Contribution of Virtual Power Plants in Electric Market Considering Uncertainty in Virtual Power Plant Connection with Upstream Network

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Today, traditional networks are changing to active grids due to the burgeoning growth of distributed energy resources (DER), which demands scrupulous attention to technical infrastructures, as well as economic aspects. Providing energy services and spinning reserve in the market is one the features of this issue. In this study, from economic point of view, the aggregation of DERs in a distribution network to participate in joint energy and reserve markets is investigated. This approach, which is predicated upon price-based unit commitment method, has considered virtually all the technical data in the proposed model. It is worth to mention that uncertainties of loads market prices, as an inherent characteristic of the electricity markets, are treated in this study, and their effect on the operation of virtual power plants in energy and reserve markets has been thoroughly discussed. The innovation of this paper is to consider the uncertainty in connection between the virtual power plant and the upstream network, along with the mentioned uncertainties.

To this end, in this paper, a 4-bus network is considered as a virtual power plant in which the condition of optimal operation of distributed generations, energy storage systems and removable load considering uncertainty in energy price and connection with upstream network and also, uncertainty in delivery of spinning reserve have been studied to maximize the profit of virtual power plant. Simulation has been carried out in MATLAB environment using teaching-learning based optimization algorithm (TLBO) for 24 hours on the proposed network.

keywords: *virtual power plant, teaching-learning based optimization algorithm, distributed energy sources, energy market and reserve, uncertainty, reserve delivery.*

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NOMENCLATURE

i, j Index for buses

i' amount of active and reactive exchanged power between virtual power plant (VPP) and the ith neighboring grid (positive sign for purchasing from the neighboring grid and negative sign for selling to it)

N total number of buses

$P_{DG_i^t}; Q_{DG_i^t}$ amount of active and reactive power generated by ith DG unit at hour t for the energy market

$R_{DG_i^t}$ amount of active power generated by ith DG unit at hour t for reserve market

$P_{IL_i^t}; Q_{IL_i^t}$ amount of curtailed load of ith IL at hour t

$R_{IL_i^t}$ amount of curtailed load of ith IL allotted to spinning reserve market at hour t

$P_{DG}^{\min}; P_{DG}^{\max}$ minimum and maximum active power generation of ith DG unit

$\rho_{L,t}$ retail energy price

η_{str} efficiency of EES

$P_{\text{int}_i^t}; Q_{\text{int}_i^t}$ index for hours

$P_{E_t}; Q_{E_t}$ amount of active and reactive exchanged power between VPP and upstream network (positive sign for purchasing from the neighboring grid and negative sign for selling to it)

$SUC_{DG_i^t}; SDC_{DG_i^t}$ start up and shut down costs of ith DG unit

$MUT_i; MDT_i$ minimum up time and minimum down time of ith DG unit

$P_{str_i^t}$ amount of charged/discharged capacity of ith EES at hour t in kW (positive sign for charging state and negative sign for discharging state)

$\rho_{E,t}$ energy market price

$\rho_{R,t}$ spinning reserve market price

$\rho_{\text{int}_i^t}$ price of power exchange with neighboring grid

r_t probability of reserve delivery

R_i^{up}, R_i^{Down} ramp-up and ramp-down rate of ith DG unit

1. INTRODUCTION

In recent decades, according to restructuring in electric industry, energy generation systems in power system have tended from centralized generation in great power plants to small scale generation in distribution networks and using distributed energy resources (DER) such as distributed generation and energy storage systems. In order to implementation of DERs and improve their presence in electric markets, the idea of virtual power plant has been proposed and used by many researchers. Virtual power plant is an economical-technical and practical structure which interconnects distributed generation and consumption sources in a way that virtual power plant operator would be able to manipulate DERs [1]. Virtual power plant provides the capability of presence in energy markets and spinning reserve in an economical and reliable way in order to gain maximum profit through integration of various DERs at network level and propose a flexible operational profile [2]. In this regard, in [3] optimal operation of a virtual power plant consist of several CHP units based on the decentralized control strategy has been provided. In [4] a plan to response to new demand has been proposed which can be applied in the area of virtual power plants to contribute in electric market. In [5], DERs integration has been carried out using units contribution per base price and optimal purchase proposals has been obtained in electric and spinning reserve markets. In [6] the strategy of optimal proposals for virtual power plant has been discussed. In [7], the virtual power plant speculation has been studied in energy market and extra service of spinning reserve in which if virtual power plant is connected to network in more than one point, in order to reduce operational expenses and increase profit, more exports and less imports will be done from the point which price forecast is more expensive and also less exports and more imports will be done from the point which is less expensive. The problem of optimal proposal strategy of a virtual power plant consist of wind farm, photovoltaic power plant and a gas power plant has been provided in [8]. This problem has been formulated as a complex-integer number linear planning and consist of long term bilateral contracts with regard to virtual power plant contribution in DA market. Virtual power plant in [9], starts to planning energy storage systems and price proposal in the market according to the amount of available wind and forecasted real time prices.

