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Participating of Micro-grids in energy and spinning reserve markets – Intra-day market

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Abstract

Due to uncertain nature of wind and photovoltaic power units, the participation of this units in electricity markets is subjected to significant deviation penalties. This issue leads to despondency or even admission of these units in the competitive environment. With regard to this fact that the low deviations are available when predictions are performed in a short-term horizon and also distributed generation (DG) units have several potential benefits to provide ancillary services, in this article the participation of DG units in intra-market ancillary services is investigated. The intra-day market consists of 3-8 hours scheduled horizon time and will lead to reduction in deviations. Here, three kinds of uncertainties, consist of renewable DG unit's output, load and price of electricity markets will be predicted by using an adaptive neuro-fuzzy inference system (ANFIS). The proposed method is optimized by Genetic Algorithm (GA) and is tested on a test system. The results supported the efficiency of proposed method.

Keywords: Micro-grid; ancillary services; spinning reserve; Intra-market; Distributed generation.

1. Introduction

In recent decades, Distributed Generations (DGs) have had an increasing penetration in power systems. Furthermore the ability to provide ancillary services, such as spinning reserve, non-spinning reserve, and reactive power injection and etc., by the DGs which are located close to the loads, is considered as an efficient and economical solution to support the system. Therefore it is expected that in deregulated environment, in addition to supply the future energy needs, DGs due to their ability in providing ancillary services gain a special significance. However their uncertain nature and limited predictability of generated electricity from these units and the need to create Spot market for maintaining the network stability made the presence of these sources dependent on paying remarkable deviation penalties in the process of adjustment and settlement of the market.

To solve this problem, DG should be integrated with the system operation. This goal can be achieved through integration of distributed generation or to be more accurate, by distributing energy resources (DER) in a micro-grid. Distributed energy resources refer to the distributed generation units, storage systems and interruptible loads.

Even though micro-grid has many benefits, the integration of micro-grid into the traditional distribution system imposes technical challenges of system operation in several aspects, such as energy management strategy, protection design, reliability and so on. Among these issues, research of interaction paradigm between micro-grid and traditional system is crucial for maximizing potential benefits of micro-grid.

References [2-5] examine the participation of micro-grid in Energy and Ancillary services markets. These researches or practical application would facilitate effectiveness and profitability of most micro-grids. However, uncertainty including renewable DG units' power output, market price, and lines/units reliability is not considered in these studies. Generally, Energy storage systems (ESS) and interruptible load are added to micro-grid to reduce imbalances between load and generation. But it seems due to influence of uncertainties in maximizing of micro-grid profits, we must find more efficient ways.

In [6] some of uncertainty includes power output of renewable DG units and load is taken into account. The high accuracy will be attained when the time horizon of study is short-term, therefore in [7] the Intra-day Market (IM) is suggested to reduce the impact of uncertainty. In this method, during the day light, in several periods of time, the micro-grid will be allowed to update suggestions that it has offered to the market.

Since DG units have the potential ability in providing ancillary services and this important issue has not been considered in IM markets. in this paper, a stochastic bidding strategy with consideration of uncertainties include renewable DG unit's output, load and price fluctuations for participation of micro-grid in the IM (energy and spinning reserve) is proposed.

1. Micro-grid Components and their Modeling

The micro-grid under study consists of DG units (including dispatchable and non- dispatchable units) and final consumers (including interruptible and non-interruptible loads). The ownership and management of All of DG units is undertaken by micro-grid. The energy of final consumers is provided at Retail price. This price has been set in several levels for different periods of time in a day. The micro-grid also signs an agreement about maximum amount of load interruption, interruption hours and costs of interruption with interruptible loads.

Modeling for the sake of participation in electricity market means that power production costs can be determined by micro-grid components. In studies of participation in electricity market, the time horizon is usually short-term and only operating costs of power generation is modeled.

The operating cost of dispatchable DG units is modeled as a quadratic function of their productivity, which is as the follow [4]:

$$C(P_{DG}) = \alpha_i + \beta_i P_{DG} + \gamma_i P_{DG}^2 \quad (1)$$

Where α_i, β_i and γ_i are Positive Coefficients of the cost function.

