LOCATION AND CONTRACT PRICING EVALUATION OF DISTRIBUTED GENERATION UNDER A COMPETITIVE FRAMEWORK

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Abstract – This paper presents a comparison between different approaches for the optimal location and contract pricing of dispatchable Distributed Generation (DG) in distribution systems. Regarding the ownership of DG, three different cases have been considered: a) when the DG units belong to the Distribution Company (DisCo); b) when the DG units belong to a single owner; and c) when the DG units belong to different owners. The location and contract pricing is evaluated considering a market structure in which the DisCo can purchase energy either from the DG units within its network, and/or from the wholesale energy market. Tests are performed using a 34-bus distribution system. The three cases are analyzed and compared.

Keywords: Distributed generation, genetic algorithms, game theory.

1 NOMEMCLATURE

The following nomenclature is used throughout the paper.

1.1 Indices

n, m	Bus indexes
j	Distributed generation unit index.
l_{mn}	Index of line connecting nodes *m, n*.

1.2 Parameters

$\rho_{SE}(t)$	Wholesale energy price at the substation in period *t* [€/MWh].
Δ_t	Length of the time interval *t* [h].
S_{lmn}^{Max}	Maximum apparent power limit in the line connecting nodes *m, n* [Mva].
V_n^{Max}	Maximum voltage limit in bus *n* [V].
V_n^{Min}	Minimum voltage limit in bus *n* [V].
P_{DGj}^{Max}	Maximum active power limit of DG unit *j* [MW].
P_{DGj}^{Min}	Minimum active power limit of DG unit *j* [MW].
P_{SE}^{Max}	Maximum active power limit of the substation [MW].
P_{SE}^{Min}	Minimum active power limit of the substation [MW].
Q_{SE}^{Max}	Maximum reactive power limit of the substation [Mvar].
Q_{SE}^{Min}	Minimum reactive power limit of the substation [Mvar].
Q_{DG}^{Max}	Maximum reactive power limit of DG unit j [Mvar].
Q_{DG}^{Min}	Minimum reactive power limit of DG unit j [Mvar].
c_{DGj}	Production cost of DG unit *j* [€/MWh].
$P_{Dn}(t)$	Active power demand in bus *n* in period *t* [MW].
$Q_{Dn}(t)$	Reactive power demand in bus *n* in period *t* [Mva].
g_{mn}	Real part of element m, n of the admittance matrix [mho].
b_{mn}	Imaginary part of element *m, n* of the admittance matrix [mho].
N_{DG}	Number of DG units.

1.3 Variables

$P_{SE}(t)$	Active power supplied by the substation in period t [MW].
$Q_{SE}(t)$	Reactive power supplied by the substation in period *t* [Mva].
$P_{DGj}(t)$	Active power supplied by the DG unit *j* in period *t* [MW].
$Q_{DGj}(t)$	Reactive power supplied by the DG unit *j* in period *t* [Mva].
$V_n(t)$	Voltage magnitude of node *n* in period *t* [V].
θ_{mn}	Angle between nodes *m, n*.
λ_{DGj}	Contract price of DG unit *j* [€/MWh].
μ_{nj}	Binary decision variable indicating the allocation of DG unit *j* in bus *n*.
P_{lmn}	Real power in line connecting nodes *m, n* [MW].
Q_{lmn}	Reactive power in line connecting nodes *m, n* [Mvar].
S_{lmn}	Apparent power in line connecting nodes *m, n* [Mva].

1.4 Sets

J	Set of indices of DG units.
T	Set of time intervals.
N	Set of indices of network nodes.

2 INTRODUCTION

Distributed Generation can be broadly defined as the production of electricity by small generators located near the final consumers or in the distribution network [1]-[2]. Despite of the fact that most of current DG technologies are not competitive with centrally dispatch generation, it is also true that DG can bring along some benefits such as reduction of power losses [3], improvement of voltage profile [4], deferral of investments [5] and mitigation of power quality problems [6]. The potential benefits of DG depend on its size and location as well as the parameters of the network. Bearing this in mind, the optimal location of DG is of great interest not only for DisCos but also for potential investors on DG. The problem of optimal location of DG has been the focus of several studies. The methodologies used to approach such problem include the use of metaheuristics [7]-[8], classical optimization techniques [9] and analytical approaches [10]-[11]. Most of these methodologies are presented from the standpoint of the utility, aiming to maximize the potential benefits of DG. In contrast, the methodologies presented in this paper not only consider the interest of the utility, but also the interest of DG owners.