Since price based generation planning is a suitable method for proposing a virtual power plant to participate in the energy market and spinning reserve, in this paper, considering the uncertainty of VPP connection with the upstream network and the uncertainty of the delivery of spinning reserve that not mentioned in [11], It has been trying to bring the results as well as the profit from energy sales by the virtual power plant closer to reality.

In the section 2 of this paper, the problem is proposed and explained, in section 3 modelling of uncertainties used in the study is discussed, in section 4 discussion and simulation results for three different scenario are explained and finally in section 5 overall conclusion is provided.

2. PROBLEM DESCRIPTION

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A. Operation Costs of Virtual Power Plants

DG operation cost has been shown in equation (1):

$$C(P_{DG}) = \alpha \times P_{DG}^2 + \beta \times P_{DG} + \gamma \tag{1}$$

In which α, β and γ are operation cost coefficients [12]. Equation (2) shows storage systems operation cost:

$$C(P_{str}) = (0.1 \times P_{str}) + 0.35 \tag{2}$$

Load shedding cost is as follow:

$$C(p_{IL}) = \alpha_{IL} \times P_{IL}^2 + \beta_{IL} \times P_{IL} \tag{3}$$

In which α and β are load shedding penalty coefficients [13].

B. Objective Function

The objective function of proposal problem has been shown in (4) considering uncertainties in order to maximize VPP benefit which means revenues subtract from costs. Costs has been explained in the last section but revenues are due to presence in energy and spinning reserve market and also the revenue of supply retail loads [11].

$$\begin{aligned} Benefit = & -\sum_{t=1}^{24} \rho_{E,t} \times E_t + \sum_{i=1}^{No_{tie}} \sum_{t=1}^{24} \rho_{\text{int}_i^t} \times P_{\text{int}_i^t} \\ & + \sum_{t=1}^{24} \left[r_t.\left(\rho_{E,t} + \rho_{R,t}\right) + (1-r_t).\rho_{R,t} \right] R_t + \sum_{t=1}^{24} \rho_{L,t} \times P_{Load} \\ & - \sum_{i=1}^{No_{DG}} \sum_{t=1}^{24} \left[r_t.C\left(P_{DG_i^t} + R_{DG_i^t}\right) + (1-r_t).C\left(P_{DG_i^t}\right).I_t \right] \\ & - \sum_{i=1}^{No_{DG}} \sum_{t=1}^{24} \left[SUC_{DG_i^t} + SDC_{DG_i^t} \right] \\ & - \sum_{i=1}^{No_{cutr}} \sum_{t=1}^{24} r_t.C\left(P_{IL_i^t} + R_{IL_i^t}\right) + (1-r_t).C\left(P_{IL_i^t}\right).L_t \end{aligned} \tag{4}$$

In which $\rho_{E,t}$, $\rho_{R,t}$ and $\rho_{L,t}$ are price in energy market, reserve market and retail market respectively. E_t is exchanging power with upstream network, R_t is equal to sum of removable loads power and DG for reserve market in the t_{th} hour and r_t is the possibility of reserve delivery in t_{th} hour. P_{IL} and R_{IL} are the amount of disconnected load and disconnected load to deliver to reserve market in each hour respectively.

C. Problem Constraints

- Please DG capacity constraint

$$P_{DG}^{\min} \leq (P_{DG} + R_{DG}) \leq P_{DG}^{\max} \tag{5}$$

- Removable load constraint

$$0 \leq (P_{IL} + R_{IL}) \leq P_{IL}^{\max} \tag{6}$$

- DG upper limit

$$(P_{DG^{t+1}} - P_{DG^{t}}) \leq R^{Up}, \forall t = 1, 2, \ldots, 24 \tag{7}$$

- DG lower limit

$$(P_{DG^{t}} - P_{DG^{t+1}}) \leq R^{Down}, \forall t = 1, 2, \ldots, 24 \tag{8}$$

- Energy storage constraints

$$-(Cap_i^{t-1} - P_{str_i^t}^{\min}) \leq \sum_{k=1}^{24} P_{str_i^t} \leq (P_{str_i^t}^{\max} - Cap_i^{t-1}) \tag{9}$$

$$Cap^t - Cap^{t-1} \leq R_{ch}, \forall t = 1, 2, \ldots, 24 \tag{10}$$

$$Cap^{t-1} - Cap^t \leq R_{Dch}, \forall t = 1, 2, \ldots, 24 \tag{11}$$

- Power balance constraint

$$\begin{aligned} &P_{E_t} + R_{E_t} + P_{DG_i^t} + P_{\text{int}_i^t} + P_{IL_i^t} + (P_{Ch_i^t} - \eta P_{DCh_i^t}) \\ &-P_{load_t} = \sum_{j=1}^{N} \left|V_{i,t}\right| \left|V_{j,t}\right| \left|Y_{ij}\right| \cos(\delta_{j,t} - \delta_{i,t} + \theta_{ij}) \end{aligned} \tag{12}$$