Operating costs of non-dispatchable distributed generation units is limited to maintenance costs, so they can be ignored.

Based on what is in [2], the consumer's cost curve of a load to cut (limit) it's load, is assumed as a function of un-served load and is modeled as a quadratic polynomial.

$$C(P_{curt}) = \alpha_i P_{curt} + \beta_i P_{curt}^2 \quad (2)$$

Where α_{int} and β_{int} are not used load Coefficients.

2. Bidding Strategy of Micro-grid

The bidding strategy contains information about market participants willing to buy or sell energy and also have information about how much power, at what price, in what area and at what time must be exchanged. Bidding strategy has very significance role in maximizing the profit of market participants as well. Generally, bidding strategies can be divided into two categories: equilibrium and non-equilibrium strategies.

Equilibrium models such as supply function and Cournot equilibrium are widely applied for the development of the bidding strategy of generation companies (GenCos) and analyzing market power in energy markets. However, unit constraints such as minimum on/off time, ramping limits, and startup and shut down costs are not considered in most of the equilibrium models.

Price-based unit commitment (PBUC) non-equilibrium model can overcome these constraints and is a good strategy for the multiple markets (energy and ancillary services), so in this paper the bidding strategy is based on PBUC.

3. Objective Function

The aim of the micro-grid from participating in power and ancillary services markets is to maximize profit by providing consuming load of its consumer, power exchange with the upstream network or electricity market and the provision of ancillary services. The objective function of the problem is given in (3). The first term of objective function represents the total revenue from bidding in market and providing power to end customers. The Second term is unit cost to provide power and ancillary services, the third term is for payback cost of load interruption and the fourth term is imbalances costs.

$$\begin{aligned} profit &= \sum_{t=1}^{24}\left(\rho_{E,t}\times E_t + \rho_{AS,t}\times AS_t + \rho_{L,t}\times L_t\right) - \\ &\sum_{t=1}^{24}\left(\sum_{i=1}^{N_{DG}}\left(C_{DG\,i,t}\left(E_{DG\,i,t} + AS_{DG\,i,t}\right)\right)\right) - \\ &\sum_{t=1}^{24}\left(\sum_{k=1}^{N_{curt}}\left(C_{curt\,k,t}\times AS_{curt\,k,t}\right)\right) - \sum_{t=1}^{24} C_{\Delta p,t} \end{aligned} \quad (3)$$

Where: ρ is price in energy and ancillary services markets and retain rate, N_{DG}, N_{curt}, C and AS are the number of dispatchable DG units, the number of interruptible loads, cost function, energy bid for energy market and energy bid for ancillary services market, respectively.

Also the costs of imbalances are calculated like in (4).

$$C_{\Delta p} = \begin{cases} \rho_{up}\left(P_{GEN} - P_{DM}\right) & \text{if} \quad P_{GEN} \geq P_{DM} \\ \rho_{down}\left(P_{DM} - P_{GEN}\right) & \text{if} \quad P_{GEN} \leq P_{DM} \end{cases} \quad (4)$$

Where: P_{DM} is the power bid for the market, P_{GEN} is the real time generation, ρ_{up} and ρ_{down} are price in negative and positive markets, respectively.

4. Constraints

Constraint related to the balance of supply and demand for energy and ancillary services is given in (5).

$$E_t + \sum_{i=1}^{N_{DG}}\left(E_{DG\,i,t} + AS_{DG\,i,t}\right) + \sum_{k=1}^{N_{curt}} AS_{curt\,k,t} = L_t + Loss_t \quad (5)$$

Where L is load of micro-grid and LOSS is losses of micro-grid.

Constraints related to the DER are as follow:

A. DG power generation limits:

$$P_{DGi,t}^{min} \leq \left(P_{DGi,t} + AS_{DGi,t}\right) \times I_{i,t} \leq P_{DGi,t}^{max} \quad (6)$$

Where I is binary variable of DG situation.