In this paper we consider a business scheme in which the DG owner is interested in engaging in business with the DisCo. We work under the hypothesis that to attend the expected demand, the DisCo is able to purchase energy either from the wholesale energy market, or from the DG units within its network. The amount of energy to be purchased from each supplier is determined by means of an optimal power flow (OPF)-based dispatch. Such dispatch implicitly considers the impact of DG units in the network. The potential investors must decide the location and contract price of the DG units aiming to maximize the profits obtained from the energy sold to the DisCo. Note that the business scheme considered in this paper does not necessarily correspond to an unbundled framework.

Regarding ownership, we have considered three different scenarios. In the first scenario the DG units belong to the DisCo. Due to the unbundling of electric energy industry, in some countries, utilities are not allowed to own DG. Consequently, this first scenario has been designed only for comparative purposes. We have developed this first scenario under the assumption that the DisCo owns and operates DG units; consequently, the DisCo also decides over the location of them. In this case a specialized Genetic Algorithm (GA) is used to identify the location of the DG units that minimizes energy payments.

In the second scenario two different agents are considered, namely, the DisCo and the DG owner. On one hand the DisCo pretends to minimize the payments incurred in attending the expected demand; on the other hand, the DG owner pretends to maximize his profits. This two-agent relationship is represented by a bilevel programming structure in which the DG owner is the leader and the DisCo is the follower. As in the first case, the resulting optimization problem is solved using a specialized GA. Due to the fact that, under a bilevel programming approach, an agent must decide over the quantity of energy to be produced, the comparison is restricted to dispatchable DG technologies. Note that in this scenario, the DisCo does not own the DG units. In this case the DG units would produce when indicated by the DisCo (such production is determined by an OPF-based dispatch). However; they still are free either to sell their production surplus or use it for their own purposes. To account for that situation it would only be necessary to modify the limits of constraints (8) and (9).

In the third scenario we consider that the DG units belong to different owners, consequently, the potential investors strive to find the best locations of the DG units and their corresponding contract prices. Each DG owner is interested in maximizing his own profits, while the DisCo pretends to minimize the energy payments. This scenario is modeled as a non cooperative game and its Nash Equilibrium is found using specialized software.

The main contributions of this paper are fourfold

1. It provides a comparison of location and contract pricing of DG considering ownership issues.
2. In all models, the impact of the DG units in the network is implicitly considered by means of an AC optimal power flow model.
3. The reaction of the DisCo to the location and contract prices of the DG units is implicitly considered.
4. The interests of both, the potential investors and DisCo are explicitly modeled.

This paper is organized as follows, Section 3 provides the mathematical formulation of the three scenarios under study, Section 4 describes the specialized GA, Section 5 presents an illustrative example, and finally, conclusions and final remarks are discussed in Section 6.

3 PROBLEM FORMULATION

This paper provides a comparison of different methodologies for the location and contract pricing of dispatchable DG units. The three scenarios under study are described below.

3.1 Scenario 1. The DG units belong to the DisCo

In this scenario we consider the location of several DG units with the sole purpose of minimizing total energy payments. This problem is given by equations (1) to (13). Equation (1) represents the objective function. The first term corresponds to the cost of the energy purchased in the wholesale energy market and provided through the substation. The second term corresponds to the cost of the energy provided by the DG units. Equations (2) and (3) correspond to the active and reactive power balance equations in the substation, respectively. Equations (4) and (5) correspond to the active and reactive power balance equations in the nodes different from the substation, respectively. Equations (6) and (7) correspond to the limits of active and reactive power supplied through the substation, respectively. Equations (8) and (9) correspond to the active and reactive power limits of the DG units, respectively. Equations (10) and (11) correspond to the voltage and power flow limits respectively. Equation (12) establishes that there is a fixed number of DG units, and equation (13) indicates that the same DG unit cannot be allocated to more than one bus.