AND $i \in S_b : t = 1, 2, 3, ...24$

3. UNCERTAINTIES MODELLING

A In this study, uncertainties in energy price, load, reserve delivery and also VPP connection with upstream Network have been investigated. To generate stochastic data, log-normal probability distribution function (PDF) is deployed for price values [14], while load values are generated using normal PDF.

A. Scenario generation for price value And Reserve Delivery

The price data which is extracted from [15] comprises both anticipated price values and corresponding standard deviations resulted from price forecast procedure. Having generated 1000 random price scenarios, a 1000 branch fan-type scenario tree is built and reduced to 30 scenarios using backward reduction method afterwards. Each scenario represents three strings for energy, reserve, and retail prices for a 24 h time horizon. Every member of this string is generated using log-normal PDF with a mean value equal to forecasted price and standard deviation as mentioned before. Also, to indicate reserve uncertainty, a parameter (r_t) has been used in the objective function which is equivalent to 0.9.

B. Scenario generation for load value

In order To include load uncertainty, load curve is uniformly scaled with a five step load factor as shown in Table.1. The probability values assigned to load factors represent a stepwise estimation of normal PDF with a mean value equal to 1 and a standard deviation equal to 0.1.

Table 1. The Probable Distribution is attributed to the uncertainty in load with Upstream Network

Scenario	Load factor	Probability
1	1.1	0.1
2	1.05	0.2
3	1	0.4
4	0.95	0.2
5	0.9	0.1

Table 2. The Probable Distribution is attributed to the uncertainty in exchange power with upstream Network

Scenario	Exchange power factor	Probability
1	1	0.7
2	0.8	0.2
3	0.6	0.1

C. Uncertainty in VPP connection with upstream network

To consider the uncertainty of the connection with upstream network, which is the uncertainty in the exchange of power with the upstream network, three modes are considered, for which a probability coefficient is assumed for each case in accordance with table.2.

D. Uncertainty augmented objective function

To observe the effect of uncertain parameters on benefit, the expected value of the benefit is maximized [11]:

$$\text{Benefit}_{\text{expected}} = \sum_{s=1}^{S} P_s \times \text{Benefit}_s \tag{13}$$

In case, price,load and connection with upstream network are deemed as stochastic parameters, the probability of each scenario is the product of corresponding probabilities associated to price and load and connection with upstream scenarios.

4. SIMULATION RESULTS ANALYSIS

In this section, numerical results from the proposed method has been discussed for a 4-bus system with a 24 hour time horizon which has been shown in Fig. 1. The forecasted load curve has been shown in Fig.2 for 24 hour period [11]. Estimated price of energy market, retail and reserve market has been indicated in Fig.3 [11]. In this study, the main focus is on VPP performance in reserve and energy markets. In order to study the impacts of present uncertainties on VPP performance in real environment, four scenarios with different uncertainties has been considered. In the first scenario, VPP performance is assessed in spinning reserve and energy markets without considering any uncertainty in energy, load, reserve delivery and also VPP connection with upstream network. In the second Scenario, only energy price values has been assumed as parameters with uncertainty in the market. In the third scenario, energy, load and reserve delivery are considered as parameters with uncertainties. Finally in the fourth scenario, the uncertainties in the third scenario and also uncertainty of VPP connection to upstream network have been