B. Power generation decrease and increase rate

$$\begin{cases} P_{DGi,t+1} - P_{DGi,t} \geq R_{DGui,t} \\ P_{DGi,t} - P_{DGi,t+1} \geq R_{DGdi,t} \end{cases} \quad (7)$$

Where R_{DGu} and R_{DGd} are Power generation increase and decrease rate, respectively.

C. Minimum on and off time

$$\begin{cases} \left[T_{i,t-1}^{off} - MDT_i\right] \times \left[I_{i,t-1} - I_{i,t}\right] \geq 0 \\ \left[T_{i,t-1}^{on} - MUT_i\right] \times \left[I_{i,t-1} - I_{i,t}\right] \geq 0 \end{cases} \quad (8)$$

Where T^{off} is number of DG's off time, T^{on} number of DG's on time, MUT minimum hour of on time, MDT minimum hour of off time.

D. Maximum provision power for spinning reserve

$$P_{DGi,t} \leq \min\left\{\left(10 \times MSR\right), \left(P_{DGi,t}^{max} - P_{DGi,t}\right)\right\} \quad (9)$$

Where MSR is power generation increase rate in one minute.

E. interruptible loads limits

$$0 \leq \left(AS_{curtk,t}\right) \times I_{i,t} \leq P_{curtk,t}^{max} \quad (10)$$

Constraint related to the intra-network of micro-grid is as follow:

A. Balance between active and reactive power consumption and generation

$$P_{i,t}\left(V_t, \theta_t\right) - P_{g_{i,t}} + P_{d_{i,t}} = 0 \quad (11)$$

$$Q_{i,t}\left(V_t, \theta_t\right) - Q_{g_{i,t}} + Q_{d_{i,t}} = 0 \quad (12)$$

Where d is consumption in node, g is generation in node and I refers to the node.

B. Node voltage limits (ranges)

$$V_i^{min} \leq V_{i,t} \leq V_i^{max} \quad (13)$$

C. Exchanged power limit

$$\left|E_t + AS_t\right| \leq E_{exch}^{max} \quad (14)$$

Where E_{exch}^{max} is maximum Exchanged power with the main grid.

5. Proposed method

Uncertainty factors like renewable DG unit's power output, load, price of energy and ancillary services markets and reliability (fail) of production units and lines, can affect the optimal performance of micro-grid. Traditional methods, which considered only one scenario for micro-grid can be invalid and can affect micro-grid's expected total profit from participating in day ahead electricity market. On the other hand, High accuracy is available when prediction is performed in a short-term horizon. This factor will be lead to that our predictions become more accurate and we have less imbalances and our costs will be reduced.

With respect to the explanation above, in this paper, in two steps the impact of uncertainty on the profitability of micro-grid will be examined. As The first step micro-grid operator sends bids to the following day market. To this end, several scenarios to reduce the impact of uncertainty (including the output power of renewable DG units, load and market price fluctuations, which include energy, spinning reserve and imbalance market prices) is produced. After that, during the goal day through several stages, micro-grid operator updates the bids that has sent to the market. The intra-day market structure has shown in Figure 1. In following section, the proposed method will be explained.

6. Uncertainties Forecasting

Various studies have developed various methods for more accurate prediction of these factors. Among these neural network, models based on time series, a variety of innovative methods and etc. can be mentioned. In this paper, for forecasting each factor of uncertainties, an adaptive fuzzy neural inference system (ANFIS) (which adapted from [8]) was used.

This algorithm is used to find the next DM prices based on the knowledge of previous day's data. Firstly, ANFIS is trained and then ANFIS will do predictions with high accuracy.

In this paper, for training ANFIS, the information of last 7 days, prices of the same day in the last year, day-type of the target day which is considered zero for the weekend and 1 for the weekdays and weather factor are used as the input of learning machine. For predicting the uncertainty factors initially, parameterized model for determining relationship between input and output, membership function and rules governing training will be used. Next, input/output data, which can be used for training ANFIS, will be collected. Then ANFIS can be used for Forecasting. Forecasting method structure is shown in Fig. 2. Also Historical data of Spanish load, wind speed, solar irradiation and market prices are available in [9-12] respectively.