$$\underset{P_{DGj}(t),P_{SE}(t)}{Min} \sum_{t\in T}\Delta_t \rho_{SE}(t)P_{SE}(t)+\sum_{t\in T}\sum_{j\in J}\Delta_t c_{DGj}P_{DGj}(t) \quad (1)$$

$$P_{SE}(t)-P_{Dn}(t)-P_n(t)=0; \quad \forall t\in N/_{n=SE}, \forall t\in T \quad (2)$$

$$Q_{SE}(t)-Q_{Dn}(t)-Q_n(t)=0; \quad \forall t\in N/_{n=SE}, \forall t\in T \quad (3)$$

$$\mu_{nj}P_{DGj}(t)-P_{Dn}(t)-P_n(t)=0; \quad \forall t\in N/_{n\neq SE}, \forall t\in T \quad (4)$$

$$\mu_{nj}Q_{DGj}(t)-Q_{Dn}(t)-Q_n(t)=0; \quad \forall t\in N/_{n\neq SE}, \forall t\in T \quad (5)$$

$$P_{SE}^{Min} \le P_{SE}(t) \le P_{SE}^{Max}; \quad \forall t\in T \quad (6)$$

$$Q_{SE}^{Min} \le Q_{SE}(t) \le Q_{SE}^{Max}; \quad \forall t\in T \quad (7)$$

$$P_{DGj}^{Min} \le P_{DGj}(t) \le P_{DGj}^{Max}; \quad \forall j\in J, \forall t\in T \quad (8)$$

$$Q_{DGj}^{Min} \le Q_{DGj}(t) \le Q_{DGj}^{Max}; \quad \forall j\in J, \forall t\in T \quad (9)$$

$$V_n^{Min} \le V_n(t) \le V_n^{Max}; \quad \forall n\in N, \forall t\in T \quad (10)$$

$$-S_{lmn}^{Max} \le S_{lmn}(t) \le S_{lmn}^{Max}; \quad \forall l_{mn}\in L, \forall t\in T \quad (11)$$

$$\sum_{n\in N}\sum_{j\in J}\mu_{nj} = N_{DG}; \quad \mu_{nj}\in\{0,1\} \quad (12)$$

$$\sum_{n\in N}\mu_{nj} \le 1 \quad (13)$$

The active and reactive power injections are given by (14)-(15).

$$P_n = V_n\sum_{n\in N}V_m\left[g_{nm}\cos\left(\theta_{nm}\right)+b_{nm}sin\left(\theta_{nm}\right)\right] \quad (14)$$

$$Q_n = V_n\sum_{n\in N}V_m\left[g_{nm}sin\left(\theta_{nm}\right)+b_{nm}\cos\left(\theta_{nm}\right)\right] \quad (15)$$

The apparent power flow in the line connecting nodes *m, n* is given by (16)-(18).

$$S_{lmn} = \sqrt[2]{P_{lmn}^2+Q_{lmn}^2} \quad (16)$$

$$P_{lmn} = V_m^2 g_{mn} - V_m V_n g_{mn}\cos(\theta_{mn}) - V_m V_n b_{mn} sin(\theta_{mn}) \quad (17)$$

$$Q_{lmn} = -V_m^2 b_{mn} + V_m V_n b_{mn}\cos(\theta_{mn}) - V_m V_n g_{mn} sin(\theta_{mn}) \quad (18)$$

The problem given by (1)-(13) corresponds to a Mixed- Integer Nonlinear Programming Problem, and is solved using a specialized GA described in section 4.

3.2 Scenario 2. The DG units belong to a single owner different from the DisCo

In this scenario the interaction of two agents is considered: the DisCo and the DG owner. Such interaction is represented through a bilevel programming scheme. A Bilevel Programming Problem (BPP) is an optimization problem in which one of the constraints is also an optimization problem. As its name suggests this problem consists of two levels, in this case the upper level corresponds to the DG owner who decides over the contract price and location of the DG units aiming to maximize his profits (equation (19)). The lower level corresponds to the DisCo that receives the information of the upper level and decides over the quantity of energy to be purchased aiming to minimize total energy payments (equation (20)).

$$\underset{\lambda_{DGj},\mu_{nj}}{Max} \sum_{t\in T}\sum_{j\in J}\Delta_t(\lambda_{DGj}-c_{DGj})\mu_{nj}P_{DGj}(t) \quad (19)$$

Subject to:

(12) – (13) and

$$\underset{P_{DGj}(t),P_{SE}(t)}{Min} \sum_{t\in T}\Delta_t \rho_{SE}(t)P_{SE}(t)+\sum_{t\in T}\sum_{j\in J}\Delta_t \lambda_{DGj}P_{DGj}(t) \quad (20)$$

Subject to:

(2) – (11)

Due to its hierarchical structure, BPPs are intrinsically non-convex and difficult to solve. In particular a non linear BPP that includes integer variables like the one described above can be better solved using metaheuristics than conventional optimization techniques. To solve this problem we have adopted a specialized GA described in section 4.