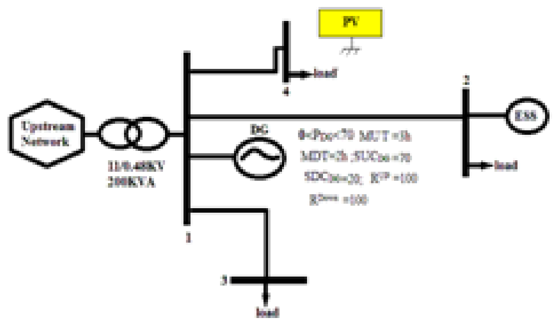

Fig. 1. understudy System

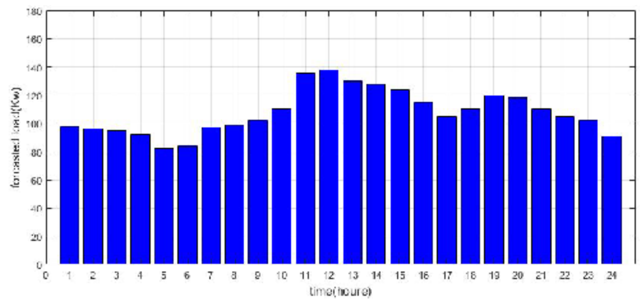

Fig. 2. Predicted Total Load In The Next 24 Hours

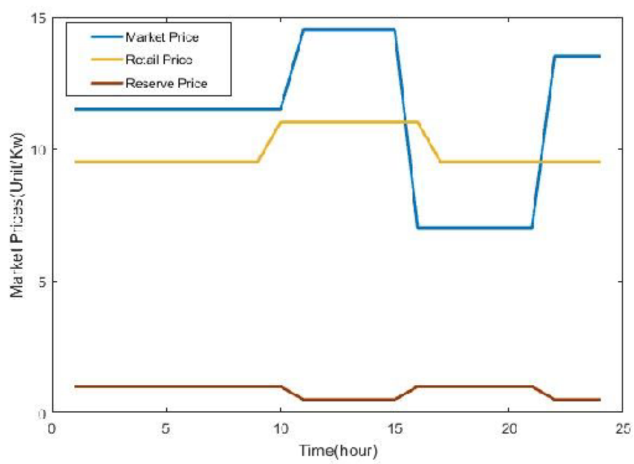

Fig. 3. Predicted Price in the Next 24 Hours

considered. Also, photovoltaic unit in the proposed model has been used only in the fourth scenario. Simulation is done in MATLAB environment using TLBO algorithm.

A. The First Scenario: without uncertainty

This scenario indicates the VPP behavior in energy and reserve market based on the definite amounts for load and energy price. Also, in this scenario, there is no uncertainty in reserve delivery and connection with upstream network. In Table. 3, DG source performance in reserve and energy markets, energy storage behavior and the amount of disconnected loads by VPP is indicated. According to Table. 3, DG generation is maximum in time period of 1-15. The reason is that in the mentioned time period, the average cost of power generated by DG is 9.5 local currency per kilowatts while energy supply cost during 1-11

Table 3. Virtual power plant performance in Scenario 1

Hour	Total DG Generation , kW	DG generation for Energy market, kW	DG generation for Reserve market, kW	Charging and discharging Of EES, kWh	Interrupted load, kW
1	100	70	30	5	0
2	100	70	30	17	0
3	100	70	30	29	0
4	100	70	30	41	0
5	100	70	30	53	0
6	100	70	30	65	0
7	100	70	30	65	25
8	100	70	30	65	25
9	100	70	30	65	0
10	100	70	30	65	0
11	100	70	30	53	25
12	100	70	30	41	25
13	100	70	30	29	25
14	100	70	30	17	25
15	100	70	30	5	25
16	0	0	0	5	0
17	0	0	0	17	0
18	0	0	0	29	0
19	0	0	0	41	0
20	0	0	0	41	0
21	0	0	0	41	0
22	100	70	30	29	0
23	100	70	30	17	0
24	100	70	30	5	0

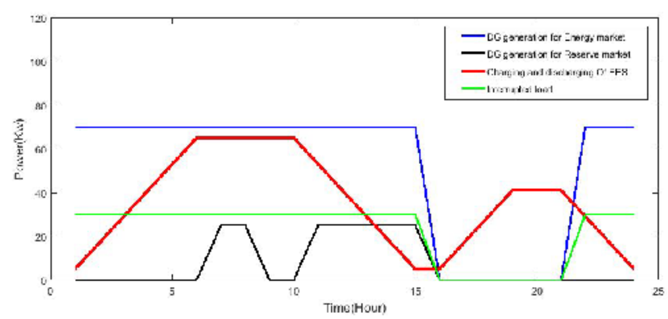

Fig. 4. Results for VPP decision making in scenario 1

from the upstream network is 11.5 local currency and during hours 11-15 is 14.5 local currency. So, DG generation with maximum power is not economically logical. Also, it is assumed that there is no uncertainty in reserve delivery ($r_t = 1$) therefor, DG sources prefer to provide maximum reserve capacity to achieve maximum profit in this scenario. Summary of the behavior of VPP in this scenario is presented in Fig. 4.

It should be noted that, reserve must ready to use in 10 minutes and since reserve preparation speed is 30 kw/min, so it can deliver only 30kw to market as reserve. During the hours 16-21, since the cost of purchasing energy from market is less than the cost of production by DG, so VPP prefers to buy from market to supply its load and during hours 22-24 is same as 1-15. It should be noted that disconnected load power is devoted to reserve market. Table.3 indicates that during hours 7-8 and 11-13, operator obtains more profit to VPP through remove system load and devote it to reserve market.