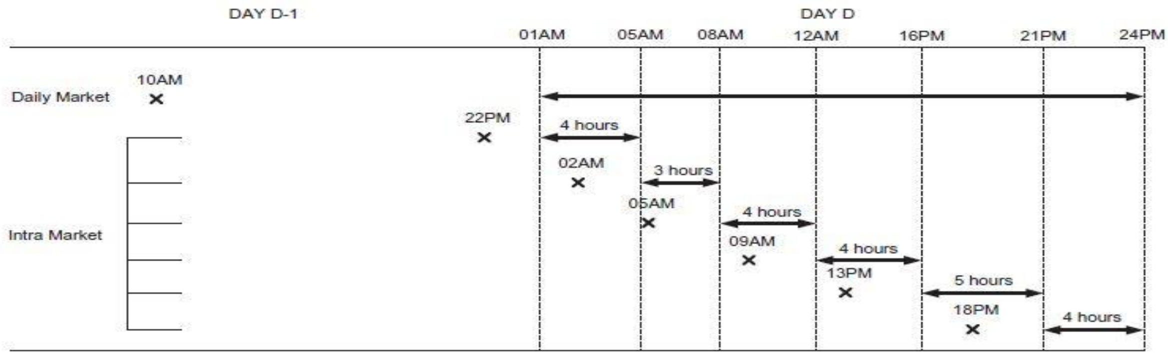

Fig. 1. Intra day market structure.

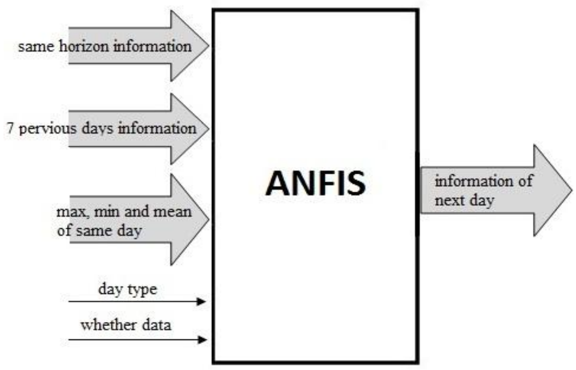

Fig. 2. The forecasting method.

7. Scenario generation

Due to uncertainties of issue, Micro-grid scenarios must be produced. Uncertainties of wind speed, solar irradiation, load and the price fluctuations cause various scenarios. For optimal performance, wide ranges of scenarios must be modeled. Latin Hypercube Sampling (LHS) is a group sampling in which a full coverage of the range of variable with sufficient accuracy will be modeled, so the LHS method was used for the scenario production of the micro-grid. The process is in the following.

Step 1: at the first, based on the method described in the previous section, for one month before the day under study necessary predictions will be done. Then with respect to errors in this 30-day predictions, forecasts for the under study day will be provided.

Step 2: Calculation of the output power of renewable units with respect to the wind speed, irradiation and the power transmission curves.

Step 3: obtaining a cumulative distribution function of each of the variables and dividing it into N equal parts.

Step 4: choosing a number randomly in any distance and transforming selected probability values (prob) to the numerical values of variables (x_e) by reverse cumulative distribution function (F^{-1}).

$$x_e = F^{-1}(prob) \tag{15}$$

8. Scenarios Reduction

Scenarios generated by LHS for micro-grid are a lot and this leads to increase in time and cost of calculations, therefore the number of scenarios must be reduced with keeping sufficient accuracy. There are various methods to reduce the number of scenario that have been reported in [8]. According to relative distance between scenarios, the backward scenario reduction technique delete a scenario in each iteration and can bring about good accuracy, so in this paper, this method has been used for reduction of scenarios. Steps are as following.

Step 1: According to the scenarios generated by LHS, the probability of each scenario is equal to 1/n and the desired number of scenarios is n* that the initial number of reduced scenarios n* = N.