3.3 Scenario 3. The DG units belong to different owners

In this scenario we consider a generalization of scenario 2. In this case, instead of a single DG owner, there are several potential investors who strive to find the locations and contract prices of their units that would render maximum profits. This scenario is approached from the point of view of non cooperative games. We consider the players to be the DG owners and their strategies the possible locations and contract price offers. For each combination of location and contract price offer it is possible to evaluate the profits of each DG owner by solving an optimal dispatch. With such information a payoff matrix is built and the Nash equilibrium is found using specialized software. The Nash equilibrium is a combination of strategies in which no player can benefit from changing his strategy unilaterally, provided that the other players keep their strategies unchanged.

Specialized software such as Gambit [12] computes the Nash equilibria by solving a system of polynomial equations. Such strategy allows finding both, pure and mixed equilibria. In a mixed equilibrium the strategies of the different players are given by probability distributions. Since the location and contract pricing of the DG units is approached in a deterministic way, we are only interested in finding pure equilibria. On the other hand, it was found that for games with more than two players with a considerable number of strategies (like the one presented in this paper), the Gambit software is unstable and often fails to find the Nash equilibria [13]. To avoid such inconvenient, we make an extensive search over the payoff matrix and check every entry to verify if it meets the condition of a Nash equilibrium. Note that such approach only guarantees finding pure equilibria. Nevertheless, as it was already stated, we are precisely interested in finding only this type of equilibria.

For the three scenarios described above we have considered a single contract price for the whole time frame under study. However; a time-differentiated energy price can be easily considered. In this case we would have to replace λ_{DGj} for $\lambda_{DGj}(t)$ in equations (19) and (20).

4 SPECIALIZED GENETIC ALGORITHM

To solve the optimization problems described in scenarios 1 and 2 a specialized GA was implemented. Such algorithm is an adaptation of the Chu-Beasley GA presented in [14].The only difference in solving scenarios 1 and 2 with the proposed GA is the codification and fitness evaluation. For solving scenario 1 only the location of DG units is coded and the fitness evaluation consists of calculating the total energy payments given by (1). In scenario 2, the codification of the solution includes two vectors that account for location and contract pricing of the DG units. In this case, the fitness evaluation consists in calculating the total profits of the DG units given by (19). Note that for this, it is necessary to first solve an optimal dispatch. The main characteristics of the proposed GA are provided below.

4.1 Codification

The codification proposals for scenarios 1 and 2 are shown in figures 1 and 2, respectively. Note that for scenario 1 only location is considered.

DG1	DG2	...	DGJ	
Bus_DG1	Bus_DG2	...	Bus_DGJ	→Location

Figure 1. Codification proposal for scenario 1.

DG1	DG2	...	DGJ	
Bus_DG1	Bus_DG2	...	Bus_DGJ	→ Location
Price_DG1	Price_DG2	...	Price_DGJ	→ Contract Price

Figure 2. Codification proposal for scenario 2.

4.2 Initial Population

In both scenarios, the initial population is randomly generated. However, it is possible to limit the location of the DG units to a reduced set of nodes representing the preference of the DisCo (scenario 1) or potential investor (scenario 2). On the other hand, contract price offers are discretized and bounded by minimum and maximum values.

4.3 Fitness Evaluation

The fitness function in scenario 1 corresponds to the minimization of total energy payments (equation (1)). Given a fixed number of DG units located as indicated by the initial population, the optimal dispatch given by (1)-(12) is solved. Note that constraints (12) and (13) are implicitly considered in the codification. In scenario 2 the fitness evaluation corresponds to the maximization of profits given by equation (19). In this case it is also necessary to solve the optimal dispatch given by (2)-(11) using (20) as objective function. Once this dispatch is solved (for a given location and contract price as indicated in Figure 2), the energy purchased from the DG units is used to calculate the profits of the DG owner using equation (19).

