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Optimal Energy Management of an Academic Building with Distributed Generation and Energy Storage Systems

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Abstract. In this paper, an optimisation algorithm is used to simulate the management of distributed energy resources in an academic building. This optimisation algorithm, called DEROP, consists of an iterative procedure reach a supply schedule with the minimum energy cost. The inputs to the algorithm are the demand forecast, the availability of each resource, the level of storage in energy storage systems and prices and efficiencies of each resource. With these data, the algorithm proposes the optimal schedule to minimise costs of energy supply. The main advantages of this algorithm are that it is fast, easy to be implemented in real buildings and flexible. The algorithm is simulated with real data to optimise management of distributed energy resources and energy storage systems in an academic building. The management of these resources is optimised for a tariff with hourly discrimination and for a tariff with no time restrictions. One of the main conclusions drawn from these simulations are that significant savings are obtained with this algorithm. Also, DEROP allows taking advantage of tariffs with hourly discrimination, even in an academic building with low night-time consumption in which, a priori, these tariffs are not profitable.

1. Introduction

In order to minimise the dependence on fossil fuels, new energy resources are being integrated in energy systems [1], such as renewable energy sources (RESs) – wind, solar, biomass and so on – and energy storage systems (ESSs). With the increase of RESs, optimal management and control of all the available resources is a key issue to be addressed and many research studies have been developed over the past years [2]. This is usually studied from the perspective of energy generation facilities [3]. Nonetheless, a perspective of final customers with distributed generation (DG) and ESSs [4] might provide better optimisation results. This perspective is focused on facilities with multiple energy sources, ESSs and loads, which are widely called energy hubs.

From the perspective of end users, optimal management of their available resources consists of controlling all energy flows in their facilities (between power grid, DG resources, ESSs and loads) to minimise the total energy costs. This requires robust energy control systems (with real-time data acquisition and processing from loads, generation resources availability, external variables such as temperature or wind speed, energy purchase prices, forecasts...) and sophisticated algorithms to achieve an optimal management of the available resources along the time.

Several algorithms to optimise energy hubs' operation have been proposed, such as in [5]. Some of them are focused on demand side management [6]. Others describe algorithms to achieve optimal management of DERs and loads along a day [7]. The main disadvantages of these algorithms are their complexity, the difficulty to implement them in a real facility and the fact that only linear functions may be used in most of them, as in [8]. Other works focus on sources management, such as [9].