Also, due to storage capacity and charging speed (12kw/hr),

Table 4. Benefit of VPP in different Scenario (monetary unit)

Benefit /Hour	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
1	-78	-74.85	-74.85	-72.12	-74.4
2	-152.5	-80.48	-82.4	-79.34	-79.51
3	-146	-59.75	-59.75	-63.32	-63.29
4	-140	-25.3	-26.3	-27.41	-29.5
5	-144.65	-58.5	-58	-58.3	-61.51
6	-152.45	-76.8	-76.47	-76.8	-72.97
7	53.1	-5	-5.4	-4.65	-5.3
8	35.62	-24.9	-22.9	-23.27	-24.4
9	2.3	-83.6	-83.6	-81.84	-83.47
10	162.34	182.3	179.1	180.4	180.8
11	274.3	224.6	221.6	221.2	223.6
12	266.5	195.9	193.85	189.62	184.1
13	284.12	248.3	240.3	238.34	239.65
14	300.87	266.62	260.12	257.1	257.43
15	329	239.4	240.3	236.61	236.71
16	463.65	437.45	427.45	421.13	423.48
17	172.91	229.24	229.24	231.76	229.78
18	174.53	206.2	203.3	205.51	206.39
19	182	226.83	228.47	227.71	229.83
20	273.65	234.68	229.68	228.6	224.12
21	264	267.8	267.65	259.23	254.62
22	30	30.4	30.4	32.51	33.63
23	114	119.52	120.52	118.94	117.1
24	116.65	164.5	155.1	152.19	151.4
Net Benefit	2650.88	2785.56	2739.41	2709.6	2694.29

it is observed that storage is charged at maximum speed in hours 1-6 and due to the constant price of energy market during hours 7-10, storage has no discharge but during hours 11-15 when the market price rises, the storage is discharged at maximum speed to reach its minimum capacity of 5 kilowatts. The storage is charged again in hours 16-19 with its maximum speed to sell stored energy at a higher prices in hours 21-24. During the hours 7-8 and 11-15, removable loads up to 25 kilowatts are disconnected. The reason is that load shedding allows the VPP to release DG source capacity to offer in the reserve market which leads to more profit. Table. 4 shows VPP profit for 24 hours for all Scenarios. As it can be observed, there is no requirement for a positive profit in the whole hours in order to achieve maximum profit and the objective of VPP is maximize profit throughout the entire period.

B. The Second Scenario: uncertainty in energy price

In this scenario, price in energy and reserve markets is considered as random parameter and its impact on VPP performance has been investigated. Results in the table 4 indicate that in comparison to the first scenario, DG generations has not changed much and power devoted to reserve market remained unchanged due to potential profitability in reserve market and maximum reserve capacity, which is 30kw, is available in the market. According to the results in Table.5, considering uncertainty in energy price has more impact on storage performance. The amount of changes in disconnected loads to offer in the reserve market has slight changes compared to the first scenario which emphasizes the profitability of contribution in reserve market. The profit of VPP in this scenario has been shown in the table.4 which is higher than total profit of the first scenario.

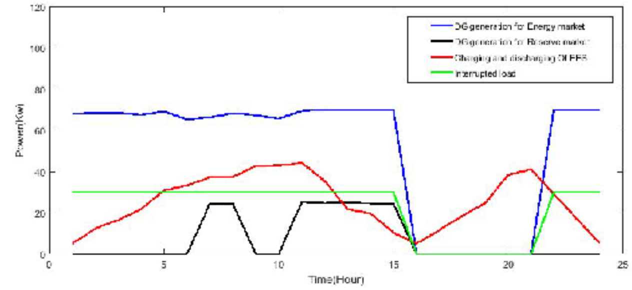

Fig. 5. Results for VPP decision making in scenario 2

Table 5. Virtual power plant performance in Scenario 2

Hour	Total DG Generation , kW	DG generation for Energy market, kW	DG generation for Reserve market, kW	Charging and discharging Of EES, kWh	Interrupted load, kW
1	98.22	68.22	30	5	0
2	98.33	68.33	30	12.33	0
3	98.5	68.5	30	16.53	0
4	97.43	67.43	30	21.73	0
5	99.1	69.1	30	30.83	0
6	95.29	65.29	30	33.2	0
7	96.33	66.33	30	37.22	24.45
8	98.23	68.23	30	37.32	24.26
9	97.33	67.33	30	42.66	0
10	95.66	65.66	30	43	0
11	99.33	69.33	30	44.2	25
12	100	70	30	35.44	24.69
13	100	70	30	21.66	24.9
14	100	70	30	19.69	24.57
15	100	70	30	10.3	24.49
16	0	0	0	5	0
17	0	0	0	11.49	0
18	0	0	0	18.5	0
19	0	0	0	24.66	0
20	0	0	0	38.36	0
21	0	0	0	41	0
22	100	70	30	29	0
23	100	70	30	17	0
24	100	70	30	5	0

summary of the behavior of VPP in this scenario is presented in Fig.5.