4.4 Selection

The selection stage is based on two tournaments. In each tournament a parent is chosen. For this, *k* individuals are randomly selected from the current population and the one with the highest fitness function is selected to be a parent. The two parents selected from the tournaments must be different from each other. The selection is performed in the same way for scenarios 1 and 2.

4.5 Recombination

For both scenarios a single point recombination scheme is selected. In this stage a position of the chromosome is randomly selected and both parents interchange their information creating two offspring. One of these is randomly selected as candidate to substitute an individual of the current population

4.6 Mutation

One of the chromosomes belonging to the offspring selected in the previous stage is randomly selected with a certain probability and is changed. In scenario 1 such change can only be done on the location of the DG units. In scenario 2 such change can be performed either on the location or contract price offer of a given DG unit with the same probability. The mutation is performed changing the information of the chromosome (location or contract price) within a specified range.

4.7 Local Improvement

Once the offspring has passed through the mutation stage a local improvement over this individual is performed. Such improvement consists in exploring neighbor solutions in search for better quality individuals. In scenario 1, a search is performed over neighbor locations within a specified range. In scenario 2, such search is performed either by location or contract price offer, with the same probability. If a better individual is found at this stage, it replaces the current offspring.

4.8 Population Substitution

In this case the offspring only replaces the worst individual of the current population, provided that it is better and different from this one. This substitution logic preserves the best individuals and the diversification of the population, avoiding premature convergence. The process stops if the incumbent (the best solution found in the process) does not change after a predefined number of generations, or when the maximum number of generations has been reached.

A flowchart of the proposed GA is shown in Figure 3.

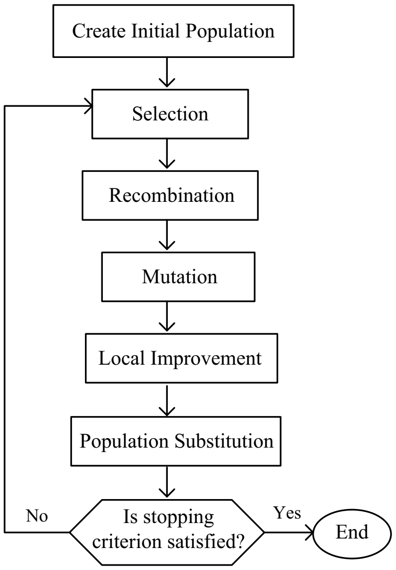

Figure 3. Flowchart of the proposed GA.

5 TESTS AND RESULTS

To compare the different approaches for optimal DG placement and contract pricing several tests were carried out with the system shown in Figure 4. This system is similar in topology to the IEEE 34-bus distribution system; however, a single-phase modified version has been used. The line data can be consulted in [15]. The load distribution in all nodes has been kept proportional to that in the original IEEE 34-bus test system [16] as shown in Figure 5.

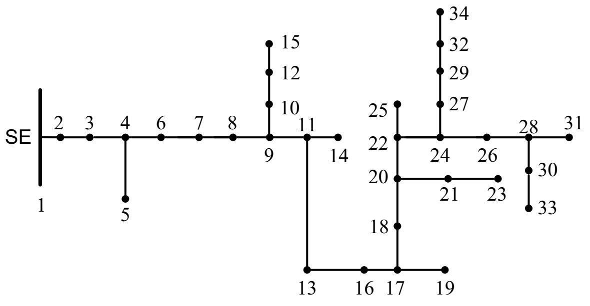

Figure 4. 34-bus distribution system.

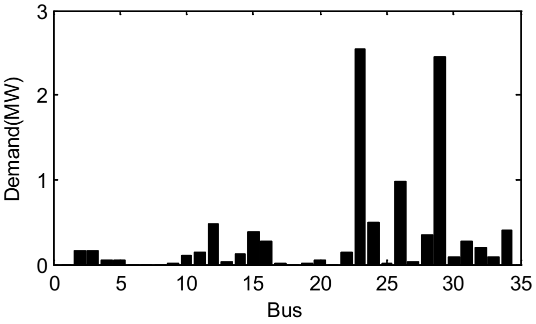

Figure 5. Load distribution of the 34-bus distribution system for a total demand of 10 MW.