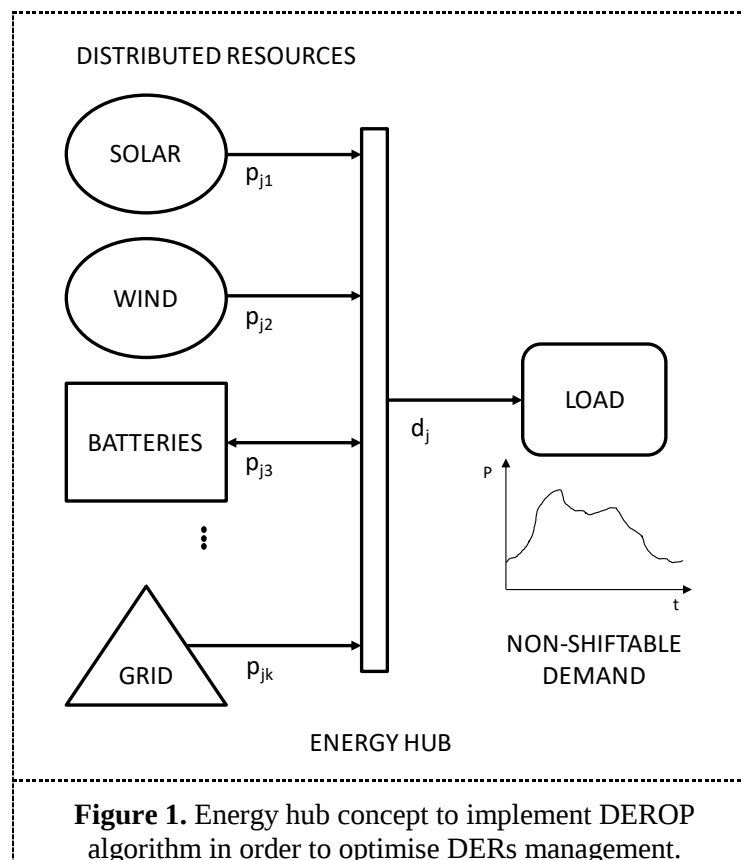


However, these works develop algorithms mainly suitable for microgrids, such as [10]. In this paper, a new algorithm for DERs optimisation in energy hubs, called DEROP, is used to minimise energy costs in an academic building. The inputs to DEROP are forecasts of demand and generation of each resource, initial level of charge in ESSs, prices and efficiency curves of each resource. From these data, DEROP calculates the optimal schedule for the energy hub using an iterative procedure. The main advantages of DEROP algorithm are that it is simple, fast and easy to be implemented in real buildings. Moreover, it is flexible, as it allows the use of non-linear functions for prices and efficiencies and users may add as many resources as needed.

This paper is organised as follows. Section 2 describes DEROP algorithm and the scenarios to be simulated. Section 3 shows a simulation step by step. Section 4 shows of the simulated scenarios. These results are compared, analysed and discussed in this section. Finally, some conclusions to this work are drawn in section 5.

2. Methodology

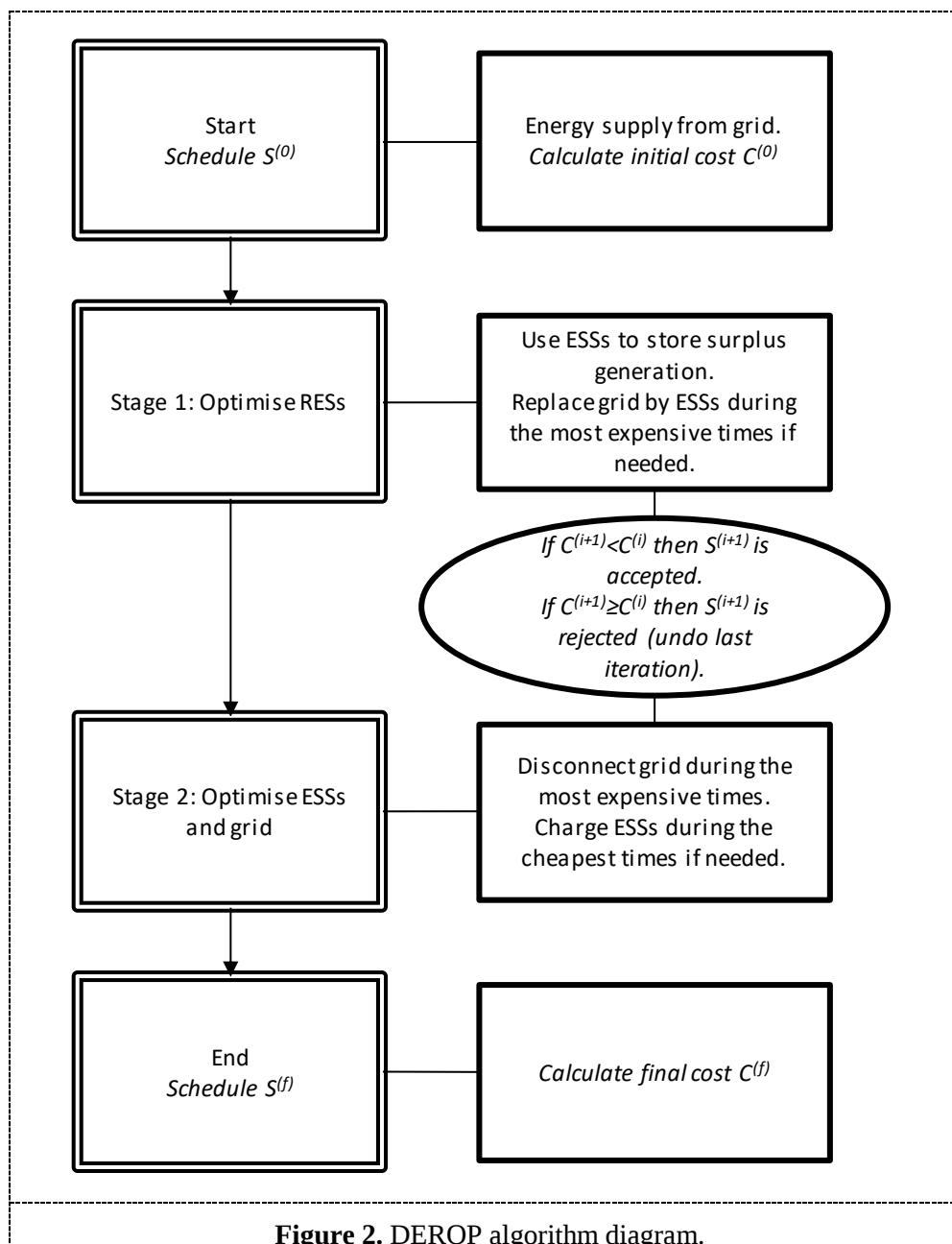
As aforementioned, an energy hub is a building or a set of buildings with several generation resources, loads and ESSs. This concept is shown in Figure 1. The goal of DEROP algorithm is to find the optimal schedule to manage DG resources, ESSs and power grid in an energy hub, to achieve the minimum energy cost. In order to do this, DEROP consists of two stages. The first stage optimises the use of DG resources. It tries to maximise the usage of RESs, using ESSs to store surplus generation and discharging ESSs in the most expensive times to allow storing energy when needed. The second stage optimises the use of power grid and ESSs. To do this, ESSs are optimally managed to allow grid disconnections in the most expensive times and charge ESSs in the cheapest times. This process is illustrated in Figure 2.



