios. As expected, the higher demands and electricity market prices in scenario A result in higher contract prices of VPPs. Conversely, lower demands and electricity market prices in scenario C result in lower contract prices of VPPs. Also, it can be concluded
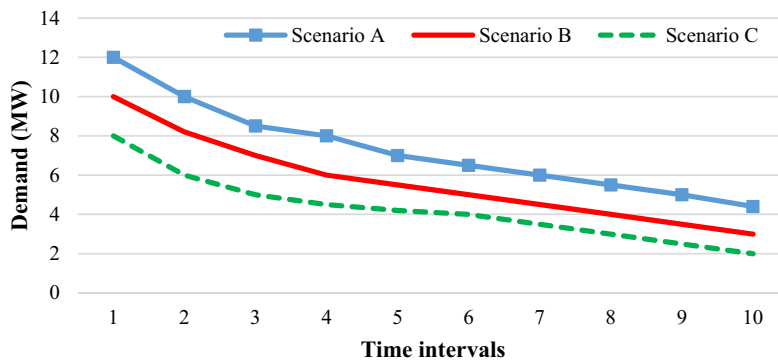
Table 1. DG parameters

DG number	$\underline{P}_{dg}$ (MW)	$\overline{P}_{dg}$ (MW)	C (€/MWh)	Bus number
DG 1	0	1	50	9
DG 2	0	1	50	17
DG 3	0	1	50	24
DG 4	0	1	50	33

Fig. 3. Demand profile of the distribution network in three different scenarios
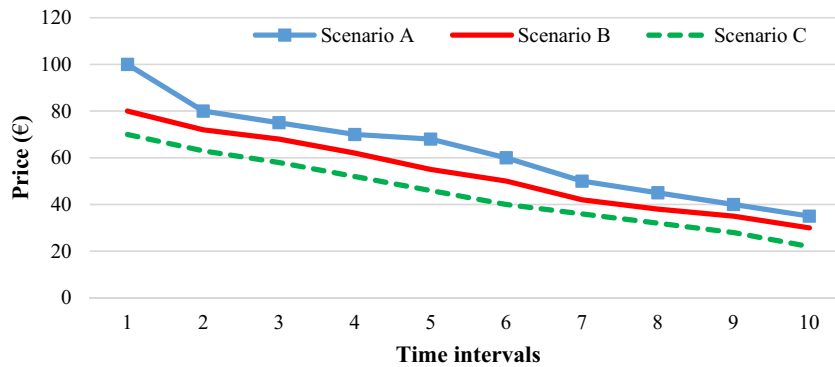
Fig. 4. Electricity market prices in three different scenarios

Table 2. Contract prices for three different scenarios

	Scenario A (€/MWh)	Scenario B (€/MWh)	Scenario C (€/MWh)
VPP1	71.58	65.02	60.01
VPP2	75.65	71.64	64.78

Table 3. Capacity factors for three different scenarios

	Scenario A (%)	Scenario B (%)	Scenario C (%)
VPP1	50	40	30
VPP2	43.07	30	20

from Table 2 that the VPP2 bids more prices than VPP1 due to the fact that VPP2, which owns DG3 and DG4, is farther away from the main substation than VPP1, which owns DG1 and DG 2. Therefore, VPP2 would make a greater contribution to reduce power losses and improve voltage profile than VPP1 does.

The VPPs' capacity factors, the ratio of the power provided and the maximum capacity of the VPPs over the considered annual time horizon, are presented in Table 3 for the three different scenarios.

In the case that the electricity market prices and demands have the largest values in scenario A, the capacity factor of the VPPs will be more than the other scenarios. Moreover, VPP1 has more capacity factor compared to VPP2 in all scenarios because of the lower contract prices

of VPP1 which make it more preferable to VPP2.

Fig. 5 depicts the purchased power from the electricity market for three scenarios. In other words, besides purchasing from the VPPs, DNO participates in the electricity market to meet its required demand. As it can be seen, the DNO activity in the electricity market is in direct correlation with its expected demand, except for time intervals 3, 4 and 5 in which DNO purchases different powers from VPPs.