Step 2: Calculation of the Kantorovich distance for each pair of scenarios.

$$KD(S_i, S_j) = \left| B_{i,t} - B_{j,t} \right| \tag{16}$$

$$B_{i,t} = (Ep_{i,t} + Rp_{i,t}) \times \left(Load_{i,t} - WP_{i,t} - PV_{i,t} \right) \tag{17}$$

Where: Ep is the price of energy markets, Rp : the market price of spinning reserve, LOAD: load of micro-grid, WP: wind power and PV is PV power of micro-grid.

Step3: selecting the scenario that has the minimum Kantorovich distance with scenario i:

$$KD(S_i, S_k) = \min\left(KD(S_i, S_j) \right) \quad 1 \le j \le n^* \tag{18}$$

Then the probability of scenario will be calculated.

$$PKD(S_i, S_k) = KD(S_i, S_k) \times P_i \tag{19}$$

Where P_i is the probability of scenario i.

Step 4: Repeating step 3 for all scenarios and calculating:

$$PKD(S_i, S_k) = \min\left(PKD(S_i, S_k) \right) \quad 1 \le k \le n^* \tag{20}$$

Step 5: between selected scenarios with regard to the event probability of chosen scenarios, one of the scenarios will be deleted and add its probability to the nearest possible scenario and the number of scenarios will be updated.

Step 6: repeating Steps 2 - 5 until reaching to the desired number of scenarios.

9. Objective Function Optimization

Based on the chosen scenarios from scenario reduction section, each scenario is considered as a deterministic scenario and objective function is optimized by genetic algorithm with the aim of maximizing profit of micro-grid from participating in the electricity markets. At the end, based on the (event) probability of each scenario, micro-grid total expected profit is calculated.

10. Participating in intra-day market

After that micro-grid bids were sent to the next day market, they will be updated at several stages during the goal day. In forecast stage, uncertainties factors of goal day of ahead market, information of the last 6 periods (intra-day market), type of day and weather condition will be used for training ANFIS system. The objective functions are also different from those in (3). The new objective function is as follow. Where IM subtitles and DA subtitles related to the intra-day and day ahead markets, respectively. Also on the above equation, only energy market bids have been entered and must be considered for spinning reserve market in the same way.

$$\begin{aligned}
profit_{IM} &= profit_{DA} + \\
&\sum_{t=1}^{24} \left(\rho_{E_{IM,t}} \times (E_{IM,t} - E_{IM,t}) + \rho_{L_{IM,t}} \times (L_{DA,t} - L_{IM,t}) \right) - \\
&\sum_{t=1}^{24} \left(\sum_{i=1}^{N_{DG}} \left(C_{DGi,t} \left(\left(E_{DG_{DAi,t}} \right) - \left(E_{DG_{IMi,t}} \right) \right) \right) \right) - \\
&\sum_{t=1}^{24} \left(\sum_{i=1}^{N_{curt}} \left(C_{curti,t} \left(\left(E_{curt_{DAi,t}} \right) - \left(E_{curt_{IMi,t}} \right) \right) \right) \right) - \\
&\sum_{t=1}^{24} \left(\sum_{i=1}^{N_{st}} \left(C_{sti,t} \left(E_{st_{DAi,t}} \right) - \left(E_{st_{IMi,t}} \right) \right) \right) - \sum_{t=1}^{24} \left(C_{\Delta p_{DA,t}} - C_{\Delta p_{IM,t}} \right)
\end{aligned} \tag{21}$$

11. Case Study

To evaluate the proposed method, different simulations and analyses are performed on a sample micro-grid (shown in Figure 3). This micro-grid consists of three commercial, industrial and residential feeders. Also micro-grid has three 15 kW wind turbines, 10 kW photovoltaic unit, 80 kW fuel cell capacity and 80 kW system micro-turbine. Detailed information about dispatchable DG units is given in [9]. All DG work at unity power factor. Also Loads can be cut up to 20 kW and dispatchable DG units can provide spinning reserve up to 25% of their capacity. In the next sections two scenarios are considered to examine the effectiveness of the proposed method.