The algorithm has been tested in an academic building, where loads cannot be managed. Real data of generation and consumption curves have been used to simulate an optimal management with DEROP.

These data correspond to wind and solar generation curves measured in the Laboratory of Distributed Energy Resources (LabDER) at Universitat Politècnica de València (UPV) and demand curves of a departmental building at UPV (building 5E) that has laboratories, classrooms, seminars and offices. Also, real prices have been downloaded from the System Operator's website [11]. With these data, DEROP starts calculating total energy costs of an initial schedule (consisting of only power grid supply) and, through an iterative procedure, it creates new schedules that gradually decrease these costs until the last iteration, where no improvement can be made.

The simulated energy hub corresponds to an academic building with a maximum demand of over 100 kW, with solar panels and a wind generator (70 kW installed of each resource) and batteries (48 V and 4000 Ah to store nearly 200 kWh).



A cost has been associated with each resource. In addition, each resource has its own efficiency curve. One of the main advantages of DEROP is its flexibility, since non-linear functions may be used for

both, costs and efficiencies. Furthermore, DEROP allows users to add as many resources as needed to optimise their management.

To test the algorithm in different situations, the same curves have been used to optimise the management of resources with two different tariffs, i.e. a tariff with hourly discrimination (scenario A) and a tariff with no time restrictions (scenario B).

3. Scenarios Simulation

The described scenarios have been simulated using DEROP algorithm with real data. The simulation of scenario A is shown below.

In this scenario there are RESs (wind and solar power) and an ESS (batteries). This scenario has an electricity tariff with hourly discrimination. The goal of this simulation is to maximise the use of RESs and manage ESSs usage to minimise overall energy costs, using DEROP algorithm.