C. The Third Scenario: uncertainty in energy price and load

In this scenario, price in the energy market and forecasted load are assumed as random parameters. In Table. 6, DG performance in energy and spinning reserve markets and also the amount of disconnected loads by VPP are observed. The second, third and fourth columns state the DG generation for energy and reserve markets In which unlike the first and second scenarios, DGs are not shut off and it is because the uncertainty in provided load. In this scenario, DG generation for reserve market shows minor changes compared to first and second scenarios. Fifth column of the table.6 indicates power storage condition which shows significant changes compared to Table. 3 and it is because of uncertainty in load and energy prices. The sixth column indicates the condition of removable loads and comparing with first scenario shows that removable loads are not sensitive to these random parameters. Table.4 shows also the hourly profits

Table 6. Virtual power plant performance in Scenario 3

Hour	Total DG Generation , kW	DG generation for Energy market, kW	DG generation for Reserve market, kW	Charging and discharging Of EES, kWh	Interrupted load, kW
1	97.1	67.1	30	5	0
2	96.2	66.2	30	10.9	0
3	96.18	66.28	29.9	15.1	0
4	98.2	68.2	30	17.2	0
5	98.3	68.3	30	22.2	0
6	97.9	67.9	30	28.4	0
7	98.9	68.9	30	31.4	23.9
8	97.5	67.5	30	38.1	24.95
9	96.01	66.08	29.93	42.1	0
10	98.3	68.36	29.94	44.3	0
11	99.2	69.6	29.6	35.8	23.26
12	100	70.5	29.5	27.6	24..3
13	100	70.15	29.85	19.6	24.35
14	99.8	69.8	30	10.1	24.3
15	100	70	30	5	24.2
16	2.01	2.01	0	12.1	0
17	2.003	2.003	0	11.02	0
18	2	2	0	26.04	0
19	2.2	2.1	0.1	33.1	0
20	2	2	0	38.89	0
21	2.0005	2.0005	0	41.1	0
22	100	70	30	29	0
23	100	70	30	17	0
24	100	70	30	5	0

Table 7. Virtual power plant performance in Scenario 4

Hour	Total DG Generation , kW	DG generation for Energy market, kW	DG generation for Reserve market, kW	Charging and discharging Of EES, kWh	Interrupted load, kW
1	96.53	67.3	29.23	5	0
2	95.32	65.92	29.4	11.4	0
3	96.04	67.02	29.02	14.8	0
4	97.91	67.91	30	17.89	0
5	97.13	68.14	28.99	21.8	0
6	96.07	67.21	28.86	29.1	0
7	96.951	68.12	28.831	33.14	23.6
8	95.01	67	28.01	36.37	23.83
9	96.01	66.01	27.62	41.51	0
10	93.63	68.36	28.89	45.13	0
11	97.63	69.6	28.03	36.33	23.1
12	98.96	70	28.96	25.76	23.4
13	98.25	69.9	28.35	20.1	22.56
14	98.62	69.2	29.42	11.031	24.06
15	99.57	69.92	29.65	5.2	23.41
16	2.03	2.03	0	11.4	0
17	2	2	0	10.02	0
18	2	2	0	27.73	0
19	2.12	2.12	0	32.41	0
20	2.004	2.004	0	34.34	0
21	2.00012	2.00012	0	42.021	0
22	99.91	70	29.91	28.6	0
23	98.99	70	28.99	17	0
24	99.7	69.86	29.84	5	0

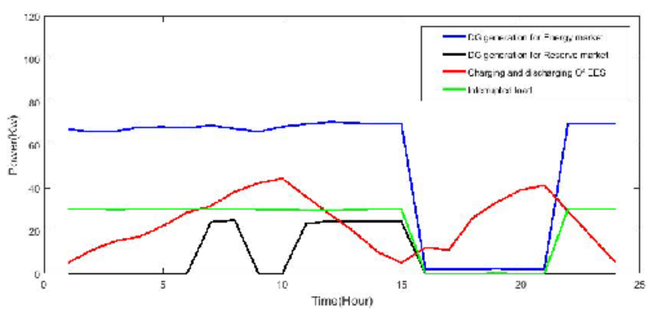

Fig. 6. Results for VPP decision making in scenario 3

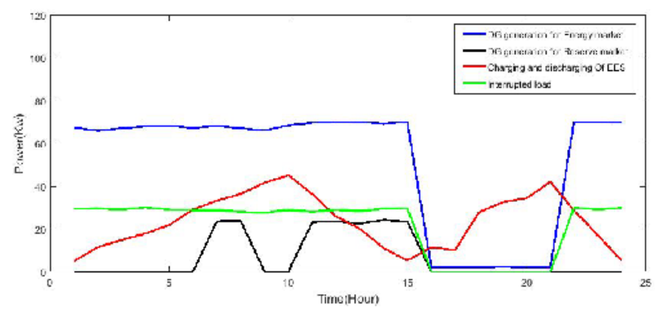

Fig. 7. Results for VPP decision making in scenario 4

of this scenario. summary of the behavior of VPP in this scenario is presented in Fig.6.