A. The first scenario: participating in day ahead market

First, we assume there is no uncertainty on the issue. The results of the simulation are shown in Figure 4. The expected profit of micro-grid is -17620 cents that 1042 cents related to the spinning reserve market. If the micro-grid only participated in energy market, total expected profit of micro-grid was -19174 cents.

Now uncertainties must be considered. According to the predictions done by ANFIS System, totally 300 scenarios are generated by LHS. Then these 300 Scenarios are reduced to 10 scenarios and each scenario has a certain possibility. Each scenario will be applied to micro-grid as a deterministic scenario and at the end, the expected total profit of micro-grid is calculated with regard to the probability of each scenario. The profit of micro-grid is -11826 cents which has 5974 cents growth.

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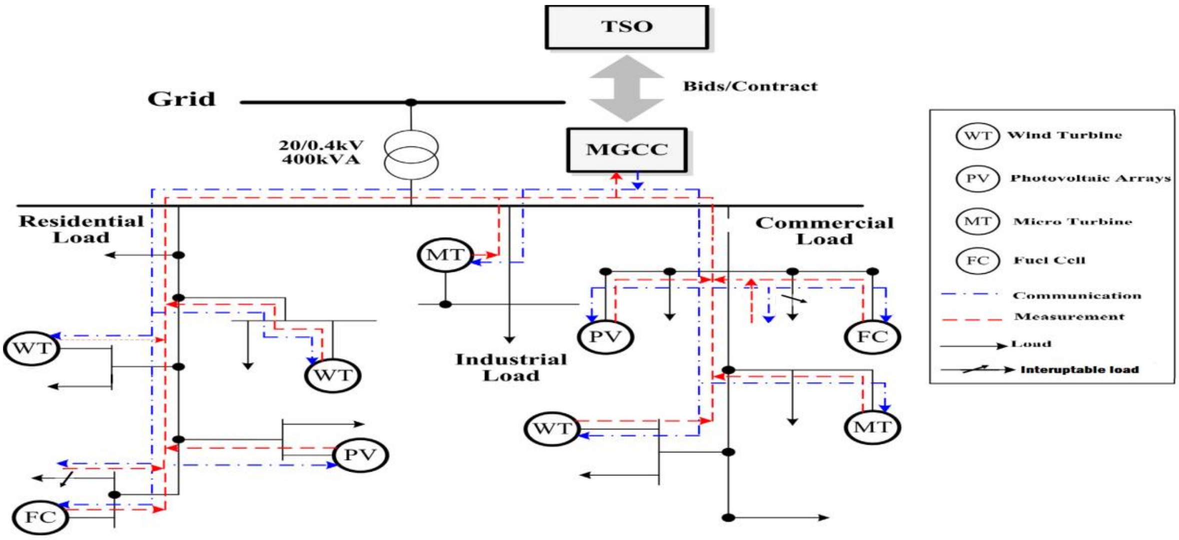

Fig. 3. A modified typical low voltage Micro-grid [6].