At the beginning of the simulation, in iteration $i=0$, the initial schedule $S^{(0)}$ consists of using grid supply for the entire simulation period (one day). Energy costs in this iteration are € 97.14, with a total demand of 1033.78 kWh. The associated emissions are 257.6 kg of CO₂.

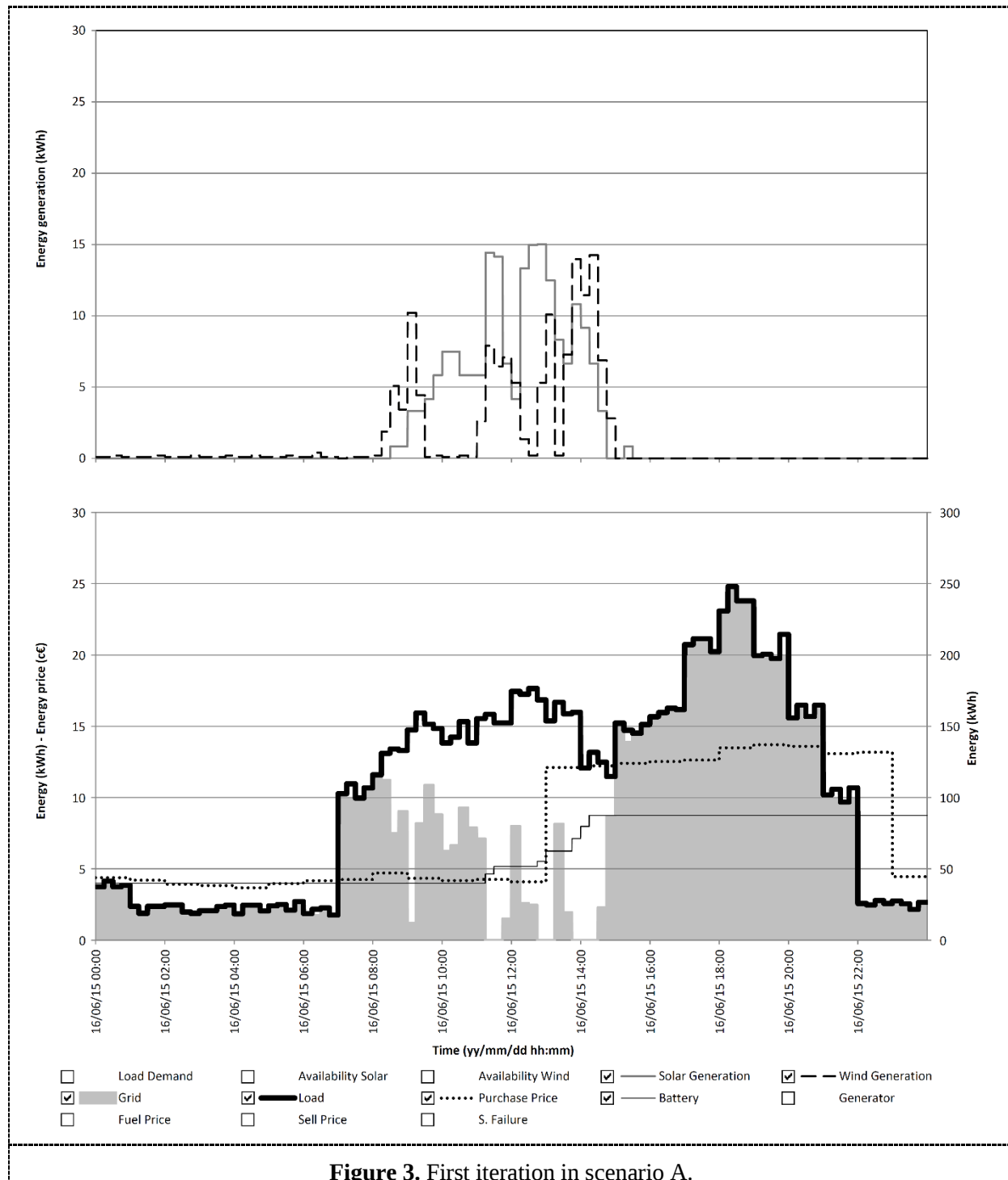
In the 1st iteration the available RESs are used and surplus generation is used to charge ESSs. The result of this step is shown in Figure 3. The total cost of supplied energy in this case is € 78.02 and the total emissions are 186.3 kg of CO₂.