D. The Fourth Scenario: uncertainty in energy, load and reserve delivery price

In this scenario, price in energy, reserve and forecasted load markets have been considered as random parameters. Also, reserve delivery is 0.9. Table.7 shows the DG unit performance in energy and reserve markets. In this scenario, DG generation for contribute in energy market has no significant changes compared to the third scenario and uncertainty in reserve delivery has more impact on power allocated to spinning reserve market. The lower the possibility of reserve delivery, the risk of contribution in reserve market is higher and VPP allocates less power to that. The condition of storage have not changed much compared with the third scenario. Sixth column of the Table. 7 shows the condition of removable loads which was expectable that less loads will be disconnected according to their allocation to reserve market and the reason is uncertainty in reserve delivery.

In Table. 4, hourly profits of VPP corresponding to the fourth scenario have been shown for 24-hour time horizon. summary of the behavior of VPP in this scenario is presented in Fig. 7.

E. The Fifth Scenario: uncertainty in load, energy price, reserve delivery and connection to upstream network with PV presence

In this scenario, in addition to considering uncertainty in load, price, reserve delivery and connection with upstream network, a PV unit has been installed on the studied 4-bus system. As the sun radiation is a random parameter and output of the PV is based on that, it has been modelled as a bimodal distribution function which is combined of two Vibal distribution as follow [16]:

$$f(G) = \omega(\frac{k_1}{C_1})(\frac{G}{C_1})^{(k_1-1)}e^{-(G/C_1)^{K_1}} + (1-\omega)(\frac{K_2}{C_2})(\frac{G}{C_2})^{(k_2-1)}e^{-(G/C_2)^{k_2}} \quad (14)$$

In which $\omega = 0.3; k_1 = 2; k_2 = 10; C_1 = 0.4C_2$ and

Table 8. Virtual power plant performance in Scenario 5

Hour	Total DG Generation , kW	DG generation for Energy market, kW	DG generation for Reserve market, kW	Charging and discharging Of EES, kWh	Interrupted load, kW
1	97.12	67.92	29.2	5	0
2	95.13	65.9	29.23	11.2	0
3	96.19	67.1	29.09	15.01	0
4	97.97	67.98	29.99	17.8	0
5	97.2	68.2	29	22.03	0
6	96.09	67.26	28.83	29.5	0
7	97	68.16	28.84	33.1	23.5
8	95.17	67.1	28.07	36.04	23.75
9	93.66	66.08	27.58	41.4	0
10	97.21	68.41	28.8	44.9	0
11	97.75	69.66	28.09	36.3	23.14
12	99.03	70.03	29	25.64	23.41
13	98.2	69.99	28.21	20.14	22.52
14	98.58	69.18	29.4	10.94	24.09
15	99.45	69.9	29.55	5.24	23.4
16	2	2	0	11.46	0
17	2.02	2.02	0	9.96	0
18	2.016	2.016	0	27.64	0
19	2.1	2.1	0	32.46	0
20	2.005	2.005	0	34.4	0
21	2.008	2.008	0	42.07	0
22	99.95	70.01	29.94	28.69	0
23	99.06	70.06	29	16.95	0
24	99.8	69.9	29.9	5	0

$C_2$is$\frac{G_{mean}}{\Gamma(1+1/k_2)}$ In Fig. 9, probability distribution function of sun radiation can be seen in each hour and also sun radiation Intensity during 24 hours has been shown in Fig. 10. To calculate PV output power based on the sun radiation intensity, equation 14 is used.

$$P_{out} = \eta^{PV} S^{PV} G \quad \textbf{(15)}$$

In witch η^{PV} is efficiency of PV, G is The intensity of the sun's radiation (KW/m2) and S^{PV} is Cross section of Pv. So PV acts as a negative load in hours that has no generation. Table. 8 shows the DG operation in energy and reserve markets in this scenario. In this scenario according to uncertainty in connection with upstream network, DG unit generates more power than the fourth scenario. Also, according to PV presence leads to purchase less power from upstream network. in this scenario unlike the first and scenario in which DG is shut off in cheap price hours, DG has not been shut off in order to reduce risk. There is no significant changes in the condition of storages and disconnected loads. VPP profit in this scenario like others has been shown Table. 4. Therefore In this scenario, VPP profit is less than second, third and fourth scenarios and is higher than the first scenario. Also like other scenarios, summary of the behavior of VPP in this scenario is presented in Fig. 8.