The annual expected profits of VPPs are shown in Fig. 6 for each scenario. The highest expected profit is obtained in scenario A because of the higher contract prices and capacity factors compared to scenarios B and C. Although VPP2 has lower capacity factor than VPP1, It
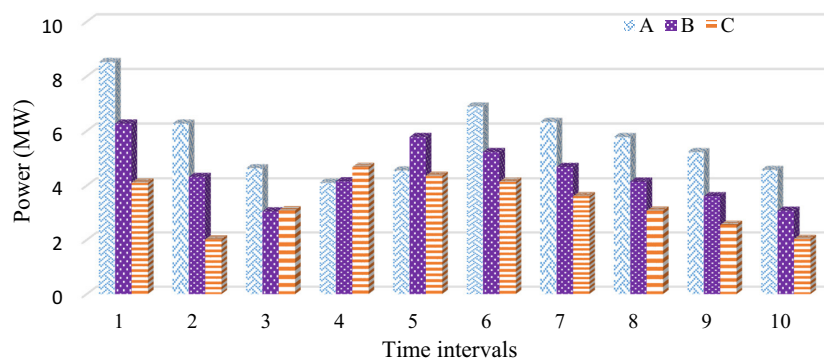

Fig. 5. Power purchased from Electricity market in three different scenarios
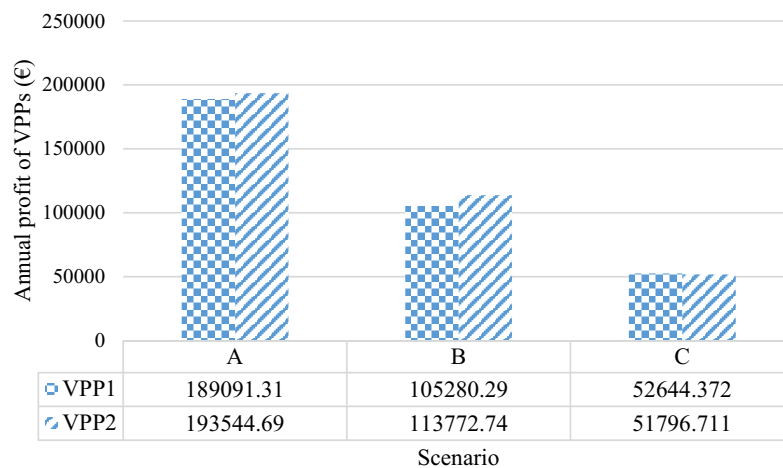
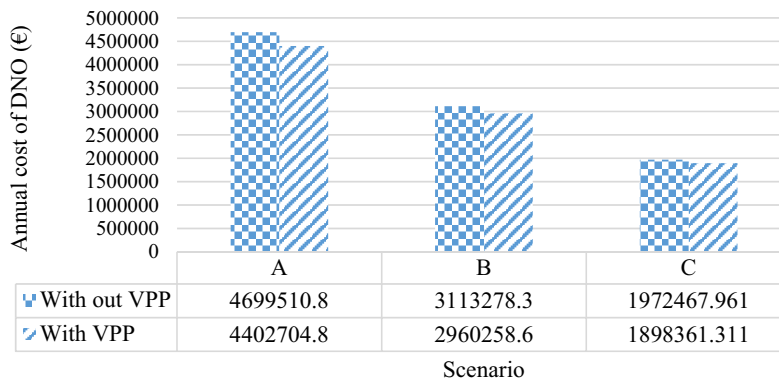**Fig. 6.** Annual expected profit of VPPs in three different scenarios