To complete the 2nd iteration DEROP algorithm looks for interval the $[t_j, t_{j+1}]$ with the highest purchase price (which takes place during the interval 19:00-19:15) and grid supply is disconnected during that time interval. To perform this simulation the selected step size is 15 minutes, although the smaller step sizes, the more accurate results may be obtained (for example, a step size of one minute could be used). As a result of this iteration the energy cost has decreased until € 75.28 and total emissions are 181.3 kg of CO₂. In the next iterations new grid disconnections are scheduled in expensive intervals, until a moment when battery is not able to meet demand. In iteration $i=6$, if a new fraction of grid supply is disconnected (during the interval 20:00-20:15) battery cannot meet demand during that interval and supply failures take place at that time. At this point, the total cost of energy has been reduced to € 66.88 and total emissions have decreased up to 166.0 kg of CO₂. Therefore, to complete iteration $i=7$, a fraction of grid supply is disconnected during 20:00-20:15 and ESS is charged during the cheapest interval (during 04:00-04:15). The result of this iteration is a total cost of € 65.12 and overall emissions of 164.2 kg of CO₂.

Continuing with this procedure the optimal situation is reached in iteration $i=28$, when there is no available time interval to disconnect grid supply charging batteries in previous intervals to meet demand and obtain an economic benefit. This situation is shown in Figure 4. In the final situation, the total cost is € 55.97 and the total emissions are 160.8 kg of CO₂.

4. Scenarios Results and Discussion

Table 1 shows the final results of both scenarios. DEROP allows great savings in energy costs in both scenarios. However, DEROP allows lower energy costs in scenario A, where the initial costs are higher. This shows that even in a facility where a tariff with hourly discrimination is not expected to be profitable, DEROP takes advantage of ESSs and allows greater savings. Furthermore, DEROP optimises scenario A faster than B (28 iterations instead of 31). The conclusion is that DEROP works faster with tariffs with hourly discrimination and it achieves better results in this case. This can be observed in Figure 5, which shows the evolution of costs throughout the simulation of both scenarios. This algorithm has been coded in Matlab and each simulation takes just a few seconds, which supports the quickness of the developed algorithm.