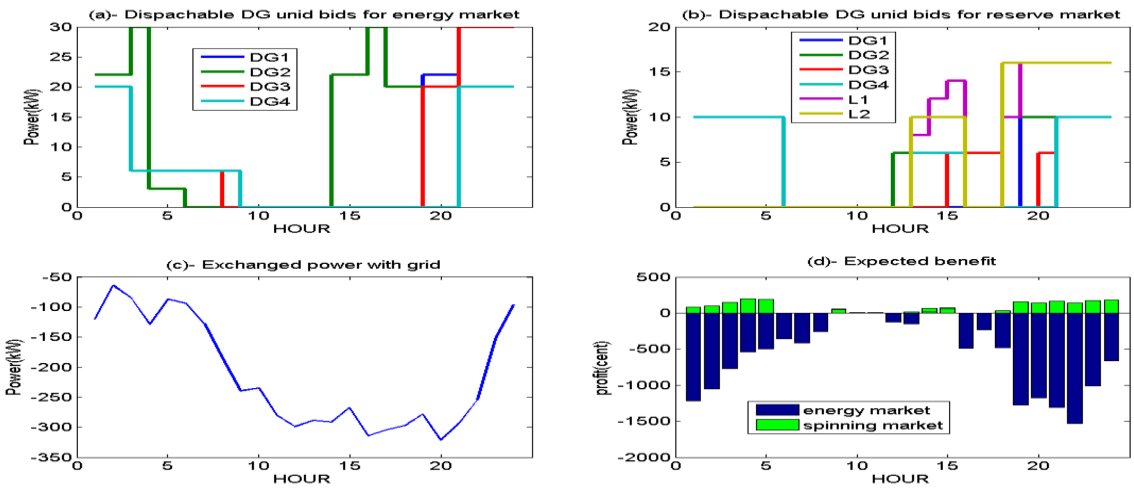

Fig. 4. a- Bids of Micro-grid for energy market, b- Bids of Micro-grid for spinning reserve market, c- Exchainged power with main grid, d- Expected benefit of Micri-grid.

For further investigation, the participating of micro-grid will be considered during a week. Simulation results for this scenario are given in Figure 5.

B. The second scenario: participating in intra-day market

In this case, the participating of micro-grid in intra-day market is considered. The total expected profit of micro-grid increases to -10937 cents. This increase in profit was caused by reducing the impact of uncertainties, increasing internal production, reducing the purchase from the network and, in general, reducing the imbalance costs. Also the results of the simulations for a week, compared to the first scenario are shown in Figure 6. As it can be seen, the results indicate that the proposed method and participating in intra-day market is effective.

12. Conclusion

In this paper, with regard to the impact of uncertainties on profit of micro-grid, this aim is considered in two cases which the total profit of micro-gird increased. Also the ANFIS system was used for forecasting the uncertainties. For reducing the impact of uncertainties in study, the survey was done in probability form using LHS method and intra-day market was suggested.

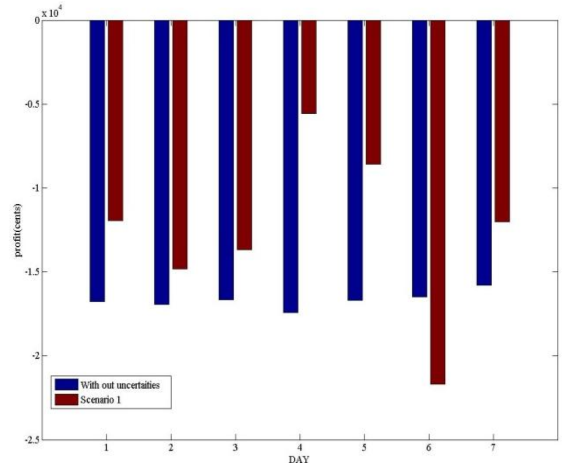

Fig. 5. Benefit comparison of Micro-grid for scenario 1.

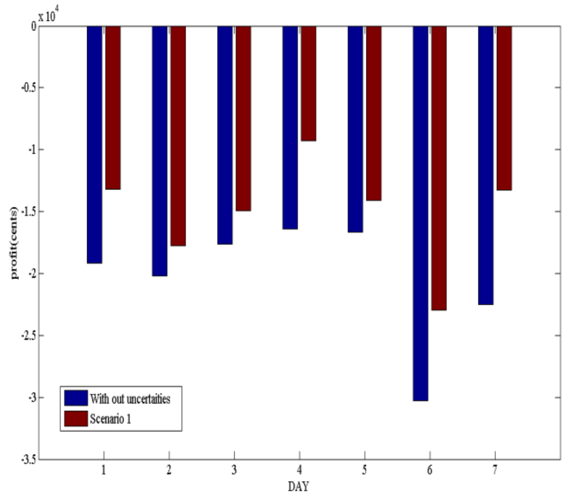

Fig. 6. Benefit comparison of Micro-grid(scenario 1 with scenario 2).

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