	A	B	C
○ VPP1	189091.31	105280.29	52644.372
◢ VPP2	193544.69	113772.74	51796.711

Scenario

Fig. 7. Annual incurred cost of DNO in three different scenarios

	A	B	C
▪ With out VPP	4699510.8	3113278.3	1972467.961
◢ With VPP	4402704.8	2960258.6	1898361.311
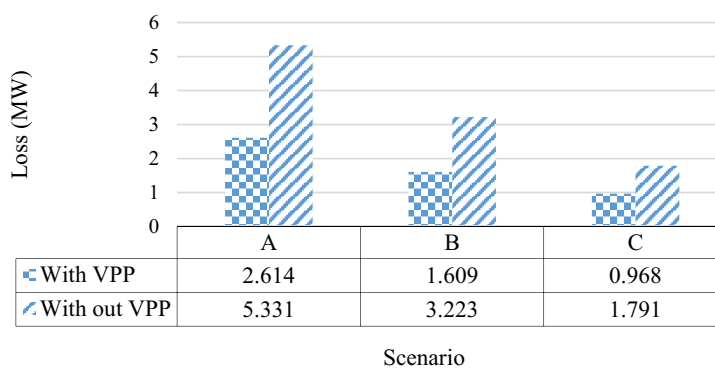
Scenario

Fig. 8. Distribution network losses in three different scenarios

	A	B	C
▪ With VPP	2.614	1.609	0.968
◢ With out VPP	5.331	3.223	1.791

Scenario

gains more profit in scenarios A and B due to the higher loading conditions of these scenarios and the position of VPP2 in distribution network enabling it to better meet technical requirements of distribution network end points. On the other hand, VPP1 achieves higher profit in scenario C due to the fact that in the lower load condition and

market prices, DNO can provide most of its required energy from either electricity market or VPP1 without violating technical constraints.

The comparison of the annual costs of the DNO to supply its demands is depicted in Fig. 7 with respect to the three scenarios. According to the results obtained, the overall annual costs of DNO decreased in all scenarios with the presence of VPPs. Furthermore, because of higher electricity market prices and demands of the distribution network in scenario A, the procurement cost of the distribution network is more than that of scenarios B and C.

Finally, Fig. 8 shows the overall power losses of distribution network in the three scenarios. DNO decreases its power losses in all scenarios using VPPs to meet its power demand.

5. Conclusion

This paper proposes a bilevel scheduling approach to model the optimal interaction of VPPs and DNO in distribution networks. VPPs schedule and aggregate the power generation of their own DGs at different points of the distribution network and determine the optimal long-term contract prices on which they sell the energy to the DNO while the DNO seeks to minimize its total incurred cost by choosing to purchase energy either from electricity markets or VPPs. The bilevel scheduling approach takes into consideration the viewpoints of the all participant agents including VPPs and the DNO. The KKT optimality conditions of the lower level problem has been applied to transform the bilevel model into a single-level mathematical program. The results show that DGs' location in the distribution network may have a significant effect on the contract prices and consequently on VPP's expected profit. The proposed approach results in potential cost savings for the DNO. Numerical results and discussions demonstrate the efficacy and usefulness of the proposed bilevel scheduling model.

References

[1] IEA, 2002. Distributed Generation in Liberalised Electricity Markets, Paris, p. 128.

[2] M. Braun, "Technological control capabilities of DER to provide future ancillary services", Int. J. Distrib. Energy Resour, Vol. 3, No. 3, pp. 191–206, Nov. 2006.

[3] G. Strbac, N. Jenkins, T. Green, D. Pudjianto, "Review of innovative network concept", Research Project Supported by European Commission, Directorate-General for Energy and Transport, under the Energy Intelligent Europe (EIE), pp. 1-30, Dec. 2006.

[4] A. Zakariazadeh, S. Jadid, "Integrated Scheduling of Electric Vehicles and Demand Response Programs in a Smart Microgrid", Iranian Journal of Electrical & Electronic Engineering, Vol. 10, No. 2, pp. 114-123, June 2014.

[5] S. Ghavidel; L. Li; J. Aghaei; T. Yu; J. Zhu "A review on the virtual power plant: Components and operation systems", IEEE International Conference on Power System Technology (POWERCON), Nov. 2016.

[6] F. Bignucolo, R. Caldon, V. Prandoni, S. Spelta, M. Vezzola, "The voltage control on MV distribution networks with aggregated DG units (VPP)", Proceedings of the 41st International Universities Power Engineering Conference, Newcastle-upon Tyne (UK), pp. 187-192. Sept. 2006.

[7] E. Mashhour, S. Moghaddas-Tafreshi, "Bidding strategy of virtual power plant for participating in energy and spinning reserve markets—Part I: problem formulation", IEEE Trans. Power Syst., Vol. 26, No. 2, pp. 949–956. May 2011.