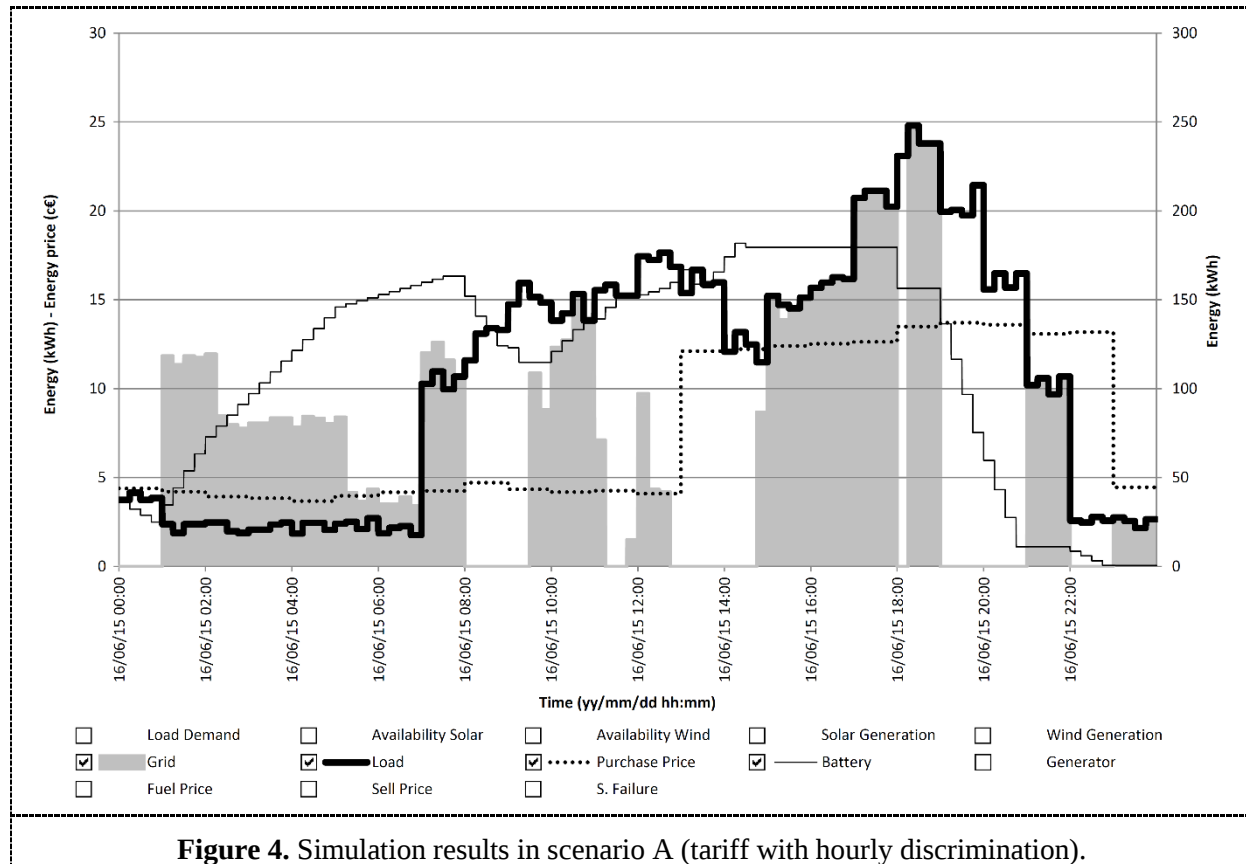


Table 1. Simulation results comparison between both scenarios.

	Scenario A	Scenario B
Cost (€)	55.97	61.14
Initial cost in $S^{(0)}$ (€)	97,14	96,82
Savings compared to $S^{(0)}$ (%)	42.38	36.85
Emissions (kg CO₂)	160.80	162.00
Emissions reduction compared to $S^{(0)}$ (%)	37.57	37.10
Solar generation (kWh)	191.67	191.67
Wind generation (kWh)	133.33	133.33
Demand (kWh)	1033.78	1033.78
Power grid supply (kWh)	669.41	669.57
Grid supply savings compared to $S^{(0)}$ (%)	35.25	35.23
Number of iterations (N)	28	31