Results show that despite considering price uncertainty in the second scenario compared to first scenario, the amount of reserve capacity remained unchanged in the highest possible point due to potential profit. On the other hand, the power allocated to energy market during hours 1-3, 6-11 and 15 had insignificant changes compared to the first scenario which is due to energy price uncertainty. In the third scenario, load uncertainty has the most impact on storages and has no significant impact on disconnected loads which means that removable loads are not

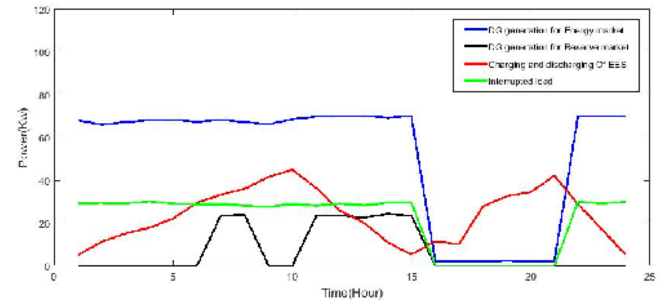

Fig. 8. Results for VPP decision making in scenario 5

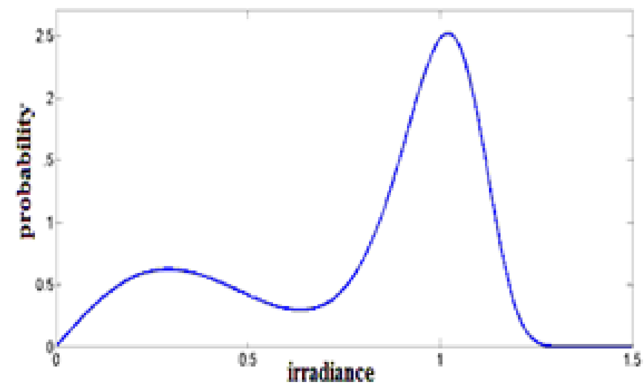

Fig. 9. The distributing function of the probability of the sun's radiation per hour

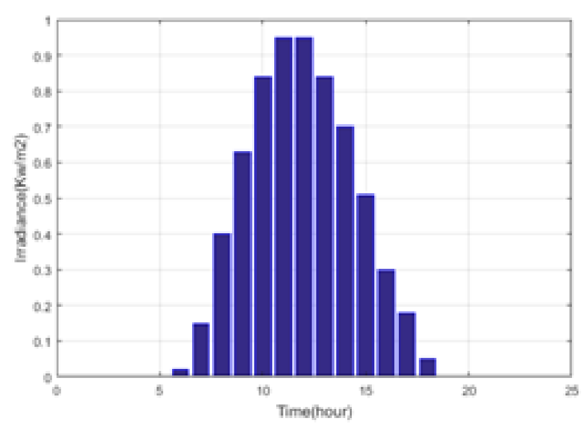

Fig. 10. The intensity of the sun's radiation per hour

sensitive to random parameters. In the fourth scenario, with considering reserve delivery uncertainty, the power allocated to reserve market is more impacted than the third scenario and the lower the cost of reserve delivery is reduced, the less power is allocated to this market despite Profitability of reserve market. In the fifth scenario, presence of different uncertainties causes VPP performance to get closer to reality and also considering the uncertainty in connection with upstream network leads to increase DG generation compared to the fourth scenario.

5. CONCLUSION

In this paper, aggregation of distributed energy resources in the form of VPP and buy-sell strategy in energy and spinning reserve markets were studied in three different scenarios. The superiority of this paper is considering uncertainty in VPP connection with upstream network as well as uncertainty in reserve delivery in order to obtain results that are closer to reality.

In this study, 5 scenarios were discussed. The results of this study improve the impacts of the considered uncertainties in VPP decision making. In order to obtain the near global optimum profit during a particular time period, the VPP strategy might be not to obtain the near global optimum profit in a particular time so that profit of entire period maximizes. Also, due to technical constraints and present uncertainties, VPP has a dual behavior. Therefore, while purchasing energy from upstream network and according to energy and reserve market condition, VPP may buy or sell energy to upstream network or may propose a part of its energy in reserve market to sell to upstream network. This behavior is due to an attempt to gain more profit because transactions in reserve market are more profitable.

Evaluation of the storage uncertainty and also power exchange with adjacent network might be useful for future work.

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