[8] E. Mashhour, S. Moghaddas-Tafreshi, "Bidding strategy of virtual power plant for participating in energy and spinning reserve markets—Part II: numerical analysis", IEEE Trans. Power Syst., Vol. 26, No. 2, pp. 957–964, May 2011.

[9] D. Pudjianto, C.Ramsay, G. Strbac, "Virtual power plant and system integration of distributed energy resources", IEE Proc., Gener. Transm. Distrib., Vol. 1, No. 1, pp. 10-16. March 2007.

[10] M. Peik-Herfeh, H. Seifi, M. K. Sheikh-El-Eslami, "Decision making of a virtual power plant under uncertainties for bidding in a day-ahead market using point estimate method", Electrical Power and Energy Systems, Vol. 44, No. 1, pp. 88-98, Jan. 2013.

[11] S. Jadid and S. A. Bahreyni, "A Stochastic Operational Planning Model for Smart Power Systems," Iranian Journal of Electrical & Electronic Engineering, Vol. 10, No. 4, pp. 293-303, Dec. 2014.

[12] Dempe S, Foundations of Bilevel Programming. Dordrecht, The Netherlands: Kluwer, 2002.

[13] M. Carrión, J.M. Arroyo, A.J Conejo, "A Bilevel Stochastic Programming Approach for Retailer Futures Market Trading", IEEE Trans, Power Syst., Vol. 24, No. 3, pp. 1446–1456, Sep. 2009.

[14] J. Yu, Y. Jiao, X. Wang, J. Cao, S. Fei, "Bi-level optimal dispatch in the Virtual Power Plant considering uncertain agents number," Neurocomputing, Vol. 148, pp. 551–557, Nov. 2015.

[15] L. Ju, Z. Tan, J. Yuan, Q. Tan, H. Li, F. Dong, "A bi-level stochastic scheduling optimization model for a virtual power plant connected to a wind–photovoltaic–energy storage system considering the uncertainty and demand response", Appl. Energy, Vol. 171, pp. 184–99, June 2016.

[16] Q. Zhao, Y. Shen, M. Li, "Control and Bidding Strategy for Virtual Power Plants With Renewable

Generation and Inelastic Demand in Electricity Markets", IEEE Trans. Sustain. Energy, Vol. 2, No. 3, pp. 277–287, Dec. 2015.

[17] J. M. Lopez-Lezama, A. Padilha-Feltrin, J. Contreras, J. I. Munoz, "Optimal contract pricing of distributed generation in distribution networks", IEEE Trans. Power Syst., Vol. 26, No. 1, pp. 128-136, Feb. 2011.

[18] OMEL, Operador del Mercado Ibérico de Energía—Polo Español S.A. [Online]. Available: http://www.omel.es.

[19] The GAMS Development Co., 2013, http://www.gams.com.

Farshid Nazari was born in Nour-Abad, Fars, Iran, in 1989. He received the BSc degree in power electrical engineering from the Shiraz University, Shiraz, Iran, in 2012, and the MSc degree in power electrical engineering from the Shahid Rajaee Teacher Training University (SRTTU), Tehran, Iran, in 2015. He is a teacher in Education, Baladeh, Fars, Iran. His researches are mostly about Distributed Generation, Virtual Power Plant (VPP), Distribution Networks, Bilevel Programming and Pricing.

Ali Zangeneh received his Ph.D. degree in electrical engineering from Iran University of Science and Technology (IUST) in 2010. He is now an assistant professor at electrical engineering department of Shahid Rajaee Teacher Training University (SRTTU). His research interests are in demand side management, smart grid, distributed generation and optimization in power systems.

Ali Shayegan-Rad was born in Hamedan, Iran, in 1990. He received the BSc degree in electrical engineering from the Kermanshah University of Technology (KUT), Kermanshah, Iran, in 2012, and the M.Sc. degree in electrical engineering from the Shahid Rajaee Teacher Training University (SRTTU), Tehran, Iran, in 2014. He is now with Oil Industrial Commissioning and Operation (OICO) Company at south pars gas field development. His research interests are load and energy management, renewable energy, power system protection, operation and planning.