For illustrative purposes, all scenarios are tested within a one-year time frame. However; in order to guarantee the viability of the investment, longer duration contracts, as well as investments costs can be considered. Three DG units labeled as DG1, DG2 and DG3 with capacity of 1.5 MW and production costs of 62, 60, and 58 €/MWh, respectively are considered._Figures 6 and 7 show the load and price duration curves considered in the analysis. For all tests the GA is set with a population of 12 individuals with k=2 and a mutation rate of 10%. The GA is set to stop if the incumbent does not change after 50 iterations or when a maximum of 200 iterations are evaluated. All buses are considered as candidates to allocate DG. For scenario 2 contract prices are discretized from 60 to 70 €/MWh at intervals of 0.5 €/MWh. The GA, as well as the subroutine to calculate the optimal dispatch, are implemented in MATLAB. Tests are performed in a laptop with a 3GB RAM and a Dual Core 2.0GHz processor. The average time for each run of the GA is approx. 1.5 h.

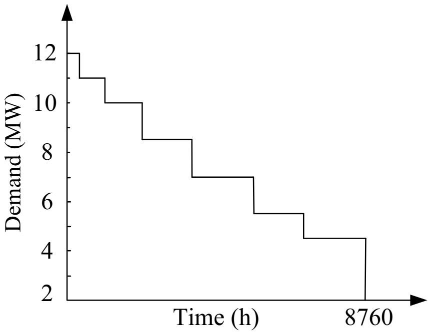

Figure 6. Load duration curve.

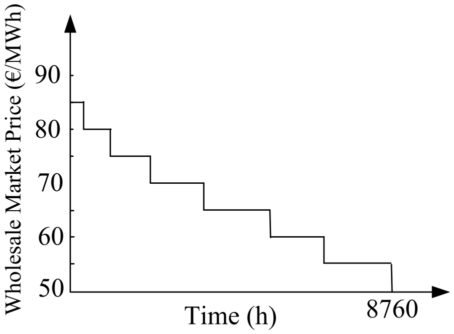

Figure 7. Price duration curve.

5.1 Results for Scenario 1

Table 1 shows the best solution obtained with the GA considering scenario 1. It can be observed that the three DG units are allocated far from the substation, and close to the highest demands. Table 1 also shows the capacity factors of the DG units. The capacity factor is defined as the ratio of the actual energy provided by a DG unit over a period of time, and the total amount of energy if it had operated at full capacity the whole time. In this case, the DG units are used proportionally to their production costs. The cheapest unit (DG3) is used almost 60% of the time, while the most expensive unit (DG1) is only used 35.15% of the time. Table 2 shows the payments and energy losses with and without DG. It can be observed that there is a significant decrease in energy payments due to the inclusion of the DG units. Furthermore, energy losses are reduced by 50%.

DG Unit	Bus	Capacity Factor (%)
DG1	29	35.15
DG2	27	42.75
DG3	25	58.33

Table 1: Location and capacity factor of the DG units in scenario 1.

	Payments (€)	Energy Losses (%)
Without DG	3,084,324.24	6.09
With DG	1,859,869.33	2.79
Difference	1,224,454.91	3.30

Table 2: Payments and energy losses with and without DG in scenario 1.

5.2 Results for Scenario 2

Table 3 shows the best solution obtained with the GA in scenario 2. It can be observed that the location of the DG units is different from that obtained in scenario 1. However, as in scenario 1, the DG units are located far from the substation and near the highest demands. It can be observed that the contract price (C. Price) offers for all DG units are the same. Furthermore, the capacity factors are quite different from those obtained in scenario 1. In this case, the DG unit with the highest production cost (DG3) operates 11.77% of the time only; also this DG unit is the one that renders the lowest profits.

Table 3 shows the payments and energy losses with and without DG. It can be observed that the inclusion of DG leads to a considerable reduction in energy payments. However, such reduction is less than the one obtained in scenario 1. That is because the energy purchased from the DG units in scenario 2 must be paid at 69 €/MWh, while the cost incurred in using the DG units in scenario 1 is their production cost.

DG Unit	Bus	Capacity Factor (%)	C. Price (€/MWh)	Profits (€)
DG1	23	11.77	69	10,832.08
DG2	24	25.00	69	29,565.00
DG3	25	24.59	69	35,551.07

Table 3: Location, capacity factors and profits the DG units in scenario 2.