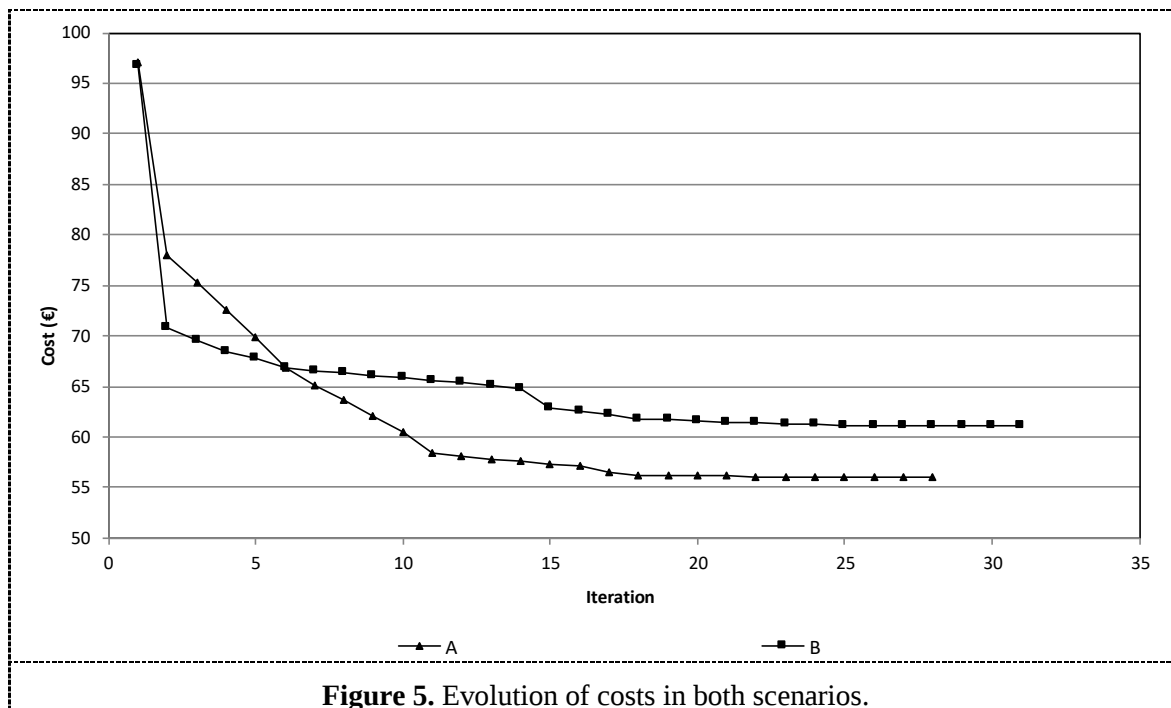


Figure 5. Evolution of costs in both scenarios.

5. Conclusions

In this paper, an optimisation algorithm for DERs management (DEROP) to reach the minimum energy cost in an energy hub is shown.

This method consists of an iterative procedure that uses data related to demand and generation forecasts for each resource, prices of each DER and initial charge state of ESSs to calculate optimal allocation of DERs in an energy hub.

The algorithm has been described and it has been tested in an academic building using real data of prices, demand and generation curves. To test it under different situations, the same building has been optimised with two types of tariff, a tariff with hourly discrimination (scenario A) and a tariff with no time restrictions (scenario B).

The operation of this algorithm in the described scenarios has been shown and the results have been analysed. The simplicity and speed of the presented method must be emphasised. By analysing both scenarios, some interesting results have been observed, such as the great savings that DEROP can reach and the positive impact of these savings both on costs and on emissions. More interestingly, the simulated facility, with low night-time consumption, has higher energy costs with tariffs with hourly discrimination, but thanks to DEROP, an optimal management of DERs allows a final cost 8.46% lower in scenario A than in scenario B. This demonstrates the great capacity of DEROP to optimally manage DERs and to take full advantage of the different tariffs. In addition, it has been demonstrated that DEROP is faster with tariffs with hourly discrimination.

The main advantages of DEROP have been proved with the simulated scenarios. DEROP is simple (its operation has been carefully described in a real example, showing the performance of each iteration), it is fast (each simulation takes just a few seconds when it is coded in Matlab), it is flexible (it allows adding as many resources and constraints as needed, in addition to using non-linear functions for costs and emissions) and it is easy to be implemented in real facilities, as it uses data that can be easily gathered with an energy management system. Moreover, DEROP allows great savings in real facilities through optimising the schedule of DERs and ESSs.

As a final comment, the developed algorithm could be used with other purposes such as minimising CO₂ emissions or optimal schedule of maintenance tasks. In addition, the methodology described in this paper might be used to define the size of RESs and study their amortisation in real facilities.

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