	Payments (€)	Energy Losses (%)
Without DG	3,084,324.24	6.09
With DG	2,489,866.17	3.95
Difference	594,458.07	2.14

Table 4: Payments and energy losses with and without DG in scenario 2.

5.3 Results for Scenario 3

In this scenario it is considered that each of the three DG units belongs to a different owner. Each DG owner is interested in maximizing his profits, while the DisCo is interested in minimizing the energy payments. This multi-agent relationship is approached from a game theory viewpoint. For each DG unit (player), a set of strategies consisting in possible locations and contract prices is considered. Locations have been considered from bus 20 to bus 30 and contract prices from 64 to 70 €/MWh at intervals of 0.5 €/MWh. Each combination of location and contract price is evaluated and the corresponding profits of each DG unit are stored in a payoff matrix. Then, every position of this matrix is checked to verify if it meets the conditions of a Nash equilibrium. A program in MATLAB has been developed to perform such task.

Two Nash equilibria are found. Table 5 shows the information corresponding to these equilibria. It can be observed that for both equilibria the contract prices of DG2 and DG3 are lower than those obtained in scenario 2. The greatest reduction in contract price offer is related to DG3. Note that a lower contract price offer is compensated with a higher capacity factor; consequently the profits of DG3 in scenarios 2 and 3 are quite similar. Table 6 shows the payments and energy losses with and without DG. It is found that for both equilibria the savings of the DisCo in energy payments, as well as the reduction in energy losses, are greater than those obtained in scenario 2. Figure 8 provides a comparison of total profits of the DG units in scenario 2 and both equilibria found in scenario 3. It can be observed that due to competition among DG units, the total profits of the DG units are lower in both equilibria than those obtained in scenario 2.

<table>
<tr><td colspan="5">Equilibrium 1</td></tr>
<tr><td>DG Unit</td><td>Bus</td><td>C. Price (€/MWh)</td><td>Capacity Factor (%)</td><td>Profits (€)</td></tr>
<tr><td>DG1</td><td>29</td><td>68.5</td><td>25.00</td><td>21,352.50</td></tr>
<tr><td>DG2</td><td>24</td><td>68.5</td><td>16.20</td><td>18,097.37</td></tr>
<tr><td>DG3</td><td>28</td><td>65</td><td>35.46</td><td>32,621.25</td></tr>
<tr><td colspan="5">Equilibrium 2</td></tr>
</table>

DG Unit	Bus	C. Price (€/MWh)	Capacity Factor (%)	Profits (€)
DG1	29	69	14.16	13,030.22
DG2	21	68.5	25.00	27,922.50
DG3	28	65	35.46	32,621.26

Table 5: Location, contract prices and profits the DG units in scenario 3.

Equilibrium 1		
	Payments (€)	Energy Losses (%)
Without DG	3,084,324.24	6.09
With DG	2,355,067.54	3.61
Difference	729,256.70	2.48
Equilibrium 2		
	Payments (€)	Energy Losses (%)
Without DG	3,084,324.24	6.09
With DG	2,373,829.78	3.65
Difference	710,494.46	2.44

Table 6: Payments and energy losses with and without DG in scenario 3.

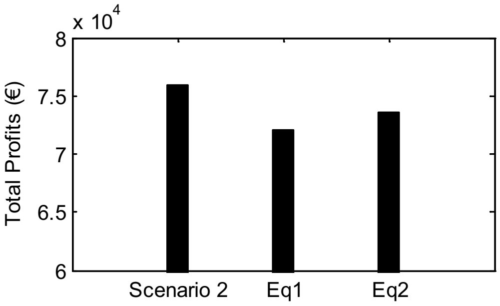

Figure 8. Total profits of the DG units in scenario 2 and the 2 equilibria found in scenario 3.

6 CONCLUSIONS

This paper presents a comparison of different approaches for the location and contract pricing evaluation of DG. Three different scenarios regarding DG ownership are considered. In all scenarios the DG units are located in buses far from the substation and near big demands. The greatest savings in energy payments are obtained in scenario 1, which considers that the DG units belong to the DisCo. On the other hand, comparing scenarios 2 and 3, it is found that the introduction of competition among DG units results in lower contract prices. Such situation benefits the DisCo which obtains greater savings in energy payments. At the same time, this competition leads to lower profits of the DG units. Future work will consider the size and number of DG units as decision variables as well as a more flexible market structure.

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